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Special Issue: Policies for Macroeconomic and Financial Stability

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International Journal of Central Banking

Policies for Macroeconomic and Financial Stability

Introduction to a Special Issue of the International Journal of Central Banking

This volume of the *International Journal of Central Banking* includes the proceedings from the conference titled "Policies for Macroeconomic and Financial Stability," hosted by the Federal Reserve Bank of Philadelphia on September 26–27, 2014. In addition to the papers and discussions, this issue contains the prepared remarks given at the conference by Charles Plosser (President and CEO, Federal Reserve Bank of Philadelphia). The conference was organized by Harrison Hong, Loretta Mester, Rafael Repullo, and John Williams.

Policies for Macroeconomic and Financial Stability*
Opening Remarks

Charles I. Plosser
President and Chief Executive Officer
Federal Reserve Bank of Philadelphia

1. Introduction

I want to welcome you to the Federal Reserve Bank of Philadelphia for this year's *International Journal of Central Banking* (*IJCB*) conference. The topic this year is "Policies for Macroeconomic and Financial Stability." I want to thank the organizers of this excellent program: Harrison Hong of Princeton University, Rafael Repullo of the Centre for Monetary and Financial Studies in Madrid, and of course, my Federal Reserve colleagues, Presidents Loretta Mester of Cleveland and John Williams of San Francisco. John is also managing editor of the *IJCB*.

Most of the papers on this year's program address the question, how should we pursue macroprudential regulation? Each paper takes a somewhat different perspective to address the question. Yet, I think you will find each one enlightening and thought provoking. They tackle hard problems that have no easy solutions.

While the papers delve into the details, I would like to step back and take a broader view for a moment. As I do, though, I will begin with the usual caveat that my views are not necessarily those of the Federal Reserve System or my colleagues on the Federal Open Market Committee.

I will discuss some broad principles that I believe we should consider as we discuss regulation and financial stability. Without some clearly defined principles to guide us, we run the risk of writing many regulations that may do more harm than good. Regulations that are not grounded on sound principles could, in fact, increase systemic risk rather than reduce it. As most of us are aware, in this arena of

*Opening remarks given at the IJCB conference on "Policies for Macroeconomic and Financial Stability," hosted by the Federal Reserve Bank of Philadelphia, September 26–27, 2014. Dr. Plosser retired as president on March 1, 2015.

regulation, the law of unintended consequences crops up on a regular basis.

So, I would like to offer some thoughts that might be useful in navigating the complications of applying macroprudential regulation in a world of uncertainty. I will stress two sources of uncertainty that, in my view, are often underestimated. The first is the uncertainty that arises from the inevitable dynamism of the economy and the institutions that we seek to regulate. This is especially true in financial markets, which, in large part, exist to repackage and redistribute financial risks. The second source of uncertainty stems from the regulations themselves.

This uncertainty leads me to stress the need for well-defined regulatory objectives. It also suggests the need for robust regulations that take explicit account of our uncertainty about the true model of the financial system and its evolving nature.

2. Macroprudential Policy Should Have Well-Defined Objectives

While research into the financial crisis has generated a wealth of insights into the mechanisms underlying financial instability, we are still some ways from defining systemic risk with any real precision. We are often content to say that systemic risks result in bank runs. But runs are an outcome or symptom; their existence does not necessarily provide us with the causal factors or the necessary conditions that give rise to them. For example, we frequently appeal to information asymmetries as a source of the problem, but we seem to focus greater effort on regulating activities or products than we do on ensuring disclosures and information. More generally, we need to better distinguish systemic risks from idiosyncratic risk taking by individual firms. These latter risks are exactly what financial intermediaries can and should be doing in a well-functioning financial market. Our task is not to stifle this risk taking by these firms.

A big step toward more precision is to measure the right things and to measure them correctly. Some of the papers on this program make progress in this direction, but they also illustrate how far we have to go on some very basic matters.

One of the papers to be presented provides evidence about the deep interconnections between a firm's credit risk and its funding liquidity or access to financing. The paper argues that a firm's liquidity cannot be measured properly without also measuring the firm's risk of insolvency in bad states of the world. I view this as an important insight, but it is also cautionary. We have already written hundreds of pages of liquidity regulations that do not incorporate the connection between credit risk and liquidity in tail states of the world.

Another interesting paper on the program examines capital requirements in a model that looks at one of the suspected sources of systemic risk, interconnectedness. Actually, the idea that interconnectedness might be an important source of systemic risk is intuitive and appealing. But how do we measure interconnectedness? How do we know when interconnectedness is a problem and when it is a desirable consequence of efficiency? Put differently, what is the market failure that arises from interconnectedness that produces the systemic risk? If it stems from information failures rather than interconnectedness per se, then we may be focusing on the wrong issues and hampering efficiency—without solving the basic problem.

Even putting aside the basic theory, the forms of interconnectedness, like so many features of a dynamic financial market, are not static. Forms of interconnectedness evolve with new technologies and, as I will note shortly, with regulation.

Perhaps a more hopeful approach is to look for regulations that work well for a wide range of measures of interconnectedness. We should also seek regulations that are cost effective and straightforward to implement and enforce.

3. Robust Macroprudential Regulation

In the past, I have argued for robust monetary policy rules that recognize that we face considerable uncertainty about the correct underlying model of the economy. I believe that the same basic framework may be useful for thinking about macroprudential policy. After all, there is no consensus on the model that generates systemic risks any more than there is a consensus model for the macroeconomy.

How do we deal with this disagreement or lack of consensus? One approach is to work harder to come up with a better model, and then to design regulations to measure and control the market failures that give rise to such risks.

Given the lack of consensus at this point on the model, a better approach might be to devise policies that are likely to work reasonably well across a wide range of models. That is, we can design policies that are robust. That doesn't necessarily mean more regulations on more products or activities; rather, it suggests regulations that are less sensitive to the specific models or underlying structures.

Why are we so uncertain about the right model? I think the answer to this provides some guidance about the types of policies that might be robust.

4. Systemic Risks Are Dynamic; They Evolve

In the face of new regulations, firms don't just stand still; they respond and adapt. During the run-up to the financial crisis, we observed this in myriad ways—for example, in banks' response to Basel II's byzantine risk-based capital requirements. Predictably, banks responded by moving high-risk assets into structures with low-risk weights—for example, asset-backed commercial paper. Notice that in this case, a complex regulation *created* model uncertainty through the mechanism of regulatory arbitrage, and there are many more examples. Note also that while it was predictable that firms would shift assets from high- to low-risk weights, it was anything but predictable *how* they would choose to do it.

Apart from regulatory arbitrage, the financial economy is always evolving through innovation. As Nobel laureate Robert Merton has often reminded us, the same basic intermediary functions are continuously repackaged in different institutional forms. Of course, this creates problems for regulations that are essentially static. Regulations are written as if the existing package of financial instruments is largely given. Static regulations may reduce credit risk or liquidity risk when this package takes one form, but they fail when the risks are repackaged in another form. Thus, we are always regulating a moving target.

As I said previously, there are no simple fixes and no silver bullets. But I do think that some regulatory approaches are more likely to be robust than others.

5. Simple Regulations Are More Likely to be Robust

I have argued elsewhere that simple regulatory policies are most likely to work in a wide range of circumstances. Complex regulations—I come back to the example of risk-based capital—invite complex regulatory arbitrage. Furthermore, securities that looked very safe yesterday may look much riskier today. For example, prior to the European Union's debt crisis, the sovereign debt of EU countries appeared to have low risk. The practical effect of Basel II was to place a zero-risk weight on such sovereign debts. After the European debt crisis, however, this regulatory decision embodied in Basel II was perhaps too naïve, or just too optimistic. In either event, ex ante regulatory rules can have unintended outcomes as markets evolve. I don't believe the answer to regulatory arbitrage or to changing risks is to further tinker with the risk weights, to add more risk buckets, or to add more contingencies.

The Federal Reserve, for example, has raised leverage requirements for those firms thought to be systemically important, and European bank regulators have adopted leverage requirements for the first time. One reason for this approach is to try to escape the difficulties of fine-tuning the ever-evolving nature of assets. This has led me to stress that simple leverage requirements should be the primary tool of capital regulation and that these leverage requirements should be set at higher levels for those firms considered to be systemically important. Risk-based capital requirements could serve a supplementary role at best.

Of course, all regulations—simple and complex—create incentives for regulatory arbitrage. While higher leverage requirements will limit some types of arbitrage, higher capital requirements will push some activities outside the banking system altogether.

6. Regulations That Utilize Market Forces Are More Likely to be Robust

I have also argued for regulations that utilize market forces to the greatest extent possible. Regulations that utilize market participants to monitor risks are less subject to regulatory arbitrage because they do not pit regulators and market participants in a game of cat and mouse. Furthermore, regulators' limited knowledge about evolving risks and reliance on complicated rules that seek to control risk by addressing each contingency will invariably lag behind market developments.

More capital and more subordinated or convertible debt in banks' capital structure—apart from their role in increasing banks' cushion against default and limiting bank reliance on short-term debt—give market participants stronger incentives to evaluate and price bank risk. Furthermore, measures of systemic risk based on market prices have proven to be relatively informative about developing problems.

7. Conclusion

To conclude, we need to be clear as regulators about what we don't know and what we can't know. Policy is always made under conditions of uncertainty. But when we design macroprudential policies, we must be clear about our objectives. At this point, we still have difficulty in defining and measuring systemic risk. Some of the papers on the program today make some progress on this subject.

However, while we can make progress in measuring risks, dynamic financial markets are continually repackaging those risks in forms that a long list of rules simply can't capture. And risks are likely to arise in places and in ways that are impossible to predict. Our fundamental uncertainty about the economy suggests that we look for robust regulatory mechanisms. Simple regulations that are designed to work across a wide range of environments, regulations that exploit market forces to control risks, and mechanisms that ease the costs of allowing financial firms to fail are more likely to work in a continually evolving world.

Capital Regulation in a Macroeconomic Model with Three Layers of Default*

Laurent Clerc,[a] Alexis Derviz,[b] Caterina Mendicino,[c] Stephane Moyen,[d] Kalin Nikolov,[e] Livio Stracca,[f] Javier Suarez,[g] and Alexandros P. Vardoulakis[h]

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We develop a dynamic general equilibrium model for the positive and normative analysis of macroprudential policies. Optimizing financial intermediaries allocate their scarce net worth together with funds raised from saving households across two lending activities, mortgage and corporate lending. For all borrowers (households, firms, and banks), external financing takes the form of debt which is subject to default risk.

*The project was developed as part of the ESCB Macro-prudential Research Network (MaRs). We are grateful for the feedback received from participants at the EABCN conference in Cambridge, the Second and the Final Conference of MaRs, the spring 2014 WGEM meeting, ESSIM 2014, the 2014 IJCB Conference, and at seminars at the Czech National Bank, Deutsche Bundesbank, Bank of Cyprus, Bank of England, Bank of Greece, Banco de Portugal, Banka Slovenije, International Monetary Fund, Norges Bank, Polish National Bank, Sveriges Riksbank, and University of Cologne. We also thank Michal Brzoza-Brzezina, Andrea Gerali, Philipp Hartmann, Donghun Joo, Nobu Kiyotaki, Michael Kumhof, Galo Nuño, Skander Van den Heuvel, and Rafael Wouters for valuable comments and suggestions and Dominik Supera for superb research assistance. The opinions expressed in this paper belong to the authors and do not necessarily reflect the views of the Eurosystem or the Federal Reserve System. Corresponding author: Javier Suarez, CEMFI, Casado del Alisal 5, 28014 Madrid, Spain. E-mail: suarez@cemfi.es.

This "3D model" shows the interplay between three interconnected net worth channels that cause financial amplification and the distortions due to deposit insurance. We apply it to the analysis of capital regulation.

JEL Codes: E3, E44, G01, G21.

1. Introduction

The recent financial crisis has clearly illustrated that prudential regulation uniquely based on the soundness of individual institutions is not sufficient to ensure financial stability. As a consequence, macroprudential policy has been proposed to factor in the macroeconomic perspective and take into account the connections between the financial and the non-financial sectors, and the central role of financial intermediaries. Such policy should therefore be designed to address the contribution of financial stability, systemic risk, and the procyclicality of the financial system to overall economic performance. Beyond incorporating financial frictions and distortions, a good model for policy analysis in this area should put the banking system, and financial intermediation more generally, at the center of the stage.

The purpose of this paper is to encompass the most relevant aspects of macroprudential concern in a single model with enough microfoundations to allow us to perform a welfare analysis of macroprudential policy.[1] The model presented in this paper is built with an eclectic perspective, trying to provide a synthesis of the most relevant interlinkages between the real and the financial sectors

[1]As further discussed in the literature review section, a number of recent papers have focused on introducing bank frictions into otherwise mainstream macroeconomic models. Some of these papers (e.g., Meh and Moran 2010, Gertler and Kiyotaki 2011) describe a bank net worth channel that operates essentially along the same lines as the conventional entrepreneurial net worth channel (notably in Kiyotaki and Moore 1997 and Bernanke, Gertler, and Gilchrist 1999) but causing fluctuations in the availability of bank credit rather than directly in entrepreneurial investment. Most papers either focus on one main bank friction (like the bank net worth channel) or otherwise capture several frictions in a reduced-form manner, without explicitly modeling the optimizing behavior of financial intermediaries and without explicitly addressing the welfare analysis of macroprudential policies.

identified in the literature.[2] This paper focuses on bank capital regulation, the key microprudential policy tool and arguably one of the main tools for macroprudential policy as well. Yet, we think of the model presented here as a first version of a framework that could be adapted to analyze other candidate macroprudential instruments, such as loan-to-value ratios, or extended so as to incorporate, for example, nominal rigidities and monetary policy.

The second main goal of the paper is to provide a model where default plays a central and material role. Up to the global financial crisis, the role of default has been largely overlooked in macroeconomics.[3] A number of papers, following Kiyotaki and Moore (1997), allow for the *possibility* of default but rule it out in equilibrium through appropriately chosen financial contracts. Other papers, using the costly state verification (CSV) setup popularized by Bernanke, Gertler, and Gilchrist (1999) (henceforth BGG), allow for equilibrium default and the deadweight losses associated with it, although most of them consider state-contingent debt that prevents default to unexpectedly fluctuate in response to aggregate shocks. Therefore, both approaches abstract from some of the consequences of default for financial stability and for the real economy. In our work, default and its costs impinge on the balance sheet of the lenders, influencing their optimal behavior and thereby macroeconomic outcomes.

Our model belongs to the class of dynamic stochastic general equilibrium (DSGE) models, but the emphasis on financial intermediation and default sets it apart from the typical business-cycle model. By the same token, our construction is far away from the classical framework of microprudential supervision, which was very limited in its analysis of the impact of macroeconomic performance on financial intermediation and lacked the mission and the analytical tools to properly consider the impact of prudential policies on the real economy. Hence, we try to bridge the gap between the micro and macro literatures, and to build a framework which allows for the welfare analysis of the relevant policy instruments.

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[2]See the report of the MaRs research network for a survey. See http://www.ecb.europa.eu/home/html/researcher_mars.en.html.

[3]For a discussion on the importance of introducing default in macro models, see Geanakoplos (2011) and Goodhart, Tsomocos, and Shubik (2013).

More in detail, the model developed in this paper assumes banks intermediate funds from savers to final borrowers, and tries to coherently put together the following ingredients: (i) household bank deposits and loans for housing purchase, (ii) corporate-sector bank borrowing to fund capital accumulation, (iii) default risk in all classes of borrowing, including bank deposits, (iv) a net worth channel operating at the level of each levered sector, and (v) a bank funding fragility channel which operates through a premium demanded by depositors who suffer deadweight losses if banks default.

The rationale for macroprudential policies in our model arises from two key distortions associated with banks' external debt financing. Both of these encourage banks to become overleveraged and to expose themselves to too much failure risk.

The first distortion stems from banks' limited liability and the existence of deposit insurance.[4] As in Kareken and Wallace (1978), deposit insurance pushes banks to take on risk at the expense of the deposit insurance agency (DIA), which may result in cheaper and more abundant bank lending than what a social planner would find optimal when internalizing the full costs of bank default (*limited liability distortion*).

The second distortion arises due to our assumption that depositors suffer some transaction costs in the event of a bank failure despite the presence of deposit insurance.[5] In equilibrium, this leads to a deposit risk premium which raises banks' funding costs when failure risk is high. Moreover, we assume that, due to banks' opaqueness, this risk premium is related to economy-wide bank default risk rather than the individual risk of the issuing bank. This creates an incentive for banks to take excessive risk because their funding costs

[4]The most frequent justification for deposit insurance in the banking literature comes from the demandability of bank deposits and the attempt to prevent bank runs (Diamond and Dybvig 1983), issues from which our model fully abstracts. An alternative explanation, closer to our CSV framework, is provided by Dewatripont and Tirole (1994), who interpret bank supervision and deposit insurance as part of a social contract whereby small and unsophisticated savers delegate to bank authorities the disciplining role that creditors typically exert on their borrowers. Authorities, in exchange, offer deposit insurance to the savers as a means to reinforce their commitment to the supervisory task.

[5]This can be seen as a shortcut for explicitly modeling the fact that some bank liabilities (e.g., wholesale funding) are uninsured and investors demand a default risk premium in order to hold them.

depend on system-wide choices rather than their own (*bank funding cost externality*).

Bank default is at the heart of both of the above distortions. Bank capital requirements make financial institutions safer and curtail their incentives to lever up excessively and lend too much. However, imposing limits on bank leverage is not without its costs. Our use of the CSV framework implies that credit may be too low from a social perspective (*CSV distortion*). Since CSV and the bank-related frictions discussed above distort credit in opposite directions, it is not clear a priori whether the social planner would like to impose high or low capital requirements. In fact, the steady-state welfare of households in our model is a hump-shaped function of credit availability as determined by bank capital regulation.[6]

We use the model to analyze the effects of capital requirements on the steady-state allocations and welfare and on the transmission of various types of shocks. On top of time-invariant capital requirements, possibly differentiated across classes of loans according to their risk, we also consider countercyclical adjustments to the capital ratios (adjustments that, in practice, might be implemented through the introduction of a countercyclical capital buffer, as in Basel III).

Three main results stand out in our analysis. First, in the context of our model, there is generally an optimal level of capital requirements. In effect, capital requirements reduce bank leverage, bank failure risk, and the implicit subsidies associated with deposit insurance. Simultaneously, they force the banks to make a greater use of bankers' limited wealth. This second aspect makes capital requirements have a potential impact on the cost of equity funding (due to its scarcity in the short run) and on the pattern of accumulation of wealth by bankers (in the medium to long run). Lower leverage and, in the short run, a larger cost of equity funding lead banks to extend less credit and to be less fragile. However, too-high levels of capital requirements may unduly restrict credit availability.

Second, we find that when bank leverage is high (because capital requirements are low), the economy is more responsive to shocks. Banks are more vulnerable not only to idiosyncratic shocks to their own performance but also to aggregate shocks, so their capacity

[6]This hump-shaped welfare function is conceptually similar to Benigno et al. (2013). However, their model is substantially different from ours.

to supply credit to the economy is more volatile. Simultaneously, their borrowers are also more levered and more fragile due to the fact that their own steady-state leverage is higher because of the subsidies implied by the limited liability distortion. The result is a powerful channel of financial amplification.

Third, the countercyclical adjustment of capital ratios may significantly improve the benefits of high capital requirements, but once again only up to a certain level. Otherwise, the effects due to the increase in bank fragility following negative shocks will backfire. This is, in fact, what happens when the reference capital requirements are ex ante too low. On the one hand, a countercyclical reduction in the requirements may on impact allow the bank to charge lower loan rates on a larger amount of loans. On the other hand, if bank fragility gets further deteriorated, banks' funding costs will increase and their net worth will register further losses. These negative effects may well offset the intended impact of the countercyclical adjustment, causing long-lasting detrimental effects on credit supply and GDP.

The rest of the paper is organized as follows. In section 2, we discuss how the paper fits into the existing literature. In section 3 we introduce the key elements of the core model, describing the equilibrium equations that directly emanate from agents' optimization. In section 4, we complete the set of equilibrium equations with those that refer to market clearing, the funding of the DIA, and the description of the regulatory tools. Section 5 describes the calibration of the model. Section 6 contains the main positive and normative results. Section 7 concludes.

2. Relation to Previous Literature

Our model builds on a large literature which includes financial frictions in general equilibrium models, including among others Carlstrom and Fuerst (1997), Kiyotaki and Moore (1997), and BGG. Financial frictions are typically found to increase the persistence of shocks and to amplify their impact, though this is not necessarily the case in all models.[7]

[7]See Brunnermeier, Eisenbach, and Sannikov (2012) for a survey of the literature.

We model the frictions affecting the relationship between borrowers and their financiers using the CSV framework of Townsend (1979) and Gale and Hellwig (1985) because it provides a rationale for the use of debt financing and for the deadweight losses associated with bankruptcy. As established by Williamson (1987) and Krasa and Villamil (1992), CSV can also be used to justify the existence of intermediaries who, by acting as delegated monitors à la Diamond (1984), economize on the potential duplication of verification costs when funding a borrower requires the funds of several savers.

Our model is thus related to that of BGG, who integrate the CSV approach into a macroeconomic setup.[8] We depart, though, from BGG and most of the subsequent literature in assuming that debt is non-contingent, which, realistically, makes our banks exposed to rises in loan default rates caused by aggregate shocks.[9]

We model the evolution of bank net worth along the same lines as in a number of recent papers (Gertler and Kiyotaki 2010; Gertler and Karadi 2011; Gertler, Kiyotaki, and Queralto 2012), which have also emphasized the presence of financing constraints for banks as a key factor in the propagation of shocks. In these papers, banks' financing constraints arise from the fact that bankers can divert a fraction of the funds under their management. In our work, the limit on banks' leverage comes from regulatory capital requirements that are put in place to reduce the over-investment (or excessive risk taking) caused by limited liability and deposit insurance (Kareken and Wallace 1978).[10] In addition, to keep track of the transmission of default risk and net worth losses across sectors, we model explicitly

[8]In a comparison of the properties of models that have collateral constraints like in Kiyotaki and Moore (1997) with models that have an external finance premium as in BGG, Brzoza-Brzezina, Kolasa, and Makarski (2013) conclude that the business-cycle properties of the latter are more in line with the empirical evidence.

[9]Our emphasis on default is similar to several models that have analyzed macroprudential issues outside the DSGE tradition, such as Goodhart, Sunirand, and Tsomocos (2006) and Goodhart et al. (2012), who study how combinations of macroprudential tools (including capital requirements) can address default and fire-sale externalities in a model where traditional and shadow banking sectors interact. Another example is Repullo and Suarez (2013), who assess capital requirements in the presence of a trade-off between causing credit crunch effects in recessions and reducing the social cost of bank failures.

[10]This view has a long tradition in the banking literature (see Bhattacharya, Boot, and Thakor 1998 for a survey). Van den Heuvel (2008) analyzes bank capital regulation in a macroeconomic model without aggregate shocks in which

the intermediation chain that links saving households with household and corporate borrowers.

Our work is connected with several recent attempts to incorporate banking in otherwise standard DSGE models; these include Goodfriend and McCallum (2007), Curdia and Woodford (2008), Gerali et al. (2010), Meh and Moran (2010), and Christiano, Motto, and Rostagno (2014). As in our paper, this literature mostly focuses on direct lending by banks, excluding securitization and investment banking activities. In most of this work the emphasis is on the role of bank lending in the propagation of shocks (typically monetary policy shocks) or in the optimal conduct of monetary policy, rather than on the rationale for macroprudential policies. Moreover, default normally does not feature prominently or at all. An exception is Angeloni and Faia (2013), who focus on capital regulation in a model where banks are fragile and subject to runs, and the main distortion arises from the fact that the projects funded by banks may be subject to costly early liquidation if banks get in trouble.[11]

Hirakata, Sudo, and Ueda (2013) also consider the full intermediation chain and allow for borrowers' and banks' default, but they consider uninsured deposits, while in our analysis the effect of deposit insurance on banks' risk taking is one of the reasons for the need for macroprudential policy. This is also the case in Martinez-Miera and Suarez (2012), who analyze the effect of capital requirements on banks' incentive to extend loans with highly correlated defaults in case a so-called systemic shock occurs. Collard et al. (2012) look at the interplay between prudential and monetary policy instruments in a related model where deposit insurance can also lead to socially excessive risk taking by banks.

Brunnermeier and Sannikov (2014) use a continuous-time methodology to solve for the full dynamics of a stylized macroeconomic model where some experts' wealth determines their ability to finance productive investment, and where the interaction with asset

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deposits offer liquidity services to households and bank leverage induces banks to get involved in risk shifting.

[11]Benes and Kumhof (2011) also analyze capital requirements in a dynamic model where, like in ours, banks finance their borrowers with non-contingent debt. However, their model adopts several other unconventional assumptions (e.g., on the monetary nature of credit extension) that make it hard to compare with the rest of the literature.

price volatility gives rise to highly non-linear dynamics. Although the paper does not discuss macroprudential policies, its results suggest that non-linearities might be important in a model like ours. Assessing this, however, is a challenge left for future research since we currently solve the model with standard perturbation methods which neglect potential non-linear effects.[12]

Finally, our paper shares the goal of finding a rationale for macroprudential policies with papers that have recently put the emphasis on pecuniary externalities, including Bianchi and Mendoza (2010), Jeanne and Korinek (2010), Bianchi (2011), Gersbach and Rochet (2012), and Christiano and Ikeda (2013). In our model the endogenous leverage of households and firms is also affected by asset prices, so pecuniary externalities might also be present, although we do not explicitly assess their contribution to distorting the allocation of credit in our economy.

3. Model Setup

We consider an economy populated by households, entrepreneurs, and bankers, whose main characteristics are as follows:

Households. Households are risk averse and infinitely lived and derive utility from a *consumption* good and from a durable good, *housing*, which provides housing services to its owners. The consumption good acts as the numeraire. Similar to Iacoviello (2005) and subsequent literature, there are two types of households that differ in their discount factor, patient and impatient. Each type is grouped in a distinct representative dynasty which provides risk sharing to its members. In equilibrium, patient households are savers who buy houses outright, while the impatient households borrow from banks, using their holdings of housing as collateral. Mortgage debt is provided to the individual members of the dynasty against their individual housing units on a limited liability non-recourse basis. This implies the possibility of defaulting on mortgage debt at an individual level with the only implication for the borrower of losing the housing good on which the mortgage is secured. Thus,

[12] A related challenge is the analysis of optimal capital requirements from the perspective of stochastic welfare rather than, as we do in this paper, from the perspective of the welfare attained in the non-stochastic steady state.

in contrast to Iacoviello (2005), mortgage loans feature default risk and, in case of default, the repossession of collateral by the banks involves verification costs similar to those considered in BGG. Both types of households supply labor in a competitive market.

Entrepreneurs. *Entrepreneurs* are risk-neutral agents specialized in owning and maintaining the stock of physical capital, which they rent in each period to the firms involved in the production of the consumption good.[13] They live across two consecutive periods and derive utility from donating a part of their final wealth to the saving dynasty (in what can be interpreted as "paying dividends") and from leaving another part as a bequest to the next generation of entrepreneurs (in what can be interpreted as "retaining earnings"). This overlapping-generations formulation, which will also be postulated for the bankers, gives us the same sort of dynamics for entrepreneurial and banking net worth as in BGG. Simultaneously, it allows us to reduce the number of classes of agents to care about in the welfare calculations. Specifically, it allows us to focus on a weighted sum of the intertemporal expected utility of the patient and the impatient households without neglecting any of the consumption capacity generated in the economy. Entrepreneurs finance their initial purchases of physical capital partly with the inherited net worth and partly with corporate loans provided by banks. Similar to household loans, corporate loans are subject to limited liability and default risk, and recovering residual returns from bankrupt entrepreneurs leads banks to incur verification costs.

Bankers. *Bankers* are the providers of inside equity to perfectly competitive financial intermediaries that we call banks. Like entrepreneurs, bankers are risk-neutral agents who live across two consecutive periods and derive utility from making transfers to the saving dynasty and leaving bequests to the next cohort of bankers.[14] At the end of each period, the gross return on bank equity is fully distributed to the bankers, who in turn distribute it to the patient households ("dividends") and to the next cohort of bankers ("retained earnings").

[13] A possible interpretation is that physical capital would suffer prohibitively high depreciation rates if owned and maintained by any other class of agents.

[14] The induced dynamics of bankers' net worth is similar to that in Gertler and Karadi (2011), where a fraction of households become bankers at random in every period and remain bankers in subsequent periods with some probability.

To complete the model overview, we need to refer to banks, consumption-good-producing firms, and capital-good-producing firms:

Banks. Banks' outside funding is made up of fully insured deposits raised among the saving households. Banks operate under limited liability and may default due to *both* idiosyncratic and aggregate shocks to the performance of their loan portfolios. Deposit insurance is funded within each period by levying lump-sum taxes on patient households, if needed. From the standpoint of savers, however, we assume that recovering the fully insured principal and interest of their deposits in the case of bank failure is costly in terms of time and effort, so that deposits may still pay a risk premium that depends on the average bank's default risk. This captures the notion that depositors are unable to properly monitor their banks and deposit risk premia depend on the general health of the banking system. Bankers' inside equity contributions are necessary for the banks to comply with the prevailing regulatory capital requirement.

Production of the Consumption Good. There is a perfectly competitive consumption-good-producing sector made up of firms owned by the patient households. These firms combine capital rented from entrepreneurs with household and entrepreneurial labor inputs in order to produce the consumption good. This sector is not directly affected by financial frictions.

Production of the Capital Good and Housing. Finally, there are two perfectly competitive sectors made up of firms which produce new units of the capital good and of housing, respectively. Like in Gertler, Kiyotaki, and Queralto (2012), these firms, owned by patient households, face investment adjustment costs and optimize intertemporally in response to changes in the price of capital. As with the consumption-good-producing sector, these sectors are not directly affected by financial frictions.

We now turn to describe all the ingredients in detail.

3.1 Households

The economy is populated by two representative dynasties made up of a measure-one continuum of ex ante identical households each. Households are risk averse and maximize some time-separable expected utility functions. One dynasty, identified by the superscript s, is made of relatively patient households with a discount factor

β^s. The other dynasty, identified by the superscript m, is made of more impatient households with a discount factor $\beta^m \leq \beta^s$. Thus, in equilibrium, the patient households save and the impatient households borrow. Dynasties provide consumption risk sharing to their members and are in charge of making most household decisions.[15]

3.1.1 Saving Households

The dynasty of patient households maximizes

$$E_t \left[\sum_{i=0}^{\infty} (\beta^s)^{t+i} \left[\log \left(c^s_{t+i} \right) + v^s \log \left(h^s_{t+i-1} \right) - \frac{\varphi^s}{1+\eta} \left(l^s_{t+i} \right)^{1+\eta} \right] \right], \tag{1}$$

where c^s_t denotes the consumption of non-durable goods and h^s_{t-1} denotes the total stock of housing held by the various members of the dynasty; l^s_t denotes hours worked in the consumption-good-producing sector, with η the inverse of the Frisch elasticity of labor supply; v^s and φ^s are preference parameters.[16]

The patient households' dynamic budget constraints read as follows:

$$c^s_t + q^H_t h^s_t + d_t \leq w_t l^s_t + q^H_t (1 - \delta^H_t) h^s_{t-1} + \widetilde{R}^D_t d_{t-1} - T_t + \Pi^s_t, \tag{2}$$

where q^H_t is the price of housing, δ^H_t is the (possibly time-varying) rate at which housing units depreciate, w_t is the wage rate, and

$$\widetilde{R}^D_t = R^D_{t-1}(1 - \gamma PD^b_t), \tag{3}$$

where R^D_t is the fixed (gross) interest rate received at t on the savings deposited at banks at $t-1$ in the previous period and PD^b_t stands for the fraction of deposits in banks that fail in period t, which computed as the average deposit-weighted bank default rate realized in period t (further specified in equation (38) below). The principal and

[15]This latter feature is convenient for the solution of the model with standard techniques (i.e., avoiding kinks).

[16]For the sake of simplicity, the analysis presented in this paper only refers to a limited set of shocks. However, it is possible to allow the preference parameters to vary over time (potentially causing fluctuations in, e.g., the equilibrium price of housing) in response to exogenous shocks.

interest of bank deposits are fully guaranteed by a deposit insurance agency (DIA) that, for simplicity, is assumed to ex post balance its budget by imposing a lump-sum tax T_t on patient households. However, we assume that in the case of bank failure, households incur a linear transaction cost γ whenever they have to recover their funds.[17] This transaction cost introduces a link between the bank probability of default and bank funding costs and a wedge between the rate of return on deposits and the risk-free rate, while preserving the usual distortions associated with limited liability and deposit insurance.[18] Finally, Π_t^s includes the profits accruing to the saving households from the ownership of the capital-good- and housing-producing firms as well as the donations ("dividend payments") received from entrepreneurs and bankers.

The housing depreciation rate is time varying and follows an AR(1) process:

$$\delta_t^H = \left(1 - \rho^{\delta^H}\right) \delta^H + \rho^{\delta^H} \delta_{t-1}^H + \varepsilon_t^{\delta^H},$$

where δ^H is the steady-state depreciation rate, ρ^{δ^H} is the persistency parameter, and $\varepsilon_t^{\delta^H}$ is an i.i.d. shock with variance $\sigma_{\delta^H}^2$.

3.1.2 Borrowing Households

The objective function of the representative dynasty of impatient households has the same form and parameters as (1), except for the discount factor, which for them is $\beta^m < \beta^s$ and will induce the members of this dynasty to borrow rather than save in equilibrium. This explains the differences in their dynamic budget constraint, which read as follows:

$$c_t^m + q_t^H h_t^m - b_t^m \leq w_t l_t^m + \int_0^\infty \max\left\{\omega_t^m q_t^H (1 - \delta_t^H) h_{t-1}^m - R_{t-1}^m b_{t-1}^m, 0\right\} dF^m(\omega_t^m), \quad (4)$$

[17] For evidence that bank failure is costly to depositors even in the presence of deposit insurance, see Brown, Guin, and Morkoetter (2013).

[18] Notice that we assume that depositors cannot attach subjective estimates of the probability of failure to each bank. This is consistent with the view in Dewatripont and Tirole (1994) that depositors lack the capacity to discipline the banks. Hence individual banks preserve their incentives to possibly take excessive risks (in the form of high leverage and cheap lending) at the expense of the DIA.

where b_t^m is the dynasty's aggregate borrowing from the banking system and R_{t-1}^m is the contractual gross interest rate on the housing loan of size b_{t-1}^m agreed upon with a bank in the previous period. The term in the integral reflects the fact that the housing good and the debt secured against it are assumed to be distributed across the individual households that constitute the dynasty. Each impatient household experiences at the beginning of each period t an idiosyncratic shock ω_t^m to the efficiency units of housing owned from the previous period and has the option to (strategically) default on the non-recourse housing loans associated with those units.[19]

The shock ω_t^m is assumed to be independently and identically distributed across the impatient households, and to follow a log-normal distribution with density and cumulative distributions functions denoted by $f^m(\cdot)$ and $F^m(\cdot)$, respectively. This shock makes the effective resale value of the housing units acquired in the previous period $\tilde{q}_t^H = \omega^m q_t^H(1-\delta_t^H)$ and, given that default is costless for households, makes default on the underlying loan ex post optimal for the household whenever $\omega_t^m q_t^H(1-\delta_t^H)h_{t-1}^m < R_{t-1}^m b_{t-1}^m$.[20] This explains the presence of the max operator in the integral in (4).

Housing Loans. After the realization of the idiosyncratic shock ω_t^m, each individual household decides whether to default on the individual loans attached to the housing held from the previous period and the residual net worth is passed on to the dynasty, which is not liable for any unpaid debt. The dynasty then makes the decisions on consumption, housing, labor supply, and debt for period t and allocates them evenly across its members.

Fluctuations in the net worth of the dynasty (as captured by the last term in the right-hand side of (4)) are driven by the changes in the net worth of the loan-repaying households as well as the realization of zero net worth from all housing units owned by members that default on their housing loans. Default in period t occurs for

[19]This shock is intended to capture idiosyncratic fluctuations in the value of houses and can be interpreted as a reduced-form representation of a sudden improvement or worsening in the neighborhood, in the social equipment available nearby, or in the resource cost of maintaining the property. See also Forlati and Lambertini (2011), who use a similar formulation.

[20]See Geanakoplos (2003) for a discussion of the ex post optimality of this type of behavior by the borrower, and Goodhart et al. (2012) for an extension to the analysis of mortgage contracts backed by housing collateral.

$$\omega_t^m \leq \overline{\omega}_t^m = \frac{x_{t-1}^m}{R_t^H},$$

where

$$R_t^H \equiv \frac{q_t^H(1-\delta_t^H)}{q_{t-1}^H}$$

is the ex post average realized gross return on housing, and

$$x_t^m \equiv \frac{R_t^m b_t^m}{q_t^H h_t^m}$$

is a measure of a household leverage. The fraction of defaulted mortgages at period t can then be expressed as $F^m(\overline{\omega}_t^m)$ and the net worth accruing to the dynasty out of its aggregate housing investment in the previous period can be written as

$$\Phi_t^m \equiv \left(\int_{\overline{\omega}_t^m}^{\infty} (\omega_t^m - \overline{\omega}_t^m) dF(\omega_t^m) \right) R_t^H q_{t-1}^H h_{t-1}^m. \qquad (5)$$

Now, using the same intermediate notation as in BGG, we can more compactly write

$$\Phi_t^m = (1 - \Gamma^m(\overline{\omega}_t^m)) R_t^H q_{t-1}^H h_{t-1}^m, \qquad (6)$$

where

$$\Gamma^m\left(\overline{\omega}_t^m\right) = \int_0^{\overline{\omega}_t^m} \omega_t^m f\left(\omega_t^m\right) d\omega_t^m + \overline{\omega}_t^m \int_{\overline{\omega}_t^m}^{\infty} f\left(\omega_t^m\right) d\omega_t^m. \qquad (7)$$

The variable Φ_t^m can be interpreted as net housing equity after accounting for repossessions of defaulting households.

Since each of the borrowing households default on the loans taken at period t according to a similar pattern of behavior, the terms of such loans must satisfy the following participation constraint for the lending bank:

$$E_t(1 - \Gamma^H(\overline{\omega}_{t+1}^H))(\Gamma^m\left(\overline{\omega}_{t+1}^m\right) - \mu^m G^m\left(\overline{\omega}_{t+1}^m\right)) R_{t+1}^H q_t^H h_t^m \geq \rho_t \phi_t^H b_t^m. \qquad (8)$$

Intuitively, this constraint says that the bankers who contribute equity $\phi_t^H b_t^m$ to the lending bank (where ϕ_t^H is the capital requirement on housing loans) should expect a gross expected return on their contribution at least as high as some market-determined required rate of return ρ_t which is exogenous for any individual bank although endogenous in the aggregate (as we explain later). Therefore, $\rho_t \phi_t^H b_t^m$ measures total gross equity returns for a given bank.

The expression in the left-hand side of the inequality accounts for the total equity returns associated with a portfolio of housing loans to the various members of the impatient dynasty. The term $\mu^m G\left(\overline{\omega}_{t+1}^m\right)$ reflects the proportional verification costs μ^H incurred in the repossession of the fraction $G^m\left(\overline{\omega}_{t+1}^m\right)$ of housing units which defaulting loans were borrowing against, where $G^m\left(\overline{\omega}_{t+1}^m\right) = \int_0^{\overline{\omega}_{t+1}^m} \omega_{t+1}^m f^m\left(\omega_{t+1}^m\right) d\omega_{t+1}^m$.

The factor $(1 - \Gamma^H(\overline{\omega}_t^H))$ plays a similar role to the factor $(1-\Gamma^m(\overline{\omega}_t^m))$ in (6) and accounts for bank leverage and the possibility that the individual bank that lends to households (the superscript H identifies claims of banks of such class) fails due to sufficiently adverse idiosyncratic or aggregate shocks to the performance of its loans. The full description of the threshold $\overline{\omega}_t^H$ of the idiosyncratic shock below which the bank fails is provided in sub-section 3.4.

Note that limited liability and the fact that bank liabilities (deposits) are insured imply that a bank can meet the required return on equity with a lower lending rate than in their absence. This suggests that these distortions act in the direction of expanding credit availability for entrepreneurs and impatient households. It should also be emphasized that the probability of households' default on their loans (and, similarly, the probability that a bank of class H defaults on its deposits) is affected by R_t^H, a variable that responds to aggregate shocks. Therefore, default in this model is a function of both idiosyncratic and aggregate shocks, unlike in BGG and most other papers in the literature, which exclude the influence of the latter by assuming that debt is state contingent.[21]

[21] Ruling out state-contingent debt implies a restriction in the contracting space. Loan and deposit contracts in our economy are incomplete in that they

Borrowing Households' Optimization Problem. With all the prior ingredients, the decision problem of the borrowing households can be compactly written as a contracting problem between the corresponding representative dynasty and its bank:

$$\max_{\{c^m_{t+i},h^m_{t+i},l^m_{t+i},x^m_{t+i},b^m_{t+i}\}_{i=0}^{\infty}} \times E_t\left[\sum_{i=0}^{\infty}(\beta^m)^{t+i}\left[\log\left(c^m_{t+i}\right)+v^m\log\left(h^m_{t+i}\right)-\frac{\varphi^m}{1+\eta}\left(l^m_{t+i}\right)^{1+\eta}\right]\right] \tag{9}$$

subject to the budget constraint of the dynasty,

$$c^m_t+q^H_t h^m_t-b^m_t\leq w_t l^m_t+\left(1-\Gamma^m\left(\frac{x^m_t}{R^H_{t+1}}\right)\right)R^H_{t+1}q^H_t h^m_t, \tag{10}$$

and the participation constraint of the bank,

$$E_t\left[(1-\Gamma^H(\overline{\omega}^H_{t+1}))\left(\Gamma^m\left(\frac{x^m_t}{R^H_{t+1}}\right)-\mu^m G^m\left(\frac{x^m_t}{R^H_{t+1}}\right)\right)R^H_{t+1}\right]q^H_t h^m_t = \rho_t\phi^H_t b^m_t, \tag{11}$$

which we impose with equality without loss of generality.[22]

3.2 Entrepreneurs

To guarantee easy aggregation and generate the same type of net worth dynamics as in Bernanke, Gertler, and Gilchrist (1999) but in a slightly more microfounded manner, we assume that entrepreneurs belong to a sequence of overlapping generations of two-period-lived risk-neutral agents. Each generation of entrepreneurs inherits wealth

cannot be made fully contingent on aggregate variables (perhaps due to verifiability problems, publication lags, potential manipulability if contractually relevant, etc.).

[22] In principle, the borrowing rate R^m_t is part of the housing loan contract and, hence, can be treated as part of the decision variables of the impatient dynasty in period t. However, treating the intermediate variable x^m_t as part of the contract variables (together with b^m_t and h^m_t) allows us to write the entire contract problem without explicit reference to R^m_t.

in the form of bequests n_t^e from the previous generation of entrepreneurs. Entrepreneurs are the only agents who can own and maintain the capital stock. They purchase new capital from capital goods producers and depreciated capital from the previous generation of entrepreneurs, and then rent it to the contemporaneous producers of the consumption good. Entrepreneurs finance their capital holdings with their own initial net worth n_t^e and with loans b_t^e received from the banks specialized in corporate loans.

An entrepreneur born at time t values the donations made to the patient dynasty at time $t+1$ ("dividends"), c_{t+1}^e, and the bequests left to the next cohort of entrepreneurs ("retained earnings"), n_{t+1}^e, according to the utility function $(c_{t+1}^e)^{\chi^e}(n_{t+1}^e)^{1-\chi^e}$, with $\chi^e \in (0,1)$.[23] Thus, once in period $t+1$, the entrepreneur solves

$$\max_{c_{t+1}^e, n_{t+1}^e} (c_{t+1}^e)^{\chi^e}(n_{t+1}^e)^{1-\chi^e} \tag{12}$$

subject to

$$c_{t+1}^e + n_{t+1}^e \leq W_{t+1}^e.$$

Optimizing behavior then yields the "dividend payment" rule

$$c_{t+1}^e = \chi^e W_{t+1}^e \tag{13}$$

and the "earnings retention" rule

$$n_{t+1}^e = (1-\chi^e)W_{t+1}^e, \tag{14}$$

and an indirect utility equal to W_{t+1}^e.

The decision problem of the entrepreneur who starts up at t can then be written as

$$\max_{k_t, b_t^e, R_t^F} E_t(W_{t+1}^e) \tag{15}$$

[23] These preferences involve impure altruism in the form introduced by Andreoni (1989) and used, e.g., in Aghion and Bolton (1997): entrepreneurs directly enjoy the "warm glow" from giving, independently of the extent to which the recipients actually benefit from the donation.

subject to the period t resource constraint

$$q_t^K k_t - b_t^e = n_t^e, \tag{16}$$

the definition

$$W_{t+1}^e = \max \left[\omega_{t+1}^e \left(r_{t+1}^k + (1 - \delta_{t+1}) q_{t+1}^K \right) k_t - R_t^F b_t^e, \ 0 \right], \tag{17}$$

and a bank participation constraint which will be fully specified in the next sub-section. In these expressions, q_t^K is the price of capital at period t, k_t is the capital held by the entrepreneur in period t, b_t^e is the amount borrowed from the bank in period t, δ_t is the time-varying depreciation rate of each efficiency unit of capital, r_t^K is the rental rate per efficiency unit of capital, and R_t^F is the contractual gross interest rate of the loan taken from the bank in period t.

Note that the depreciation rate δ_t is time varying and, similarly to the housing depreciation, follows an AR(1) process:

$$\delta_t = \left(1 - \rho^\delta\right) \delta + \rho^\delta \delta_{t-1} + \varepsilon_t^\delta,$$

where δ is the steady-state depreciation rate, ρ^δ is the persistency parameter, and ε_t^δ is an i.i.d. shock with variance σ_δ^2.

The factor ω_{t+1}^e that multiplies the return from capital holdings is an idiosyncratic shock to the entrepreneur's efficiency units of capital. This shock realizes after the period t loan with the bank is agreed to and prior to renting the available capital to consumption good producers in that date. With a role similar to the shock ω_{t+1}^m suffered by the housing held by borrowing households, the shock ω_{t+1}^e is a simple way to rationalize the existence of idiosyncratic shocks to the entrepreneurs' performance and to generate a non-trivial default rate on entrepreneurial loans. The shock is independently and identically distributed across entrepreneurs and follows a log-normal distribution with an expected value of one, and density and cumulative distribution functions denoted $f^e(\cdot)$ and $F^e(\cdot)$, respectively.

Similar to all other borrowers in our economy, an entrepreneur cannot be held liable for any contracted repayments due to banks (which amount to $R_t^F b_t^e$ in period $t+1$) over and above the gross returns that she obtains on the capital investment undertaken in the previous period, $\left(r_{t+1}^K + (1 - \delta_{t+1}) q_{t+1}^K\right) \omega_{t+1}^e k_t$. Accordingly, the max operator in (17) takes into account limited liability and the possibility that entrepreneurs default on their bank loans.

3.2.1 Entrepreneurial Loans

Let

$$R^K_{t+1} = \frac{r^K_{t+1} + (1 - \delta_{t+1})\, q^K_{t+1}}{q^K_t}$$

denote the gross return per efficiency unit of capital obtained in period $t + 1$ out of capital owned in period t. Then the entrepreneur will repay her loan at $t + 1$ whenever her idiosyncratic shock ω^e_{t+1} exceeds the following threshold:

$$\overline{\omega}^e_{t+1} \equiv \frac{R^F_t b^e_t}{R^K_{t+1} q^K_t k_t} \equiv \frac{x^e_t}{R^K_{t+1}}, \tag{18}$$

where $x^e_t \equiv \frac{R^F_t b^e_t}{q^K_t k_t}$ denotes entrepreneurial *leverage* as measured by the ratio of contractual debt repayment obligations at $t + 1$, $R^F_t b^e_t$, to the value of the capital purchased at t, $q^K_t k_t$. Notice that (18) implies (differently from BGG, where the contractual debt repayments are made contingent on R^K_{t+1}) that fluctuations in R^K_{t+1} will (realistically) produce fluctuations in entrepreneurial default rates.

When an entrepreneur defaults on her loan, the bank only recovers a fraction $1 - \mu^e$ of the gross return of the capital available to the defaulted entrepreneur, where μ^e stands for verification costs incurred by the bank when taking possession of the returns and selling the underlying capital to other entrepreneurs. Hence a bank recovers $R^F_t b^e_t$ from performing loans and $(1 - \mu^e)\, R^K_{t+1} q^K_t \omega^e_{t+1} k_t$ from non-performing loans. Ex ante, lenders recognize that under certain realizations of the idiosyncratic and the aggregate shocks, entrepreneurs will go bankrupt, especially when their ex ante leverage x^e_t is high.

The division between entrepreneurs and their bank of the total gross returns on a well-diversified portfolio of entrepreneurial investments at period t can be compactly expressed using notation similar to the one already introduced for borrowing households:

$$\Gamma^{e}\left(\overline{\omega}_{t+1}^{e}\right)=\int_{0}^{\overline{\omega}_{t+1}^{e}}\omega_{t+1}^{e}f^{e}\left(\omega_{t+1}^{e}\right)d\omega_{t+1}^{e}+\overline{\omega}_{t+1}^{e}\int_{\overline{\omega}_{t+1}^{e}}^{\infty}f^{e}\left(\omega_{t+1}^{e}\right)d\omega_{t+1}^{e}, \tag{19}$$

which gives the share of the gross returns (gross of verification costs) that will accrue to the bank, and

$$G^{e}\left(\overline{\omega}_{t+1}^{e}\right)=\int_{0}^{\overline{\omega}_{t+1}^{e}}\omega_{t+1}^{e}f^{e}\left(\omega_{t+1}^{e}\right)d\omega_{t+1}^{e}, \tag{20}$$

which denotes the part of those returns that comes from defaulted loans. Then the verification costs incurred by the bank on its portfolio of loans to entrepreneurs will be $\mu^{e}G^{e}\left(\omega_{t+1}^{e}\right)$, and the net share of the total gross returns of the portfolio that the bank appropriates can be expressed as $\Gamma^{e}\left(\overline{\omega}_{t+1}^{e}\right)-\mu^{e}G^{e}\left(\omega_{t+1}^{e}\right)$. We will use this expression below when introducing the bank's participation constraint into the entrepreneur's optimization problem.

3.2.2 Entrepreneurs' Optimization Problem

The contracting problem between the entrepreneur and her bank in period t can be written as one of maximizing the entrepreneur's expected wealth at $t+1$,

$$\max_{x_t^e,k_t} E_t\left[\left(1-\Gamma^{e}\left(\frac{x_t^e}{R_{t+1}^K}\right)\right)R_{t+1}^K q_t^K k_t\right],$$

subject to the participation constraint of the bank:

$$E_t\left[(1-\Gamma^{F}(\overline{\omega}_{t+1}^{F}))\left(\Gamma^{e}\left(\frac{x_t^e}{R_{t+1}^K}\right)-\mu^{e}G^{e}\left(\frac{x_t^e}{R_{t+1}^K}\right)\right)\right]R_{t+1}^K q_t^K k_t = \rho_t\phi_t^F(q_t^K k_t - n_t^e), \tag{21}$$

which we can write with equality without loss of generality. Just like in the case of the bank extending loans to impatient households in (10), equation (21) states that the expected payoffs appropriated by the equityholders of a bank which holds a portfolio of loans to entrepreneurs must be sufficient to guarantee the expected rate of return ρ_t that the bankers require on the wealth that they contribute to the bank. Bankers' equity contribution, $\phi_t^F(q_t^K k_t - n_t^e)$, is determined by the need to comply with a capital requirement ϕ_t^F on each unit of lending.

The factor $(1 - \Gamma^F(\overline{\omega}_{t+1}^F))$ that multiplies the left-hand side of (21) accounts for bank leverage and the possibility that an individual bank specializing in corporate loans (the superscript F identifies such class of banks) fails due to sufficiently adverse idiosyncratic or aggregate shocks to the performance of its portfolio of entrepreneurial loans. The full details of the threshold $\overline{\omega}_{t+1}^F$ of the idiosyncratic shock below which the bank fails are presented below in sub-section 3.4.

The final wealth of the entrepreneurs that start up in period t can be written as

$$W_{t+1}^e = \frac{\left(1 - \Gamma^e\left(\overline{\omega}_{t+1}^e\right)\right) R_{t+1}^K}{1 - E_t\left\{\left(1 - \Gamma^F\left(\overline{\omega}_{t+1}^F\right)\right)\left(\Gamma^e\left(\overline{\omega}_{t+1}^e\right) - \mu^e G^e\left(\overline{\omega}_{t+1}^e\right)\right)\frac{R_{t+1}^K}{\rho_t \phi_t^F}\right\}} n_t^e$$

and, since a fraction $(1 - \chi^e)$ of such wealth is left as a bequest to the next generation of entrepreneurs, the law of motion of entrepreneurs' aggregate initial net worth can be written as

$$n_{t+1}^e = (1 - \chi^e) \times \frac{\left(1 - \Gamma\left(\overline{\omega}_{t+1}^e\right)\right) R_{t+1}^K}{1 - E_t\left\{\left(1 - \Gamma^F\left(\overline{\omega}_{t+1}^F\right)\right)\left(\Gamma^e\left(\overline{\omega}_{t+1}^e\right) - \mu^e G^e\left(\overline{\omega}_{t+1}^e\right)\right)\frac{R_{t+1}^K}{\rho_t \phi_t^F}\right\}} n_t^e.$$

3.3 Bankers

We model bankers in a very similar way to entrepreneurs: they belong to a sequence of overlapping generations of risk-neutral two-period-lived agents. Bankers have exclusive access to the opportunity of investing their wealth as banks' inside equity capital. Each generation of bankers inherits wealth in the form of bequests n_t^b from the previous generation of bankers and leaves bequests n_{t+1}^b to the subsequent one. Aggregate banker net worth determines, for a given capital requirement, the equilibrium-required rate of return on bank equity and hence the lending rates.

A banker born at time t values his donations to the patient dynasty at $t + 1$ ("dividends"), c_{t+1}^b, and the bequests left to the next cohort of bankers ("retained earnings"), n^b_{t+1}, according to the utility function $\left(c^b_{t+1}\right)^{\chi^b}\left(n^b_{t+1}\right)^{1-\chi^b}$, with $\chi^b \in (0,1)$. The banker who starts up at period t receives a bequest from the previous generation of bankers and decides how to allocate this wealth as inside capital across the two classes of existing banks: the banks specializing in housing loans (the H banks) and the banks specializing in entrepreneurial loans (the F banks). There is a continuum of ex ante identical perfectly competitive banks of each class. The ex post gross return at $t+1$ on the inside equity invested in H and F banks at t is denoted $\widetilde{\rho}^H_{t+1}$ and $\widetilde{\rho}^F_{t+1}$, respectively.

If a banker starting up with wealth n^b_t invests an amount e^F_t of inside equity in one or several F banks, and the rest in one or several of the H banks, his net worth after one period will be

$$W^b_{t+1} = \widetilde{\rho}^F_{t+1} e^F_t + \widetilde{\rho}^H_{t+1}\left(n^b_t - e^F_t\right), \tag{22}$$

which the banker will distribute by solving

$$\max_{c^b_{t+1}, n^b_{t+1}} \left(c^b_{t+1}\right)^{\chi^b}\left(n^b_{t+1}\right)^{1-\chi^b} \tag{23}$$

subject to

$$c^b_{t+1} + n^b_{t+1} \leq W^b_{t+1}.$$

Optimizing behavior yields the "dividend payment" rule

$$c^b_{t+1} = \chi^b W^b_{t+1} \tag{24}$$

and the "earnings retention" rule

$$n^b_{t+1} = (1-\chi^b) W^b_{t+1}, \tag{25}$$

and an indirect utility equal to W^b_{t+1}.

The portfolio problem of the banker who starts up at t can then be written as

$$\max_{e^F_t} E_t(W^b_{t+1}) = E_t(\widetilde{\rho}^F_{t+1} e^F_t + \widetilde{\rho}^H_{t+1}\left(n^b_t - e^F_t\right)). \tag{26}$$

So, interior equilibria in which both classes of banks receive strictly positive inside equity from bankers will require the following equality to hold:

$$E_t \widetilde{\rho}^F_{t+1} = E_t \widetilde{\rho}^H_{t+1} = \rho_t, \tag{27}$$

where ρ_t denotes bankers' required expected gross rate of return on equity investments undertaken at time t. This expected return is endogenously determined in equilibrium, but both individual banks and bankers take it as given in their decisions. Specifically, ρ_t plays an essential role in the bank participation constraints, (8) and (21), that appear in the problems of each class of final borrowers.

Finally, the law of motion of the initial wealth of each generation of bankers is

$$n^b_{t+1} = \left(1 - \chi^b\right) [\widetilde{\rho}^F_{t+1} e^F_t + \widetilde{\rho}^H_{t+1} \left(n^b_t - e^F_t\right)]. \tag{28}$$

Therefore, under our assumptions, the risk-neutral bankers of each generation operate as in a one-period model (maximizing the expected one-period return on their initial wealth), but bank capital is a state variable important for aggregate dynamics (as, e.g., in Gertler and Kiyotaki 2010). As in the case of entrepreneurs, assuming that bankers directly derive utility from transferring c^b_{t+1} to the savings households will allow us to focus the welfare analysis on households' lifetime utility without neglecting the consumption capacity associated with bankers' unretained profits.

3.4 Banks

The banks which issue the equity bought by bankers are institutions specialized in extending either mortgages or corporate loans. A bank lasts for one period only: it is an investment project created at t and liquidated at $t + 1$. We assume a continuum of banking institutions of each class $j = H, F$. The equity payoffs π^j_{t+1} generated by a representative of class j after its period of operation is given by the positive part of the difference between the returns from its loans and the repayments due to its deposits:

$$\pi^j_{t+1} = \max\left[\omega^j_{t+1} \tilde{R}^j_{t+1} b^j_t - R^D_t d^j_t, 0\right], \tag{29}$$

where b_t^j and d_t^j are the loans extended and the deposits taken by the bank at t, respectively, R_t^D is the gross interest rate paid on the deposits taken at t (which is uniform across all banks given the presence of deposit insurance and the assumption that depositors cannot assign individualize estimates of the probability of failure to each bank), and $\tilde{R}_{t+1}^j$ denotes the realized return on a well-diversified portfolio of loans of class j. The max operator reflects the fact that the shareholders of the bank enjoy limited liability, so their payoffs cannot be negative.

The bank's idiosyncratic failure risk comes from the existence of an idiosyncratic portfolio return shock ω_{t+1}^j which is i.i.d. across the banks of class j and is assumed to follow a log-normal distribution with a mean of one and a distribution function $F^j(\omega_{t+1}^j)$.[24] We also allow for an aggregate shock to the bank's idiosyncratic failure risk—i.e., a bank risk shock—that, similarly to the other aggregate sources of uncertainty featured by the model, follows an AR(1) process.

Bank default is driven by fluctuations in the aggregate loan return $\tilde{R}_{t+1}^j$ (itself driven by firms' or households' default rates) and the bank-idiosyncratic shock ω_{t+1}^j. When a bank fails, its equity is written down to zero and its deposits are taken over by the DIA, which pays out all deposits in full. The DIA partly recoups this by taking over the failed bank's loan portfolio minus resolution costs, which are assumed to be a μ^j fraction of total bank assets.

The bank also faces a regulatory capital constraint:

$$e_t^j \geq \phi_t^j b_t^j, \tag{30}$$

where ϕ_t^j is the potentially time-varying capital-to-asset ratio of banks of class j. Thus, the bank is restricted by regulation to back with equity funding at least a fraction ϕ_t^j of the loans made at t. It is possible to show that in equilibrium the constraint is binding, so that the loans can be written as $b_t^j = e_t^j/\phi_t^j$ and the deposits as $d_t^j = (1-\phi_t^j)e_t^j/\phi_t^j$. Allowing the capital requirement ϕ_t^j to vary across different classes of banks is consistent with thinking of them as

[24]The fact that the shock has mean of one and is i.i.d. across banks makes it equivalent to a redistribution of gross loan returns across banks, which may be interpreted as a reduced form for the existence of imperfect diversification, e.g., due to unmodeled regional or industry specialization.

risk based (like under Basel III) or as sectoral requirements serving as tools of macroprudential policy.

Note that the role of the regulatory capital requirement is to compensate for the limited liability distortions described earlier. A higher capital requirement forces banks to get funded with a larger share of equity financing, which is more expensive than deposit financing because of two reasons: (i) equity does not enjoy the protection of deposit insurance, (ii) bankers' wealth is limited and in equilibrium appropriates some scarcity rents. Moreover, lower leverage reduces the probability of bank default and hence the overall size of the deposit insurance subsidy. The implication is an increase in the loan rates at which banks are willing to lend (i.e., a tightening of banks' participation constraints in the problems of the borrowing households and entrepreneurs) and, in equilibrium, a more restricted access to credit for households and entrepreneurs.

Let $\overline{\omega}^j_{t+1}$ denote the threshold realization of ω^j_{t+1} below which the bank fails because the realized return on its loan portfolio is lower than its deposit repayment obligations:

$$\overline{\omega}^j_{t+1}\tilde{R}^j_{t+1}b^{ij}_t \equiv R^D_t d^{ij}_t. \tag{31}$$

Using our previous expressions for b^j_t and d^j_t, we can write the threshold as

$$\overline{\omega}^j_{t+1} = (1-\phi^j_t)\frac{R^D_t}{\tilde{R}^j_{t+1}}, \tag{32}$$

that is, the product of the leverage ratio $1-\phi^j_t$ and the spread between the realized gross loan return and the gross deposit rate, $\tilde{R}^j_{t+1}/R^D_t$.

The equity payoffs in (29) can then be rewritten as

$$\begin{aligned}\pi^j_{t+1} &= \max\left[\omega^j_{t+1}-\overline{\omega}^j_{t+1},0\right]\frac{\tilde{R}^j_{t+1}}{\phi^j_t}e^j_t\\ &= \left[\int_{\overline{\omega}^j_{t+1}}^{\infty}\omega^j_{t+1}f^j\left(\omega^j_{t+1}\right)d\omega^j_{t+1}-\overline{\omega}^j_{t+1}\int_{\overline{\omega}^j_{t+1}}^{\infty}f^j\left(\omega^j_{t+1}\right)d\omega^j_{t+1}\right]\\ &\quad\times\frac{\tilde{R}^j_{t+1}}{\phi^j_t}e^j_t,\end{aligned} \tag{33}$$

where $f^j(\omega^j_{t+1})$ denotes the density distribution of ω^j_{t+1} conditional on the information available when the loans are originated at time t. Hence $F^j(\overline{\omega}^j_{t+1})$ is the probability of default of a bank of class j (conditional upon the realization of the aggregate loan return $\tilde{R}^j_{t+1}$, which enters this expression through $\overline{\omega}^j_{t+1}$).

Following BGG, it is useful to define

$$\Gamma^j(\overline{\omega}^j_{t+1}) = \int_0^{\overline{\omega}^j_{t+1}} \omega^j_{t+1} f^j\left(\omega^j_{t+1}\right) d\omega^j_{t+1} + \overline{\omega}^j_{t+1} \int_{\overline{\omega}^F_{t+1}}^{\infty} f^j\left(\omega^j_{t+1}\right) d\omega^j_{t+1} \tag{34}$$

and

$$G^j\left(\overline{\omega}^j_{t+1}\right) = \int_0^{\overline{\omega}^j_{t+1}} \omega^j_{t+1} f^j\left(\omega^j_{t+1}\right) d\omega^j_{t+1}, \tag{35}$$

which denotes the share of total bank assets which belong to banks that end up in default. Thus $\mu^j G^j\left(\overline{\omega}^j_{t+1}\right)$ is the total cost of bank default expressed as a fraction of total bank assets.

Using this notation we can write

$$\pi^j_{t+1} = \frac{\left[1 - \Gamma^j(\overline{\omega}^j_{t+1})\right] \tilde{R}^j_{t+1}}{\phi^j_t} e^j_t \tag{36}$$

and define the ex post gross rate of return on equity invested in a bank of type j as

$$\widetilde{\rho}^j_{t+1} = \frac{\left[1 - \Gamma^j(\overline{\omega}^j_{t+1})\right] \tilde{R}^j_{t+1}}{\phi^j_t}. \tag{37}$$

For completeness, notice that derivations in prior sections imply the following expressions for $\tilde{R}^j_{t+1}$, $j = H, F$:

$$\tilde{R}^H_{t+1} = \left(\Gamma^m\left(\frac{x^m_t}{R^H_{t+1}}\right) - \mu^m G^m\left(\frac{x^m_t}{R^H_{t+1}}\right)\right) \frac{R^H_{t+1} q^H_t h^m_t}{b^m_t},$$

$$\tilde{R}^F_{t+1} = \left(\Gamma^e\left(\frac{x^e_t}{R^K_{t+1}}\right) - \mu^e G^e\left(\frac{x^e_t}{R^K_{t+1}}\right)\right) \frac{R^K_{t+1} q^K_t k_t}{q^K_t k_t - n^e_t}.$$

Finally, the aggregate default rate for the banking system PD_t^b, which enters in (3), is given by

$$PD_t^b = \frac{d_{t-1}^H PD_t^H + d_{t-1}^F PD_t^F}{d_{t-1}^H + d_{t-1}^F}. \tag{38}$$

3.5 Consumption Good Production

The consumption good is produced by perfectly competitive firms which combine capital rented from entrepreneurs, k_{t-1}, and labor supplied by patient and impatient households, l_t, using a standard Cobb-Douglas production function:

$$y_t = A_t k_{t-1}^{\alpha} l_t^{1-\alpha},$$

where α is an elasticity parameter and A_t is total factor productivity (TFP) following an AR(1) process:

$$\ln A_t = \rho^A \ln A_{t-1} + \varepsilon_t^A,$$

where ρ^A is the persistency parameter and ε_t^A is an i.i.d. shock with variance σ_A^2.

Optimality in the use of the capital and labor input requires

$$r_t^K = \alpha \frac{y_t}{k_{t-1}},$$

and

$$w_t = (1-\alpha)\frac{y_t}{l_t}.$$

3.6 Capital Good and Housing Production

We model capital-good-producing firms and housing-producing firms symmetrically. They produce new units of capital and housing from the consumption good and sell them to entrepreneurs and households, respectively, at prices q_t^K and q_t^H. These firms are owned by the patient households and their technology is subject to adjustment costs. In order to produce $I_t = k_t - (1-\delta_t)\,k_{t-1}$ of new capital and $I_t^H = h_t - (1-\delta_t^H)h_{t-1}$ of new housing, the corresponding representative firm needs to spend resources of

$$\left[1+g\left(\frac{I_t}{I_{t-1}}\right)\right]I_t \quad \text{and} \quad \left[1+g^H\left(\frac{I_t^H}{I_{t-1}^H}\right)\right]I_t^H,$$

where $g(\cdot)$ and $g^H(\cdot)$ are the corresponding investment adjustment cost functions that satisfy the standard properties. Since these firms are owned by the patient households, their objective is to choose investment I_t and I_t^H in order to maximize

$$E_t\sum_{i=0}^{\infty}(\beta^s)^i\frac{c_t^s}{c_{t+i}^s}\left\{q_{t+i}^K I_{t+i}-\left[1+g\left(\frac{I_{t+i}}{I_{t+i-1}}\right)\right]I_{t+i}\right\}$$

and

$$E_t\sum_{i=0}^{\infty}(\beta^s)^i\frac{c_t^s}{c_{t+i}^s}\left\{q_{t+i}^H I_{t+i}^H-\left[1+g^H\left(\frac{I_{t+i}^H}{I_{t+i-1}^H}\right)\right]I_{t+i}^H\right\},$$

respectively.

4. Market Clearing, DIA, and Capital Requirements

4.1 Consumption Good Market

In the goods market, total output y_t should equal the total consumption demands of the savers c_t^s and the borrowers c_t^m, plus the resources absorbed in the production of the new capital I_t and the new housing I_t^H, plus the resources lost in the recovery by lenders of the proceeds associated with defaulted bank loans, in transaction costs by depositors at failed banks, or by the deposit insurance agency in the recovery of assets from failed banks:

$$\begin{aligned}
y_t &= c_t^s + c_t^m + \left[1+g\left(\frac{I_t}{I_{t-1}}\right)\right]I_t + \left[1+g^H\left(\frac{I_t^H}{I_{t-1}^H}\right)\right]I_t^H \\
&\quad + \mu^e G^e\left(\overline{\omega}_t^e\right)R_t^K q_{t-1}^K k_{t-1} + \mu^m G^m\left(\frac{x_{t-1}^m}{R_t^H}\right)R_t^H q_{t-1}^H h_{t-1}^m \\
&\quad + \gamma PD_t^b R_{t-1}^D d_{t-1} + \mu^B\left[G^H\left(\overline{\omega}_t^H\right)\widetilde{R}_t^H\left(\frac{q_{t-1}^H h_{t-1}^m x_{t-1}^m}{R_{t-1}^m}\right)\right. \\
&\quad \left. + G^F\left(\overline{\omega}_t^F\right)\widetilde{R}_t^F\left[q_{t-1}^K k_{t-1}-(1-\chi^e)W_{t-1}^e\right]\right].
\end{aligned}$$

For reporting purposes, we will also consider a measure of net output, $\widetilde{y}_t$, which is net of the expenditure associated to default:

$$\widetilde{y}_t = c_t^s + c_t^m + \left[1 + g\left(\frac{I_t}{I_{t-1}}\right)\right] I_t + \left[1 + g^H\left(\frac{I_t^H}{I_{t-1}^H}\right)\right] I_t^H. \quad (39)$$

This output measure is arguably more important when analyzing welfare, since costs associated with default do not increase household utility.

4.2 Labor Market

The total demand for households' labor by the consumption-good-producing firms, $(1-\alpha)\frac{y_t}{w_t}$, must be equal to the labor supply of the two types of households:

$$(1-\alpha)\frac{y_t}{w_t} = l_t^s + l_t^m.$$

4.3 Capital Good Market

The stock of the capital good evolves according to $k_t = (1-\delta_t)k_{t-1} + I_t$, and market clearing requires k_t to equal the demand for this good coming from entrepreneurs at t (which in turn equals the amount of capital rented to the consumption-good-producing firms at $t+1$).

4.4 Housing Good Market

The stock of housing evolves according to $h_t = (1-\delta_t^H)h_{t-1} + I_t^H$, and market clearing requires $h_t = h_t^s + h_t^m$.

4.5 Deposit Market

The deposits held by the saving households (d_t) must equal the sum of the demand for deposit funding from the banks making loans to households, $d_t^H = (1-\phi_t^H)\left(q_t^H h_t^m x_t^e / R_t^m\right)$, and from the banks making loans to entrepreneurs, $d_t^F = (1-\phi_t^F)\left[q_t^K k_t - (1-\chi^e)W_t^e\right]$:

$$d_t = (1-\phi_t^F)\left[q_t^K k_t - (1-\chi^e)W_t^e\right] + (1-\phi_t^H)\left(\frac{q_t^H h_t^m x_t^m}{R_t^m}\right).$$

4.6 Banks' Inside Equity Market

The total equity provided by bankers ($n_t^b = (1-\chi^b)W_t^b$) must equal the sum of the demand for bank equity from the banks making loans to households, $e_t^H = \phi_t^H b_t^H = \phi_t^H \left(q_t^H h_t^m x_t^e / R_t^m\right)$, and from the banks making loans to entrepreneurs, $e_t^F = \phi_t^F b_t^F = \phi_t^F \left[q_t^K k_t - (1-\chi^e)W_t^e\right]$:

$$(1-\chi^b)W_t^b = \phi_t^F \left[q_t^K k_t - (1-\chi^e)W_t^e\right] + \phi_t^H \left(\frac{q_t^H h_t^m x_t^m}{R_t^m}\right).$$

4.7 Deposit Insurance Agency

The losses caused to the DIA by the failing H and F banks are given by

$$T_t^H = \left[\overline{\omega}_t^H - \Gamma^H\left(\overline{\omega}_t^H\right) + \mu^H G^H\left(\overline{\omega}_t^H\right)\right] \widetilde{R}_t^H \left(\frac{q_{t-1}^H h_{t-1}^m x_{t-1}^m}{R_{t-1}^m}\right)$$

and

$$T_t^F = \left[\overline{\omega}_t^F - \Gamma^F\left(\overline{\omega}_t^F\right) + \mu^F G^F\left(\overline{\omega}_t^F\right)\right] \widetilde{R}_t^F \left[q_{t-1}^K k_{t-1} - (1-\chi^e)\, W_{t-1}^e\right],$$

respectively, and covering them with the lump-sum tax imposed on patient households requires $T_t = T_t^H + T_t^F$.

4.8 Bank Capital Requirements

The regulatory capital requirement ϕ_t^j applicable to each class of banks is generally specified as follows:

$$\phi_t^j = \bar{\phi}_0^j + \bar{\phi}_1^j \left[\log(b_t) - \log\left(\bar{b}\right)\right], \tag{40}$$

where $\bar{\phi}_0^j$ is the structural capital requirement (equal to its steady-state level) and the additional term captures the cyclically dependent part of the requirement due, e.g., to the existence of a *countercyclical capital buffer* (CCB) that depends on the state of the economy, as in Basel III.[25] For computational convenience, we model the

[25] To save on notation, when analyzing time-invariant capital requirements below ($\bar{\phi}_1^j = 0$), we will refer to $\bar{\phi}_0^j$ by simply ϕ^j.

countercyclical adjustment of the capital requirements as an additive term that linearly depends on the deviations of total bank credit, $b_t = b_t^H + b_t^F$, from its steady-state level, $\bar{b} = \bar{b}^H + \bar{b}^F$.[26]

5. Baseline Parameterization

The baseline parameterization of the model is partly based on values that are standard in the literature and partly on choices that, without being implausible, constitute only a first attempt to illustrate the qualitative and potential quantitative properties of the model. For most parameters of the households and entrepreneurs sectors, we rely on Gerali et al. (2010) and Darracq-Pariès, Kok Sørensen, and Rodriguez-Palenzuela (2011), which both develop DSGE models of the euro area.

Capital requirements are set at a benchmark level of 8 percent for corporate loans (compatible with the full weight level of Basel I and the treatment of non-rated corporate loans in Basel II and III) and 4 percent for mortgage loans (compatible with their 50 percent risk weight in Basel I). Parameters determining the probabilities of default of the various classes of loans are chosen so as to make their baseline steady-state values equivalent to annual rates of 0.35 percent for mortgages, 3 percent for entrepreneurial loans, and 2 percent for banks. The bankruptcy cost parameters imply losses of 10 percent of face value of deposits for depositors at failed banks and of 30 percent of asset value for creditors repossessing assets from defaulting borrowers. Table 1 reports all the parameter values. One period in the model corresponds to one quarter in calendar time.

6. Results

First, we analyze the long-run implications of different levels of capital requirements. Second, we analyze the effects of shocks to aggregate productivity, capital depreciation, and bank risk on the dynamics around the steady state. We compare the transmission of shocks

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[26]So in our formulation, the total capital charge may both increase or decrease relative to its time-invariant benchmark $\bar{\phi}_0^j$. In contrast, in Basel III the CCB is a non-negative add-on to the structural capital requirements (core equity tier 1 plus the capital conservation buffer).

Table 1. Baseline Parameterization of the Model

Description	Par.	Value
Patient Household Discount Factor	β^s	0.995
Impatient Household Discount Factor	β^m	0.98
Patient Household Utility Weight of Housing	υ^m	0.25
Impatient Household Utility Weight of Housing	υ^s	0.25
Patient Household Marginal Disutility of Labor	φ^s	1.00
Impatient Household Marginal Disutility of Labor	φ^m	1.00
Inverse of Frisch Elasticity of Labor	η	1.00
Depositor Cost of Bank Default	γ	0.10
Variance of Household Idiosyncratic Shocks	σ_m^2	0.08
Household Bankruptcy Cost	μ^m	0.30
Dividend Payout of Entrepreneurs	χ^e	0.05
Variance of Entrepreneurial Risk Shock	σ_e^2	0.12
Entrepreneur Bankruptcy Cost	μ^e	0.30
Capital Requirement for Mortgage Loans	ϕ^H	0.04
Capital Requirement for Corporate Loans	ϕ^F	0.08
Mortgage Bank Bankruptcy Cost	μ^H	0.30
Corporate Bank Bankruptcy Cost	μ^F	0.30
Capital Share in Production	α	0.30
Capital Depreciation Rate	δ^K	0.025
Capital Adjustment Cost Parameter	ψ^K	2.00
Housing Depreciation Rate	δ^H	0.01
Housing Adjustment Cost Parameter	ψ^H	2.00
Shocks Persistence	ρ	0.90
Dividend Payout of Bankers	χ^b	0.05
Variance of Mortgage Bank Risk Shock	σ_H^2	0.0119
Variance of Corporate Bank Risk Shock	σ_F^2	0.0238

under the baseline capital requirements ($\bar{\phi}_0^F = \phi^F = 0.08; \bar{\phi}_0^H = \phi^H = 0.04$) and under higher capital requirements.

6.1 Steady-State Effects of Capital Requirements

In the following, we investigate the relationship between different levels of capital requirements, ϕ^F and ϕ^H, and welfare in steady state. The welfare function for each agent is given by the conditional expectation of the corresponding lifetime utility as of a reference period t. Due to the presence of several classes of agents in the model, we consider a (utilitarian) social welfare measure that aggregates the individual welfare of the representative agents of each class. We will focus on households only.

Specifically, we compute the welfare gains associated with any particular policy change as a weighted average of the welfare gains of each household dynasty, the patient ($j = s$) and the impatient ($j = m$), measured in consumption-equivalent terms, i.e., the percentage increase in steady-state consumption, Δ^j, that would make the welfare of such dynasty under the baseline policy ($\phi^F = 0.08; \phi^H = 0.04$) equal to the welfare under alternative values of ϕ^F and ϕ^H. And we weight each individual Δ^j with the share of dynasty j in aggregate consumption under the baseline policy. So the reported social welfare gains are given by

$$\Delta W \equiv \frac{c_0^s}{c_0^s + c_0^m}\Delta^s + \frac{c_0^m}{c_0^s + c_0^m}\Delta^m, \tag{41}$$

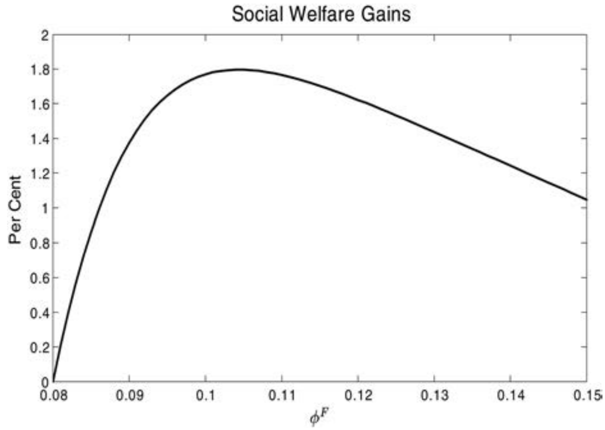
where c_0^j denotes the steady-state consumption of dynasty j under the baseline policy.

Importantly, although entrepreneurs and bankers do not enter into our social welfare criterion on their own right, the contribution of entrepreneurial and bank profits to aggregate consumption capacity is taken into account through the donations (lump-sum transfers) that these agents have been assumed to make to the patient dynasty.[27]

We start by providing a first key result of our paper, namely the steady-state relationship between the capital requirement ratio and social welfare gains. Figure 1 displays the steady-state social welfare gains ΔW associated with capital requirements higher than the baseline value. The hump-shaped relationship between higher capital requirements and social welfare gains reflects the presence of a trade-off. Higher capital requirements reduce the implicit subsidy to banks associated with limited liability and deposit insurance. Thus, in comparison with the baseline policy, an increase in capital requirements implies both a reduction in the supply of loans (which

[27]We have also considered a version of the model in which these transfers are split between the two dynasties, and the results are qualitatively and quantitatively very similar.

Figure 1. Steady-State Welfare Depending on the Capital Requirement

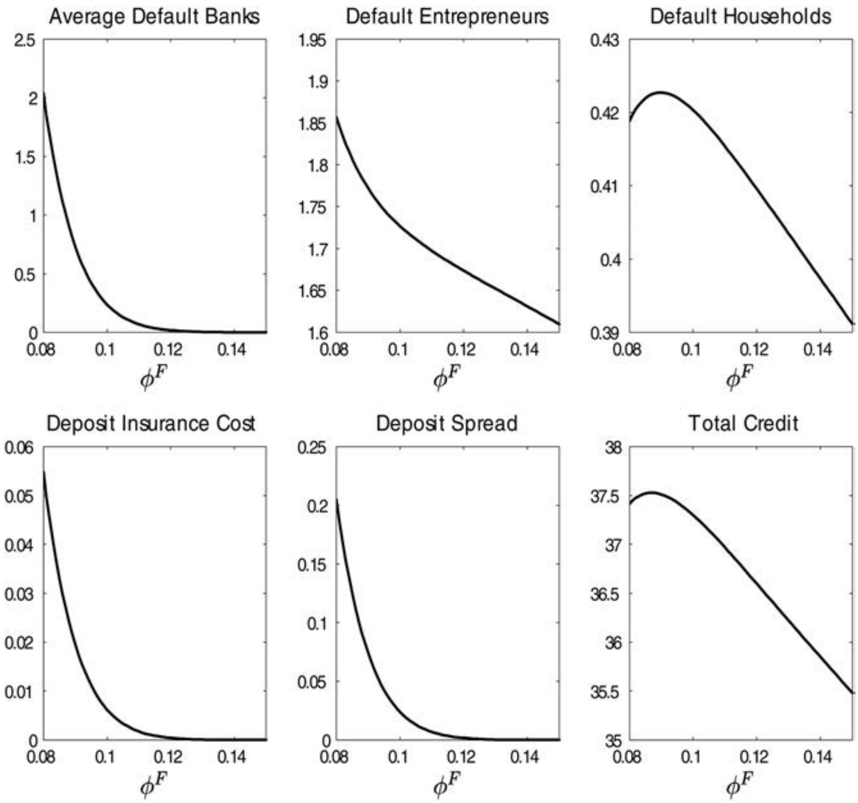


Notes: Social welfare gains are the weighted average of the steady-state gains (losses) experienced by the representative agent of each type of household (patient and impatient) measured in certainty-equivalent consumption terms. The weights are given by the consumption shares of each class of households under the initial reference policy ($\phi^F = 0.08, \phi^H = 0.04$). Alternative policies involve the value of ϕ^F described in the horizontal axes and $\phi^H = \phi^F/2$.

are provided at higher interest rates) and a lower average default rate of banks (see figure 2). The implied reduction in the social cost of banks' default has a positive effect on economic activity, notably consumption and investment (figure 3). This effect dominates at first. In contrast, the negative effects on economic activity coming from the reduction in the supply of credit to the economy dominate when capital requirements are high enough (actually, at levels in which banks' default rate is virtually zero). Note that the initial increase in credit displayed in figure 4 is due to the reduction in the cost of deposit funding. Indeed, banks are less fragile and depositors require a lower premium in compensation for their anticipated costs of bank default.

Under the calibration reported in section 5, we find that the optimal capital requirement should be around 10.5 percent for business loans and 5.25 percent for mortgages (50 percent risk weight). This is consistent with Bank for International Settlements (2010) and

Figure 2. Steady-State Values Depending on the Capital Requirement (I)

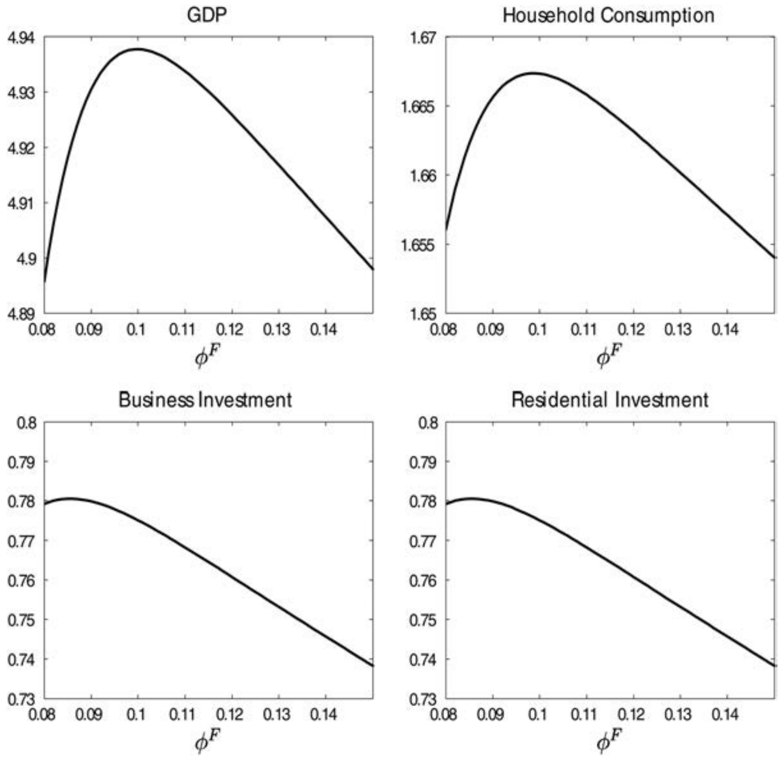


Notes: Alternative policies involve the value of ϕ^F described in the horizontal axes and $\phi^H = \phi^F/2$.

Miles, Yang, and Marcheggiano (2013). However, our model would not support higher capital ratios, such as the value of 25 percent recently suggested by Admati and Hellwig (2013). In our model, too-high capital requirements would excessively restrict credit availability while reducing default rates only marginally, resulting in a net welfare loss.

Overall, our setup provides a clear rationale for capital regulation, which arises as a welfare-improving response to the excessive

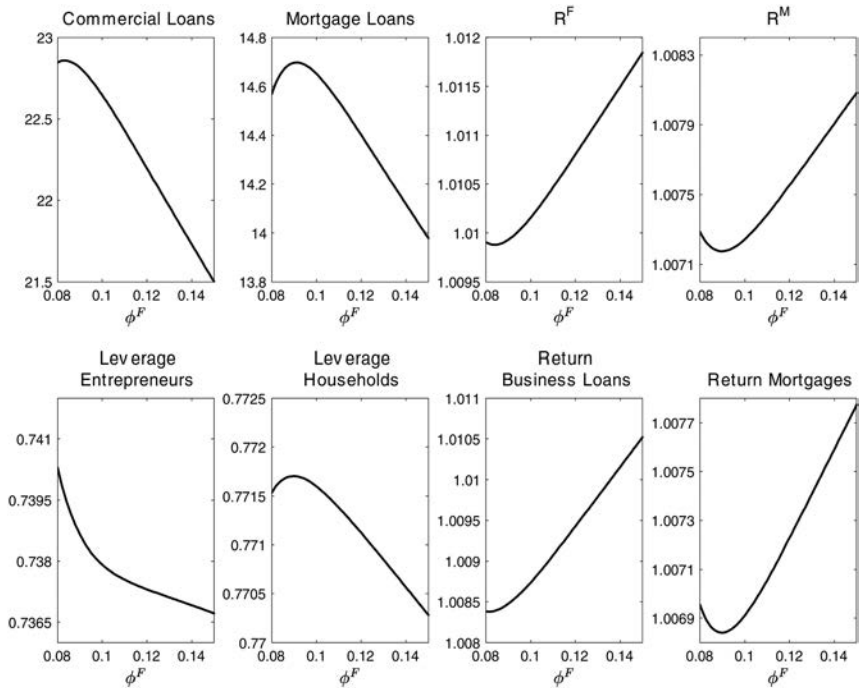
Figure 3. Steady-State Values Depending on the Capital Requirement (II)



Notes: Alternative policies involve the value of ϕ^F described in the horizontal axes and $\phi^H = \phi^F/2$.

leverage otherwise induced by deposit insurance (among banks and also at the sectors borrowing from them). Importantly, banks' equity funding in the model is limited by the wealth endogenously accumulated by the bankers who own and manage the banks. So capital requirements reduce bank leverage, bank failure risk, and the implicit subsidies associated with deposit insurance, and, simultaneously, they also force the banks to make a greater use of bankers' limited wealth. In the short run, this second aspect makes capital requirements have a potential impact on the cost of equity funding (due to the scarcity of bankers' wealth). However, over time, bankers

Figure 4. Steady-State Values Depending on the Capital Requirement (III)



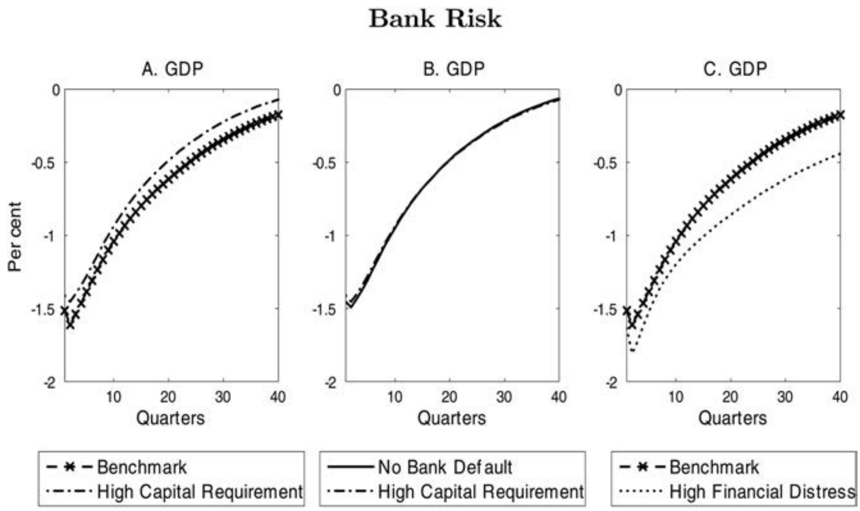
Notes: Alternative policies involve the value of ϕ^F described in the horizontal axes and $\phi^H = \phi^F/2$.

accumulate additional wealth, and the cost of equity funding in the new steady state is the same as under lower requirements. So the steady-state results are entirely due to banks' lower leverage and their possibly higher weighted average cost of funds.

6.2 Capital Requirements and Shock Propagation

The second set of results concerns the model responses to structural shocks, in a first-order approximation around the deterministic steady state. Figure 5 reports the response of GDP to a 1 percent decline in aggregate productivity. It compares the response of GDP under alternative parameterizations of the model. We find that

Figure 5. Impulse Responses after a Negative TFP Shock (I): The Effect on GDP under Different Assumptions on the Bank Capital Requirement and Bank Risk

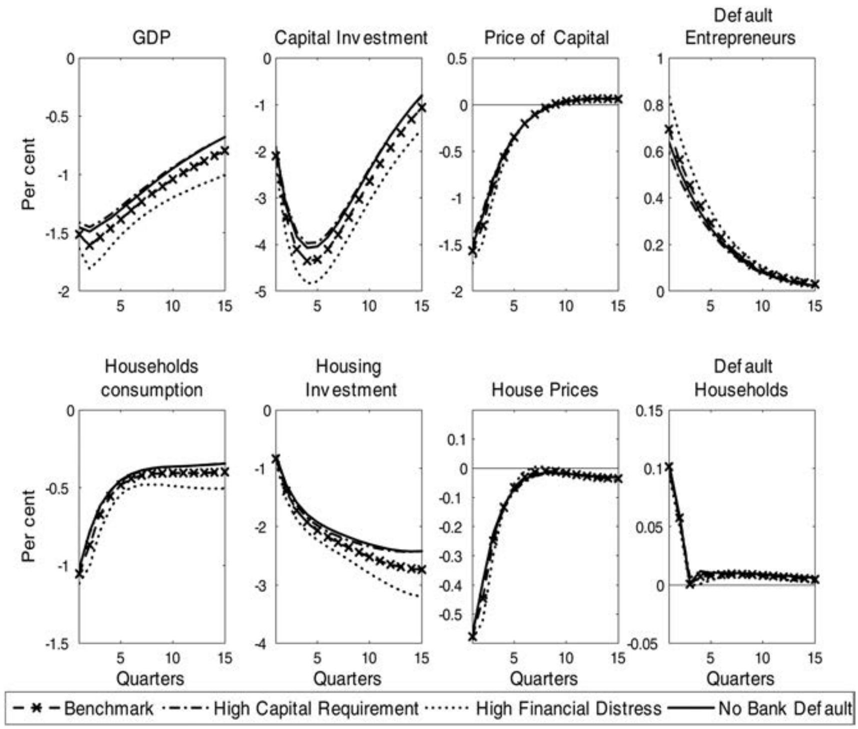


Notes: "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

higher capital requirements (i) mitigate the effects of a reduction in aggregate productivity (panel A), and (ii) mimic the dynamics of a no-bank-default economy (panel B). Comparing the benchmark economy with an economy with higher financial distress in the banking sector (i.e., higher bank risk as captured by σ^F and σ^H), we also find that high financial distress greatly exacerbates the negative effect of productivity shocks (panel C).

Figures 6 and 7 report on the effect of a negative productivity shock on the key variables in the model. Each graph with the impulse response functions contains four lines. We report the responses of the variables in the benchmark economy, i.e., $\phi^F = 0.08$ and $\phi^H = 0.04$ (starred line) and in the economy with capital requirements closer

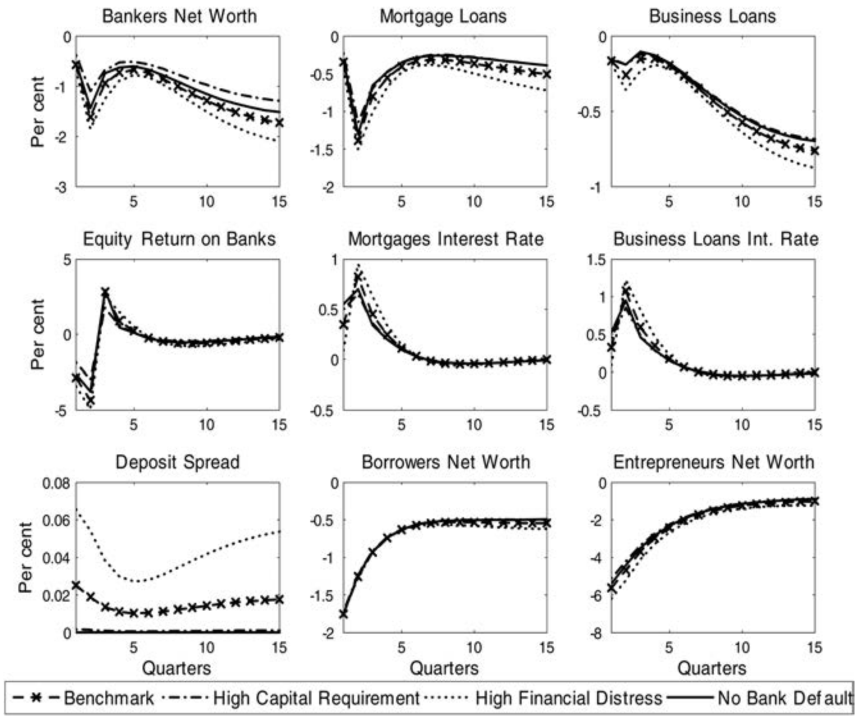
Figure 6. Impulse Responses after a Negative TFP Shock (II)



Notes: "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

to the welfare maximizing ones, i.e., $\phi^F = 0.105$ and $\phi^H = 0.0525$ (dashed line). Further, we also consider a parameterization with no bank default, i.e., $\sigma^F = \sigma^H \approx 0$ (solid line) and with high financial distress, i.e., $\sigma^F = 0.0238$ and $\sigma^H = 0.0119$ (dotted line). This set of results allows us to understand the role of capital regulation for the propagation of shocks.

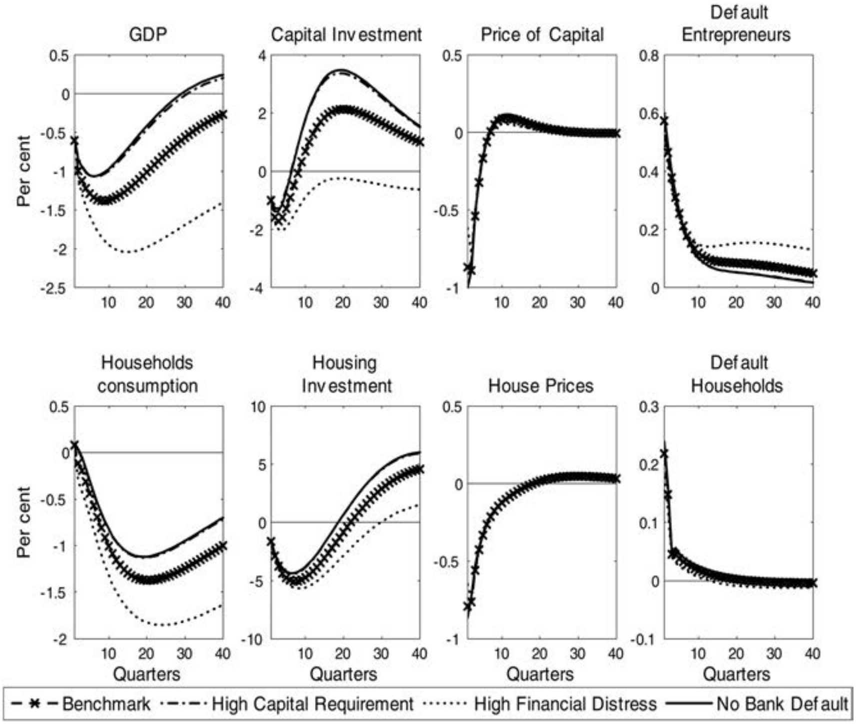
Figure 7. Impulse Responses after a Negative TFP Shock (III)



Notes: "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

An exogenous reduction in aggregate productivity implies a reduction in spending and production. Thus, the relative price of housing and physical capital decline, leading to an increase in the default by households and entrepreneurs (figure 6). Higher borrowers' default reduces bank capital and, thus, the supply of loans (*bank capital channel*). At the same time, bank default increases, leading to an increase in the cost of deposit funding, which further increases

Figure 8. Impulse Responses after a Shock to the Housing and Capital Depreciation (I)

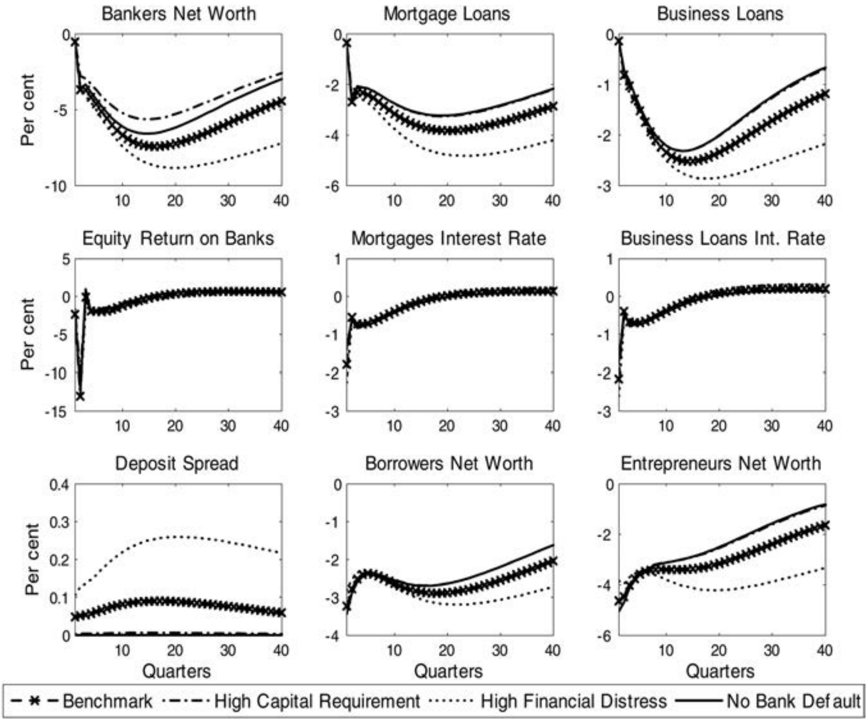


Notes: "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

the bank lending rates that banks have to charge in order to satisfy bankers' participation constraints (*bank funding channel*). Both channels further contribute to the reduction in the price of houses and physical capital, leading to higher default rates among borrowers (figure 7).

Figures 8 and 9 replicate the same analysis for a persistent negative depreciation shock, namely a negative shock to the value of the

Figure 9. Impulse Responses after a Shock to the Housing and Capital Depreciation (II)



Notes: "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

stocks of housing and physical capital (the shock is assumed to hit both stocks in the same proportion at the same time). Also here, even more so than for TFP shocks, the presence of bank default leads to very strong amplification (especially noticeable in, e.g., the response of GDP). In the model with a high capital requirement or no bank default, we find a mild and short contraction of output, but under high bank risk the implied recession is much deeper and long lasting. The difference can be largely explained by the different effect on bank capital and bank defaults. Bank capital declines (figure 8) and this restricts the supply of loans in a very persistent way, especially under the high-bank-risk calibration. In addition, bank defaults increase, leading to a rise in the cost of deposit funding, which further depresses economic activity and amplifies the decline in bank capital. Our model features a powerful interaction between bank capital and the bank cost of funding channels of crisis transmission. The result is a deep and persistent decline in economic activity in the economy with low capital requirements (i.e., the benchmark economy).

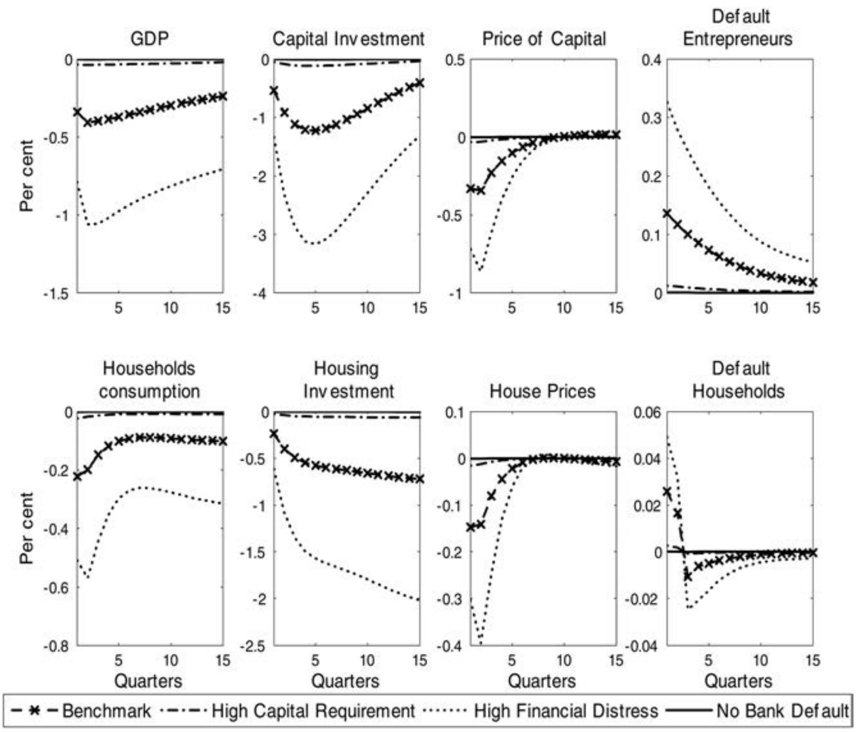
Figures 10 and 11 report on the dynamic effects of shocks to the standard deviation of the idiosyncratic shocks to banks' performance, which we interpret as a shock to "bank risk." Similar to the results for the depreciation shock, the effects of the shock are very mild in the economy with high capital requirements or an initially low level of bank risk ("no-bank-risk" economy). In the benchmark economy, a high starting value for bank risk, coupled with low capital requirements, has the opposite effect of greatly amplifying the transmission of the shock. Again, the difference is largely explained by the diverging paths for bankers' net worth and the cost of deposit funding.

Figure 12 provides an overview of the key results. Overall, these results suggest that, first, an economy with "high capital requirements" (set close to the welfare-maximizing ones) behaves very similarly to an economy with no bank default. Thus, high capital requirements insulate the economy from the bank net worth channel and prevent excessive volatility due to banks' excessive lending and excessive failure risk. Additionally, the figures show that when bank leverage is high (because capital requirements are low), the economy is more responsive to shocks. This evidences that limited liability and the deposit insurance subsidies, which allow banks to meet the required rate of return on equity with lower lending rates, constitute a potentially powerful channel of financial amplification and contagion.

6.3 Countercyclical Capital Adjustments

Figures 13 and 14 summarize the results of running the same exercises as in prior figures but comparing economies with cyclically

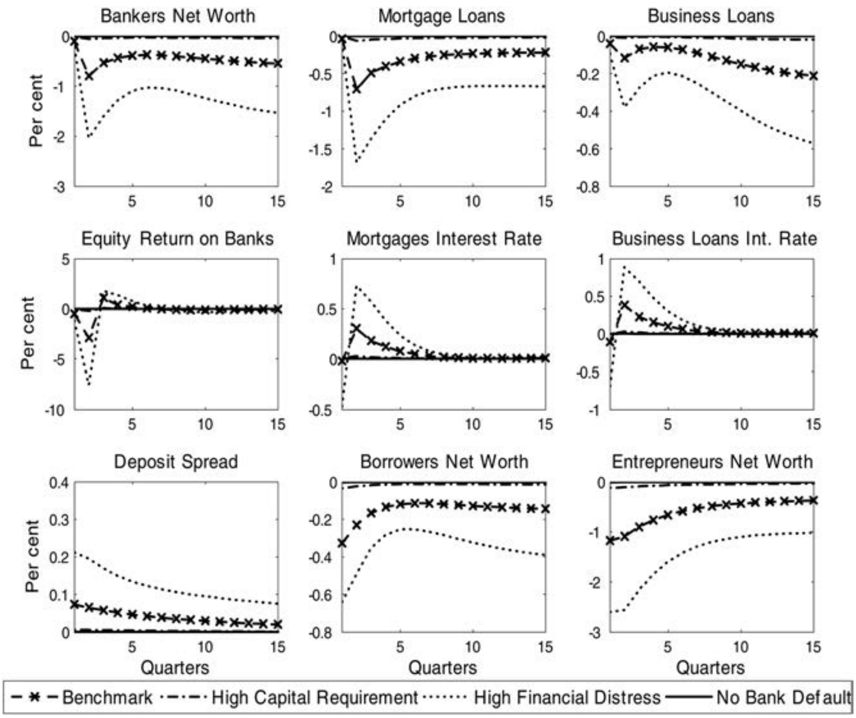
Figure 10. Impulse Responses after a Shock to Bank Risk (I)



Notes: "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

flat capital requirements like in the previous sub-sections with economies in which the capital requirements are cyclically adjusted. In particular, in terms of equation (47), we set $\bar{\phi}_1^j = 0.3$ so that the capital requirements vary according to the percentage deviation of total credit from its steady-state level, in a symmetric fashion.

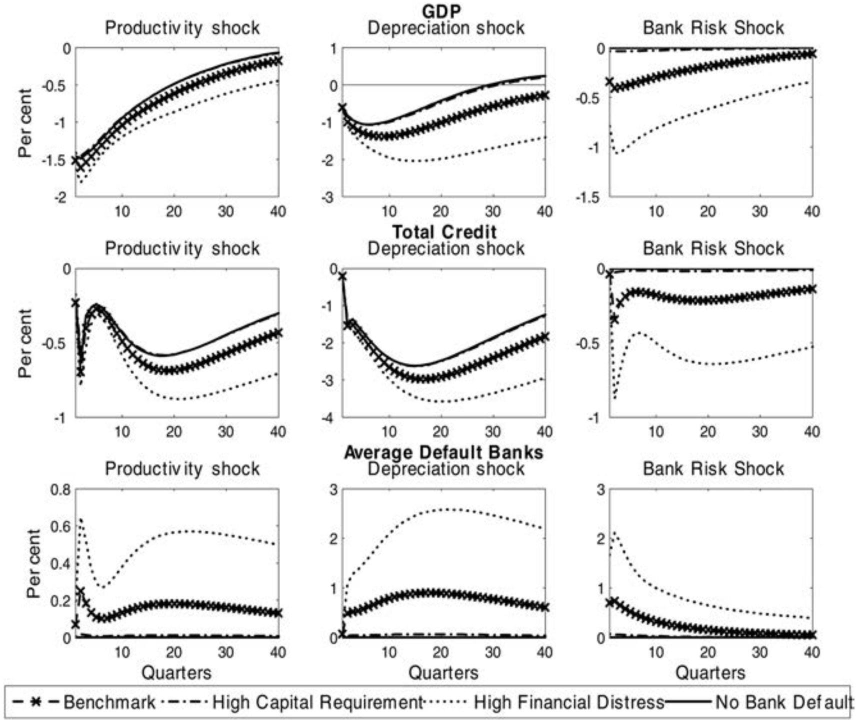
Figure 11. Impulse Responses after a Shock to Bank Risk (II)



Notes: "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

The results suggest that introducing a countercyclical adjustment mitigates the reduction in the supply of credit to the economy, but does so at the cost of an increase in bank default and, thus, a higher overall cost of funds for banks. It turns out that the countercyclical adjustment adds stability when associated with a high level of capital requirements (i.e., when bank default risk is already very low).

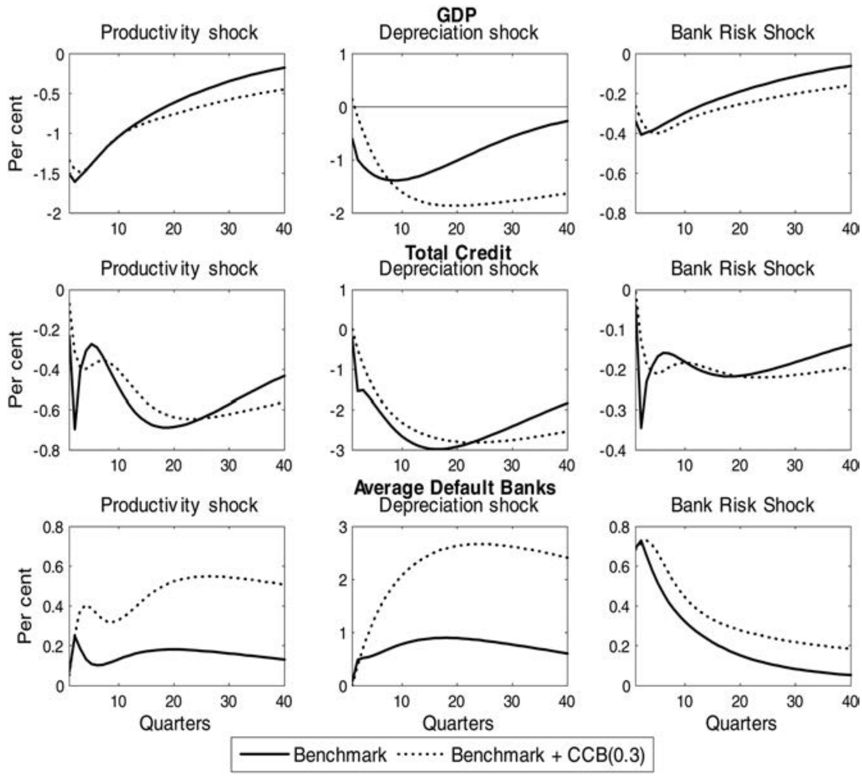
Figure 12. Overview of Key Impulse Responses after a Shock to Productivity, Depreciation, and Bank Risk



Notes: A depreciation shock is a shock to the depreciation rates of capital and housing. A bank risk shock is an idiosyncratic shock to each bank's ability to extract payoffs from its loans. "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.525$. "High financial distress" describes an economy with a variance of the idiosyncratic shock to banks' performance higher than in the baseline parameterization. "No bank default" describes an economy in which the variance of the idiosyncratic shock to bank performance is zero. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

In contrast, when the countercyclical adjustment is added to the economy with low capital requirements, we find that for most shocks and variables the result is more rather than less amplification. The countercyclical adjustment of the capital requirements actually helps moderate the negative output effects of the shocks in the short run.

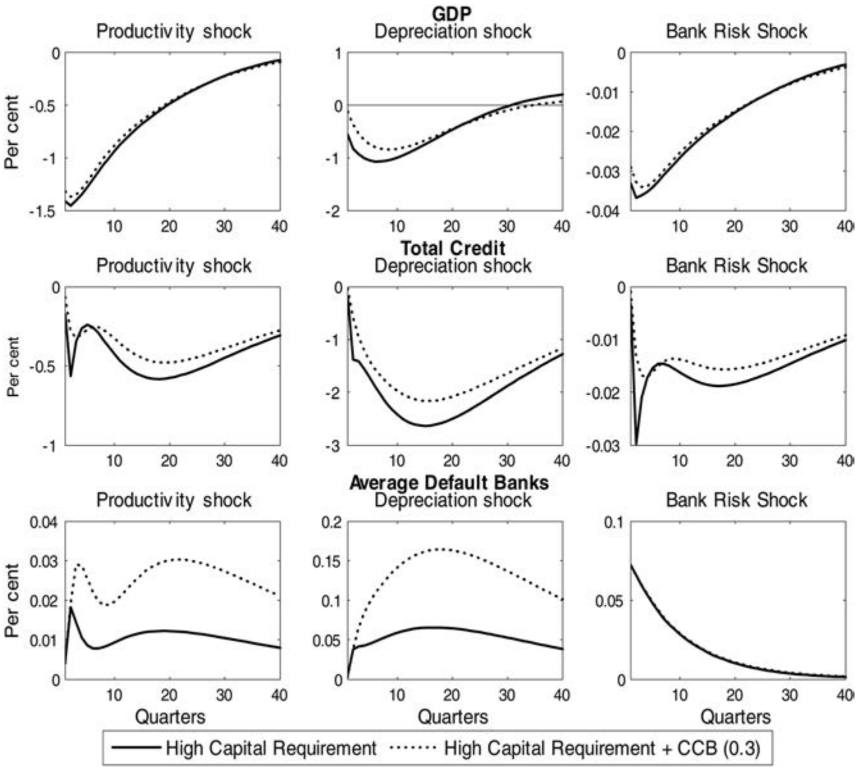
Figure 13. Overview of Key Impulse Responses after a Shock to Productivity, Depreciation, and Bank Risk: Benchmark Capital Requirements



Notes: A depreciation shock is a shock to the depreciation rates of capital and housing. A bank risk shock is an idiosyncratic shock to each bank's ability to extract payoffs from its loans. "Benchmark" describes the economy with $\phi^F = 0.08$ and $\phi^H = 0.04$. "Benchmark + CCB(0.3)" describes an economy in which the capital requirement reacts to the percentage deviation of total loans (corporate and mortgage) from their steady-state values, with coefficient of 0.3. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

However, the effects are negative over the medium/long run. Overall, the lesson from this exercise is that relaxing capital standards only works well when the starting capital requirement position is strong.

Figure 14. Overview of Key Impulse Responses after a Shock to Productivity, Depreciation, and Bank Risk: High Capital Requirements



Notes: A depreciation shock is a shock to the depreciation rates of capital and housing. A bank risk shock is an idiosyncratic shock to each bank's ability to extract payoffs from its loans. "High capital requirement" describes the economy with $\phi^F = 0.105$ and $\phi^H = 0.0525$. "High capital requirement + CCB(0.3)" describes an economy in which the capital requirement reacts to the percentage deviation of total loans (corporate and mortgage) from their steady-state values, with coefficient of 0.3. GDP is defined as net of bankruptcy costs due to default. It is therefore a measure of "net output."

7. Conclusions

In this paper we have proposed a DSGE model with multiple financial frictions affecting households, entrepreneurs, and banks. One distinctive feature of our model is that it contains three layers of default and that, unlike most models in previous literature, default has material consequences for the banks' balance sheets. The model allows us to study the macroeconomic consequences of default: the impact of idiosyncratic and aggregate shocks on household and corporate defaults, the effect of loan defaults on bank performance (bankers' net worth, bank failure probabilities), and the feedback effects coming from the importance of these bank variables for the availability and cost of bank credit.

We have focused the policy analysis on bank capital requirements. In our model, bank capital regulation tackles several distortions that may push credit provision away from the first-best solution (the solution that a social planner would select). On the one hand, banks have limited liability, bank deposits enjoy government guarantees, and the pricing of deposits does not fully reflect the risk of failure of each individual bank, which encourages banks to expand their own leverage and potentially become excessively fragile and extend excessive credit to the real economy. On the other hand, costly state verification makes external financing costly, borrowers' investment capacity is limited by their net worth, and this reduces credit compared with the socially optimal level in an ideal economy without these costs. Bank capital regulation needs to find a compromise between reducing the distortions associated with bank failure risk and ending up constraining credit supply excessively. In our baseline calibration, we find that a reasonable compromise can be found at levels of the capital ratio around 10.5 percent, which is above the Basel III levels of capital but below more radical proposals such as those of Admati and Hellwig (2013).

In terms of the dynamics of the model, we find that shock propagation and amplification are large when idiosyncratic bank risk is high and the bank capital requirements are low. Our impulse response analysis indicates that the welfare-maximizing capital requirements largely eliminate the additional amplification otherwise coming from banks' financial vulnerability (bank defaults and fluctuation in bankers' net worth). Finally, our analysis of the effects of making capital requirements countercyclical reveals an interesting non-monotonicity: it is moderately stabilizing when the steady-state level of the requirements is sufficiently high but quite destabilizing when the steady-state level of the requirements is low.

Importantly, the current parameterization and analysis constitute only a first exploration of the quantitative properties of our model, so the results reported above should be taken with caution. First, the model could be properly calibrated and the analysis could be improved by dealing with non-linearities and stochastic welfare. Then, there are aspects of the construction that might be improved or generalized by relaxing some of the simplifying assumptions of the current setup (such as banks' inability to raise outside equity or the features that make bank capital requirements binding at all times). Additionally, the model could be extended to introduce liquidity risk (and its regulation) and to allow for securitization (and its regulation). Finally, our model is entirely real and considers no nominal rigidities and, hence, has no room for (conventional) monetary policy. However, it would be relatively straightforward to add nominal rigidities in order to study the interplay between macroprudential policy (capital regulation) and monetary policy. Several of these extensions appear to be interesting avenues for future research.

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Discussion of "Capital Regulation in a Macroeconomic Model with Three Layers of Default"

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How do shocks to productivity and asset quality generate large fluctuations of aggregate production when banks, firms, and some households are credit constrained? What are the effects of alternative macroprudential policies? In order to answer these questions, the authors develop a macroeconomic framework in which the effects of shocks propagate through the fluctuations of asset prices and balance sheets of households, firms, and banks. A particular feature of their framework is that the liquidation of assets after bankruptcy is very costly, because a significant fraction of the assets is depreciated during the process. Since the banks have limited liability and the government uses a general tax (through deposit insurance) to cover the loss incurred by depositors after a bank's default, banks and their customers receive the implicit subsidy from the government when the probability of bank default is positive. This generates a serious moral hazard, as banks rely on deposits too much to make risky loans to households and firms. The regulation of bank capital requirement is essential to mitigate this moral hazard problem and the distortion of resource allocation. The authors use their quantitative model to show that there is a significant gain in welfare by raising the capital requirement from the present standard of 8 percent to 10.5 percent of risky loans to the private sector. A further increase of capital requirement will reduce social welfare because the financial intermediation becomes too small. This paper asserts that it is more important to set the average capital requirement at an optimal level than to fine-tune the capital requirement procyclically.

Because my comments are largely specific to their model, let me highlight the key assumptions. There are infinitely lived households

Figure 1. Diagram of Balance Sheets of Households, Entrepreneurs, and Banks

Patient Households	
Deposits $d_t^H + d_t^F$	
House $q_t^H h_t^s$	Net Worth n_t^s

Mortgage Banks	
Mortgages b_t^m	Deposit d_t^H
	Net Worth n_t^H

Industrial Banks	
Loans b_t^e	Deposit d_t^F
	Net Worth n_t^F

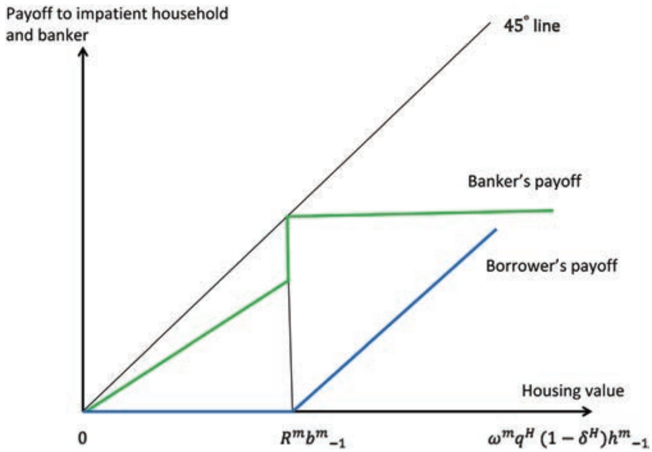
Impatient Households	
House $q_t^H h_t^m$	Mortgage b_t^m
	Net Worth n_t^m

Entrepreneurs	
Capital $q_t k_t$	Loan b_t^e
	Net Worth n_t^e

with patient and impatient types. There is a sequence of entrepreneurs and bankers who live for two periods. The entrepreneurs and bankers are risk neutral, distribute a fraction of gross returns as dividends to their owners (patient households), and save the rest, which becomes the net worth of the entrepreneurs and bankers of the next generation. There is one homogeneous output. Capital stock and housing are subject to aggregate and idiosyncratic shocks to the depreciation, and can be accumulated by investment in capital stock and housing. Production of new capital and housing are subject to the adjustment cost; the production technology of new capital and housing is decreasing returns to scale in the short run even though it is constant returns to scale in the long run.

The balance sheets of households, entrepreneurs, and banks are described in the diagram in figure 1. Patient households are ultimate lenders, who save their wealth in the form of housing and deposits to mortgage banks and industrial banks. Mortgage banks use the deposits and net worth to make mortgage loans to impatient households. Industrial banks use the deposits and net worth to make loans to entrepreneurs. Impatient households and entrepreneurs are ultimate borrowers. Impatient households put together their net worth and mortgage to buy houses. Entrepreneurs use their net worth and loans from industrial banks to buy capital stock for production.

Figure 2. Payoff to Impatient Household and Mortgage Bank



All the debts are secured by collateral assets and are non-recourse, as the borrower can walk away from the debt obligation, leaving the collateral asset behind, without further penalty. The face value of debt is non-contingent in terms of goods. Figure 2 describes the payoff to the mortgage borrower (impatient household) and the mortgage bank as functions of the value of the collateral house. The horizontal axis is the value of the house which the impatient household (borrower) bought with debt in the last period. The total collateral value $\omega_t^m q_t^H (1-\delta_t^H) h_{t-1}^m$ is subject to the aggregate shock to the depreciation rate δ_t^H, the housing price q_t^H, and an idiosyncratic quality shock ω_t^m. When the collateral housing value is at least as large as the debt obligation $R_{t-1}^m b_{t-1}^m$ (which equals the gross real interest rate times the debt from the previous period), the borrower repays the debt in full. The banker's payoff equals the face value of debt $R_{t-1}^m b_{t-1}^m$, and the borrower's payoff equals the gap between the collateral value and the debt obligation. When the collateral housing value is smaller than the debt obligation, the borrower walks away with zero net payoff. When the banker liquidates the collateral house, the banker loses a fraction μ^m in the process and obtains only $(1-\mu^m)\omega_t^m q_t^H (1-\delta_t^H) h_{t-1}^m$ as its payoff. We can think of this bankruptcy cost as a cost of verifying the collateral value or an extra depreciation during the process of default.

Figure 3. Payoffs to Mortgage Bank, Depositors, and Government

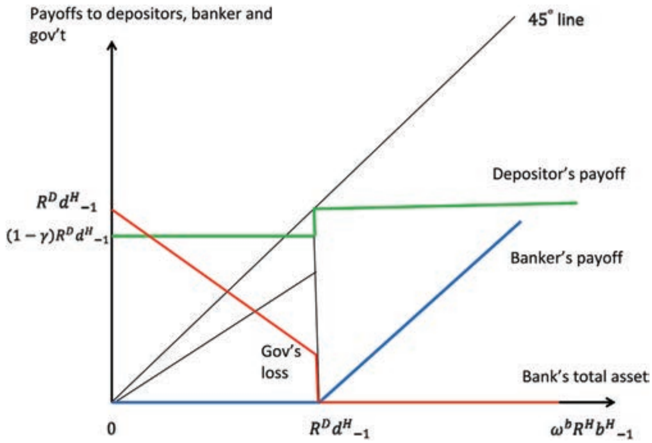


Figure 3 describes the payoffs to the mortgage bank, the depositors, and the government as functions of the total asset value of the mortgage bank. The horizontal axis is the total asset value of the mortgage bank $\omega_t^H \widetilde{R}_t^H b_{t-1}^H$, which equals the product of aggregate mortgage loans made in the previous period b_{t-1}^H, the realized average rate of returns on mortgage loans $\widetilde{R}_t^H$ (which is the average rate of return on all mortgage loans after taking into account the fraction of defaulted loans), and an idiosyncratic shock to the loan performance of this bank ω_t^H. When the total asset of the bank is larger than or equal to the deposit obligation $R_t^D d_{t-1}^H$, the bank pays the depositors in full and keeps the rest as its payoff. The government is not involved in this case. But when the total asset of the bank is smaller than the deposit obligation, the bank defaults. The government liquidates the bank asset, loses a fraction of μ^H of the asset value, and obtains only $(1-\mu^H)\omega_t^H \widetilde{R}_t^H b_{t-1}^H$ after liquidation. The government covers the loss incurred by depositors by taxing as much as $R_t^D d_{t-1}^H - (1-\mu^H)\omega_t^H \widetilde{R}_t^H b_{t-1}^H$. Even though the depositors recover the deposit returns through the government deposit insurance, they lose a fraction γ of the total returns on deposits due to the disruption of deposit service. Therefore, in this economy, the bankruptcy of the banks is extremely costly because the society loses a significant amount of resources—the sum of the costs of liquidating bank assets and disruption of deposit service, $\mu^H \omega_t^H \widetilde{R}_t^H b_{t-1}^H + \gamma R_t^D d_{t-1}^H$. (Note that μ^H is 30 percent and γ is 10 percent in the authors' calibration.)

Moreover, because the government pays a large fraction of the loss incurred by depositors from general tax revenues after banks default, the government subsidizes banks' risk taking, indirectly subsidizing both banks' borrowers and depositors. This causes serious moral hazards of excessive leverage and defaults of banks, as well as too many deposits and too much borrowing from banks by impatient households and entrepreneurs.

Because the government deposit insurance causes significant moral hazards and frequent defaults of banks which are very costly to the society, it is not surprising that regulation of minimum capital requirement of banks is beneficial. The question is, how should we set capital requirements? On the one hand, a higher capital requirement reduces the distortion induced by implicit subsidy of deposit insurance. On the other hand, a higher capital requirement reduces the size of financial intermediation and aggregate investment and production. According to the authors' model, the level of capital requirement which maximizes the average welfare of patient and impatient households is 10.5 percent for entrepreneurial loans and about half of that level, 5.25 percent, for mortgage loans. This level is higher than the present level of 8 percent for business loans, but not as high as Admati and Hellwig (2013) recommend, 25 percent. Concerning another issue of regulations about whether we should increase capital requirement during a boom rather than a recession, the authors' model says that the welfare gain from setting the average level of capital requirement at an optimal level is greater than that from adjusting capital requirement procyclically, similar to Admati and Hellwig.

I believe the paper addresses very important questions about macroprudential policy. The authors choose an eclectic approach to put together many frictions: (i) costly state verifications of returns on housing, capital, and bank loans; (ii) government deposit insurance and cost of disruption of deposit service to households; and (iii) collateral constraints on impatient households and entrepreneurs, capital requirement of banks, and limited saving of banks and entrepreneurs. These frictions lead to powerful propagation of shocks to returns on housing, capital, and bank loans through the fluctuations of balance sheets of banks, entrepreneurs, and impatient households.

It is impressive that the authors include all these frictions in a consistent model.

Nonetheless, there are some limitations of the authors' eclectic approach. Their framework does not explain a few fundamental questions. Why do we use non-contingent debt contracts for finance instead of equity contracts? The use of equity contracts would enable the lender and borrower to share the risk of returns on the borrower's asset, avoiding large fluctuations of the borrower's net worth. Why do we have banks in order to transfer funds from patient households to entrepreneurs and impatient households? Why do we need government deposit insurance when the deposit insurance causes such large distortions without proper regulations? Of course, answering all these questions is beyond the scope of this paper. But because the authors are analyzing the welfare implications of the model and making policy recommendations, they should be aware of these questions and try to tighten their theory by referring to the existing literature. Concerning the use of debt contracts, we learn from Townsend (1979) and Gale and Hellwig (1985) that the debt contract is an optimal contract if it is costly for the lender to verify the realized return on the borrower's asset. The only problem for the authors in applying this argument is that the idiosyncratic shock to the asset return is costly to verify, but the aggregate shock is not very costly to verify. Then the aggregate shock is shared between the borrower and the lender under the optimal contract, which would reduce the financial accelerator significantly. Perhaps the authors can argue that the idiosyncratic shocks are much larger than the aggregate shocks for the returns on assets of the individual borrower and thus it is not easy to disentangle the idiosyncratic and aggregate shocks within a period so that the debt contract is an approximately optimal contract.

Concerning the role of banks, Diamond (1984) and Willamson (1987) show that when savings of many households are needed to fund a borrower's project and it is costly for any individual lender to verify the returns of the project, it is efficient to delegate the monitoring role to one lender, the banker (because it is not efficient for many lenders to monitor one project simultaneously). In an ideal situation in which the banker can completely diversify the risk of returns on private loans by lending to many borrowers, the banker can provide safe returns to the other savers (depositors), and thus the other savers do not have to monitor the banker. But when the banker cannot completely diversify the risk of returns on private loans, then a difficult question of "monitoring the monitor" arises. (See Krasa and Villamil 1992.) One solution is that the banker holds significant equity relative to the risky loans to absorb the default risk of borrowers so that many depositors do not have to closely monitor the banker. Another solution is that the government (or regulator) monitors the banker as a delegated monitor of depositors after the banker defaults on their obligation to the depositors. If the government guarantees the returns to the depositors through deposit insurance, the depositors do not have to worry that the banker and the government may collude and divert their funds together. A related but different argument for the rationale of prudential regulation is made by Dewatripont and Tirole (1993). Of course, this paper's main argument that deposit insurance causes moral hazards of banks (especially after deregulation) has a long tradition, including Kareken and Wallace (1978).

The authors assume that bankers and entrepreneurs live for two periods, do not consume themselves, and derive utility from the dividend payment to impatient households and the bequest to the next generation of bankers and entrepreneurs. I understand that this is a convenient shortcut to simplify the analysis, but I do not fully understand the roles of entrepreneurs and bankers in this model. Are they real persons who have their own objectives, or are they the agents of impatient households? If they are real persons, why does the social welfare not depend upon their utility? If they are agents of impatient households, why is their objective risk neutral when the impatient households are risk averse? It reminds me of the corporate governance of the Chinese giant company Alibaba, where equityholders receive some dividends and might enjoy capital gains, but they do not have control over the management.

Despite the above theoretical problems, I find the quantitative analysis of this paper for policy evaluation interesting. Yet, the authors perhaps exaggerate the magnitude of resource cost after defaults, because it seems enormous that 30 percent of houses, capital, and bank assets disappear from the economy after they default. Although some resources are wasted after defaults, I consider the effect of defaults to be largely redistribution; the creditors lose and debtors gain from the limited liability. Perhaps one of the reasons why the authors need such a large social cost of defaults is that the model does not have powerful enough propagation through the fluctuation of asset prices. In their model, the supply of housing and capital is elastic in the long run, even though it is imperfectly elastic in the short run. Thus, the long-run prices of housing and capital are constant and normalized to be unity; their prices cannot be away from unity for a long time. (Even if the asset prices fluctuate in their model, it is largely because their depreciation shocks are persistent by assumption.) I find it a serious limitation, especially for housing. A large part of housing value is the value of land, and the supply of land is inelastic. Thus the housing price can fluctuate and can be away from the normal level for a long time. In Japan, the aggregate land value more than doubled in the 1980s, but it declined since 1992 for more than two decades to a level below that of 1980. If housing and capital contain factors of production with limited elasticity of supply, such as land and intangible capital, then the value of housing and capital would fluctuate more; the fluctuation of net worth of impatient households, entrepreneurs, and banks would be larger; and the financial accelerator effect would be more significant even without the large costs of bankruptcy.

When the prices of housing and capital fluctuate significantly, the idiosyncratic shock to the returns on the bank loan pool, a measure of financial distress, would fluctuate endogenously (instead of being exogenous as in this paper). Each bank often has a comparative advantage in making loans in particular areas and industries, and their collateral value tends to fluctuate more than the national average. Then, when the probability of declining collateral value increases with recession in some regions and industries, the idiosyncratic shock to the returns on the bank loans increases endogenously. In other words, the financial accelerator operates both at local and at aggregate levels, which causes a significant increase in financial distress.

While this paper makes a significant contribution to our understanding of propagation through the balance sheets of banks, entrepreneurs, and households, I still believe we have a way to go in learning the costs and benefits of macroprudential regulation.

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Did the EBA Capital Exercise Cause a Credit Crunch in the Euro Area?*

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We exploit a unique monthly data set of euro-area bank balance sheets to document the impact of the EBA's 2011/12 capital exercise on bank lending. We find that banks in a banking group forced to increase its CT1 capital ratio by 1 percent had an annualized loan growth (over nine months) that was 1.2 percent lower than that of banks in unconstrained groups. We also find at the country level that banks that did not have to recapitalize did not substitute for more constrained lenders. Our results are of particular relevance for the decisions facing the new European Single Supervisory Mechanism.

JEL Codes: C21, E51, G21, G28.

1. Introduction

In October 2011 the European Banking Authority (EBA), the institution charged with setting harmonized supervisory standards for banks in EU member states, announced that major European banking groups would have to increase their core tier 1 (CT1) capital ratios to 9 percent of their risk-weighted assets (RWA) by June

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2012. These groups were also required to hold a new temporary capital buffer to cover risks linked to sovereign bond holdings. The announcement came largely as a surprise, as the EBA had just conducted rigorous stress tests in the summer of 2011 and had already released detailed information on the exposure of European banks to sovereign risk. The announcement also came at a time when the euro area was still perceived as extremely fragile, following a tumultuous summer on the sovereign debt markets of several member states. Many observers were concerned that impaired bank balance sheets were leading to weak credit supply and aggravating the recession in several countries. Unsurprisingly, the timing of the EBA's capital exercise therefore soon came under fire from critics for having contributed to a "credit crunch" in the euro area.[1]

In this paper, we evaluate the impact of this unexpected increase in regulatory capital requirements on bank lending to the euro-area real economy. We do this using information released by the EBA on measured capital shortfalls for some sixty banking groups in addition to a novel data set compiled by the Eurosystem of monthly balance sheets for some 250 large individual banks resident in the euro area (the IBSI database in the following). Controlling for bank characteristics and demand at the level of country of residence, we find that banks in a banking group that had to increase its capital by 1 percent of risk-weighted assets tended to have annualized loan growth (over the nine-month period of the exercise) that was 1.2 percentage points lower than that of banks in groups that did not have to increase their capital ratios. Although comparable with the findings of other empirical studies on the bank capital/lending relationship, our results are at the lower end of available estimates, which may reflect the difficulty in disentangling the effects of this regulatory capital shock from other events happening during this period of turmoil, like the long-term liquidity injections of the Eurosystem (LTROs). We also collapse our data set at the country level in order

[1]Cf. this statement by ECB President Mario Draghi in response to questions by journalists on January 12, 2012: "I think there are usually, by and large, three reasons why banks may not lend. ... The second reason is a lack of capital. ... So your question is about the second, a lack of capital. Now, the EBA exercise was in a sense right in itself, but it was decided at a time when things were very different from what they are today. ... So in itself under these circumstances the EBA exercise has turned out to be pro-cyclical."

to assess aggregate effects and find that banks that were not constrained to recapitalize did not substitute for those that had to increase their capital ratios. This suggests that the capital exercise had tangible procyclical macroeconomic effects.

Capital requirements have been the cornerstone of modern banking regulation since the late 1980s. Since then, proposals for increasing requirements have been contentious and the role of tightened capital regulations in aggravating recessionary episodes has been widely discussed.[2] The theoretical literature on the relationship between bank capital and credit supply indeed suggests that banks may respond to a shock that increases their capital constraint by reducing credit supply, at least temporarily.[3] However, in spite of an abundant empirical literature, the magnitude (if not the sign) of the short-term response of loan supply to a shock increasing bank capital requirements remains a much-debated issue.[4]

Indeed, any attempt to evaluate the impact of a capital requirement shock on lending supply faces several challenges. First, new regulations, such as Basel I to III, have generally been announced well ahead of their implementation explicitly in order to allow banks to smoothly adjust their balance sheets. This makes the task of identifying an unexpected shock to capital requirements and measuring the short-term impact on loan supply quite difficult.[5] Second, as with

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[2]See, e.g., Institute of International Finance (2010), a think tank representing large international banks, for an alarming perspective on the possible consequences of the recent Basel III capital package on credit supply and growth, and Admati et al. (2011) for a contradictory view.

[3]Standard arguments based on informational frictions in the market for bank equity point to reasons why issuing more equity capital can be costly for banks, at least in the short run, thus departing from the Modigliani and Miller (1958) theorem. Cf. notably the pecking-order theory of Myers and Majluf (1984) and the debt overhang problem of Myers (1977).

[4]Bernanke and Lown (1991), Hancock and Wilcox (1994), and Peek and Rosengren (1997) are classic references here. More recent examples, with varied methodological approaches and varied degree of granularity of the data used, are Aiyar, Calomiris, and Wieladek (2014), Albertazzi and Marchetti (2010), Basset and Covas (2012), Berrospide and Edge (2010), Bridges et al. (2014), Brun, Fraisse, and Thesmar (2014), Francis and Osborne (2009), Maurin and Toivanen (2012), and Puri, Rocholl, and Steffen (2011). See also Hanson, Kashyap, and Stein (2010) for a recent and rather consensual survey.

[5]For example, the role of Basel I capital regulations in contributing to the slowdown in the United States in the early 1990s is still debated. See, for example, Furfine (2001) vs. Berger and Udell (1994).

the 2007–9 sub-prime crisis, regulators may increase requirements on account of a deterioration in the credit quality of borrowers during a downturn. Similarly to the difficulty of measuring the impact of a bank capital shock more generally, disentangling demand and supply effects is therefore not straightforward. Third, changes to bank regulations tend to affect all large banks of a given country at the same time, making it difficult to construct appropriate control groups of untreated but similar institutions.

The characteristics of the EBA's exercise and of our data set allow us to address these challenges in a rather satisfying way. First, a remarkable feature of the EBA capital exercise was that it was largely unexpected. Importantly, the EBA announced its exercise just a few months after having drawn relatively tough conclusions from its own July 2011 stress tests, although none of the eight banking groups which failed the stress tests were part of the capital exercise. This surprise effect limits the odds that participating banks could have preemptively adjusted their balance sheets, which would bias downward the estimated effect on lending. Furthermore, the level of the new required core-tier-1-to-RWA ratio was substantially higher than that planned under the transition to Basel III and explicitly not related to the level of risks of any particular banking group, but rather to ensure that all large European banks accumulated sufficient capital cushions to withstand a further deterioration in the sovereign debt crisis. The horizon set by the EBA to meet the higher requirement (about eight months) was also remarkably short compared with, for example, the pace of the Basel process, making it more plausible that the observed change in lending over the period was a consequence of the capital requirement shock. All of these elements mean the capital exercise provides us with a rare opportunity to observe a rather neat exogenous regulatory shock to bank capital.

Second, an attractive feature of our data set is that while we observe the capital shock at the banking-group level, we measure the response of credit at the level of constituent banks, which may be located in different euro-area countries. For the non-financial sector of a given country, we can therefore compare the change in credit received from resident banks belonging to the same group and from resident banks belonging to different groups facing different EBA requirements and, possibly, headquartered in different countries. This disaggregated information about banking groups, as well as the multi-national nature of the capital exercise, allows us to improve upon the type of controls for credit demand typically used in similar studies. Indeed, our results are robust to the inclusion of alternative measures of country-specific effects, including country dummies.

Third, the design of both the EBA sample of European banking groups and of the IBSI sample of euro-area banks allows us the possibility of constructing a representative sample of euro-area lending institutions and of designing credible control groups. Indeed, while the EBA data set has a wide coverage of large European banking groups, including all the European global systemically important financial insistutions (G-SIFIs), the IBSI data set includes many individual banks of similar size and scope, which may or may not belong to groups monitored by the EBA. In our baseline analysis, we restrict ourselves to only using banks that were part of groups subject to the capital exercise. However, we show that our results are robust to enlarging the control group to include banks in groups not subject to the EBA exercise.

From a policy perspective, we view our findings as providing a useful benchmark for the new European Single Supervisory Mechanism (the SSM, which took over the direct supervision of all major euro-area banking groups in November 2014), as the decisions it will have to make may include higher capital requirements and new regulatory capital weights imposed on sovereign debt holdings.[6] Indeed, our study is the first to provide an assessment of the effect on bank credit of a well-identified regulatory capital shock at the euro-area level. Clearly, our results best illustrate the likely consequences of a regulatory tightening in the short run and, importantly, of a tightening implemented in a period of financial market stress. Indeed, the sovereign debt crisis was raging in late 2011, with many concerns related to possible feedback loops between banks' and sovereigns' credit quality.[7] At the same time, the magnitude of our estimated elasticity of loan growth to a regulatory capital tightening (−1.2

[6]Cf. the interview of Danièle Nouy, Head of the SSM, with the *Financial Times* of February 10, 2014 (available at: http://www.bankingsupervision.europa.eu/press/interviews/date/2014/html/sn140210.en.html).

[7]The macroeconomic effects of such a regulatory shock could be dampened in more normal times, as healthier banks would then presumably be better able to substitute for the reduction in credit supplied by capital-constrained banks.

percent for a tightening by 1 percentage point) lies at the lower end of available estimates from comparable recent micro studies, which range between roughly −1 percent and −10 percent.[8] This contained estimated effect may reflect that a lot was going on in late 2011 in addition to the event that we study. Indeed, at least two period-specific factors may have contributed to dampening the consequences of the capital shock arising from the EBA's exercise. First, in early December 2011, the Eurosystem launched its three-year long-term refinancing operations (LTROs), thus injecting in two waves (in late December 2011 and early March 2012) some €1 trillion at very favorable rates into the euro-area banking system. Although the amount borrowed by each bank was not public information, this move led to a general loosening of funding conditions on financial markets (as measured, for instance, by the credit default swap (CDS) spreads and equity returns of major banks), thus possibly improving the ability of banking groups to raise new equity. We have no way of controlling for this contrarian LTRO effect, however, as all the individual banks we observe are located in the euro area and thus equally entitled to bid at the Eurosystem's facility. Second, the EBA explicitly called for an adjustment of capital ratios with minimal resort to deleveraging, and discussions with regulators—in particular, in some stressed countries—lead us to conclude that national supervisors exerted moral suasion upon the managers of major domestic banks in order to minimize the impact of the required adjustment on lending to the real economy.

The rest of the paper is organized as follows. Section 2 summarizes the timeline and the requirements of the EBA capital exercise. We provide details on our data set and our methodology in section 3. Section 4 presents the results of our baseline regression at the

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Nevertheless, asymmetries of information only alleviated by relationship lending could also limit such substitution.

[8]At the lower end, Francis and Osborne (2009) find a reduction of −1.2 percent on average after four years and Bridges et al. (2014) find an elasticity of −2 percent in the first quarter, both for the United Kingdom. At the higher end of available estimates, Aiyar, Calomiris, and Wieladek (2014), also for the United Kingdom, find coefficients of between −6 and −9. For France, Brun, Fraisse, and Thesmar (2014) find coefficients of similar magnitude. Note also that the meta-analysis run by the Macroeconomic Assessment Group of the Basel Committee on Banking Supervision (2010) finds a median contraction of loan growth by −1.4 percent over eighteen months.

bank level and provides evidence that the estimated impact of the capital exercise on credit provision is not related to information revelation by the EBA, confirming our interpretation. In section 5, we outline a series of robustness tests that we undertake on our baseline results. Section 6 presents results of our analysis on country aggregates, while section 7 concludes.

2. The EBA Capital Exercise

2.1 Overview

The EBA announced its capital exercise (referred to hereafter as the capital exercise) on October 26, 2011, requiring banks to "strengthen their capital positions by building up a temporary capital buffer against sovereign debt exposures" and to raise their core tier 1 capital ratio to 9 percent "after accounting for [this] additional buffer against sovereign risk holdings."[9] These targets were to be met by June 2012. The exercise was undertaken with the aim of building confidence in the ability of euro-area banks to withstand credit shocks, including those arising from their holdings of sovereign bonds.

The capital exercise followed closely the July 2011 EU-wide stress tests. As a result of these tests, the EBA had urged national regulators to "promptly" require a capital strengthening for banking groups which failed the tests, i.e., banks with a core tier 1 ratio below 5 percent at the end-2012 horizon under the most adverse scenario. Note that for the capital exercise, the EBA used a sub-sample of the

[9] A bank's capital shortfall/surplus was calculated using the following formula: $Shortfall_{Sept2011} = (0.09 \times RWA_{Sept2011} - CoreTier1_{Sept2011}) + (SovereignBuffer_{Sept2011})$.

Eligible core tier 1 capital was defined in a methodological note of December 8, 2011 as the same used in the previous EBA-led stress tests. Capital comprised the highest-quality capital instruments (common equity, i.e., ordinary shares or similar instruments) but also some government support measures and some types of newly-issued contingent convertibles (CoCos), as detailed in the EBA's documentation. The sovereign buffer was calculated by removing prudential filters on sovereign assets in available-for-sale portfolios and by using a conservative valuation of sovereign debt exposures in held-to-maturity and loans and receivables portfolios, whereby banks were required to build a capital buffer against the difference between the book value of these assets and their market value as of September 30, 2011.

population of banking groups participating in the stress tests. Importantly, however, none of the eight banking groups which failed the tests were included in the following capital exercise. Furthermore, only nine out the sixteen groups which narrowly passed the test and were urged as a consequence to take "specific steps to strengthen their capital position" were finally included in the capital exercise.[10] Finally, the level of the new required core-tier-1-to-RWA ratio was substantially higher than that planned under the transition to Basel III and explicitly not related to the level of risks of any particular banking group.[11] As a result, it is fair to assume that the heightened requirement came as a surprise for most of the banking groups involved.

The EBA published an initial country-level estimate of required capital raising on October 26, 2011. On December 8, 2011, it published a formal recommendation with bank-level figures based on September 2011 balance sheet data. Twenty-seven banks were identified as having an aggregate capital shortfall of €76 billion and were required as a consequence to submit capital plans to the EBA through their national supervisory authorities by January 20, 2012.[12] The EBA published a preliminary assessment of the plans on February 9, 2012, emphasizing that the measures were not "viewed

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[10]These were "banks whose CT1R is above but close to 5% [under the adverse scenario], and which have sizeable exposures to sovereigns under stress." We show below that accounting for the case of these weaker banks, which might have anticipated their recapitalization before the launch of the capital exercise, does not affect our baseline results.

[11]The minimal level of CT1 ratio under stress required to pass the July 2011 stress test was 5 percent, while the required minimum CET1-to-RWA ratio under Basel II was 2 percent. The Basel III regulation set this minimum at 7 percent. A countercyclical buffer of up to 2.5 percent and a capital surcharge for G-SIFIs are also included in the package, but the phasing in of the new requirements was planned to be progressive, with a first mandatory increase of the minimal CET1 ratio from 2 to 3.5 percent in January 2013 and a gradual implementation of the additional CET1 buffer after this date.

[12]The capital exercise covered seventy-one banks, thirty-seven of which showed an aggregate shortfall of €115 billion. Three of these banks (Dexia, Volksbank AG, and West LB) were not required to submit capital-raising plans, as they were undergoing "deep restructuring." Plans were also not requested from six Greek banks which were being recapitalized in the context of an EU-IMF program. One bank (Bankia) that submitted a plan subsequently entered intensive restructuring and exited the capital exercise. Cf. EBA press release of July 11, 2012.

Table 1. Timeline of EBA Announcements

October 26, 2011	– Announcement of capital exercise requiring banks to build up a temporary capital buffer against sovereign exposures and to establish a core tier 1 capital ratio of 9 percent by June 2012. – Publication of estimated country-level capital shortfall based on June 2011 balance sheet data (total shortfall of €106 billion). – Final shortfall scheduled to be published in November 2011 based on end-September data. – Banks initially expected to submit recapitalization plans by end-2011.
December 8, 2011	– Publication of bank-by-bank shortfall: total of €115 billion for thirty-seven banks. Ten of these banks subsequently exited the capital exercise. – Submission of recapitalization plans by January 20, 2012.
February 9, 2012	– Publication of preliminary assessment of banks' capital plans: twenty-seven banks to fill a total shortfall of €76 billion.
July 11, 2012	– Publication of preliminary report on the implementation of the capital requirements; "vast majority" of banks meet 9 percent core tier 1 ratio.
October 3, 2012	– Publication of final report and end-June balance sheet data.

as having a negative impact on lending into the real economy." On July 11, 2011, the EBA published its preliminary report on the capital exercise, stating that the "vast majority" of banks had met the capital requirement.[13] The final report, including end-June 2012 detailed balance sheet information for all participating banks, was published on October 3, 2012. Table 1 provides a summary of this timeline of the capital exercise.

The timing of the capital exercise was criticized by a number of commentators for potentially aggravating a credit crunch in the

[13] At this time, government backstops were being put into place for four of the twenty-seven banks.

euro area. However, in its communication, the EBA consistently emphasized the need for banks to address capital shortfalls without constraining credit provision to the real economy. For example, the recommendation of December 8, 2011 outlined a hierarchy of capital-raising measures, emphasizing the use of liability management and stating that national authorities could only agree to asset disposals if they did not "lead to a reduced flow of lending to the EU's real economy." Furthermore, the EBA and national authorities were to ensure that capital targets were "not achieved through excessive deleveraging, disrupting lending into the real economy."

In total, the twenty-seven banks increased their capital by €115.7 billion. According to the EBA's final report, €83.2 billion of this related to direct capital measures, while €32.5 billion related to the impact of RWA measures. Contributing to the latter figure was a fall in RWAs of €42.9 billion (0.87 percent of total RWAs as of September 2011) arising from reductions in lending. The EBA concluded: "In line with the Recommendation, capital plans have not led directly to a significant reduction of lending into the real economy. A deleveraging process had already started before the capital exercise and will need to continue in an orderly fashion."

3. Data and Methodology

3.1 Data Sources

The data used in our analysis come from three sources. Firstly, we use consolidated banking-group balance sheet data published by the EBA as part of its capital exercise. These data, which are available on the EBA's website, are available for three dates: September 2011, December 2011, and June 2012. The data contain the capital shortfall/surplus calculated by the EBA. The capital exercise initially covered seventy-one banking groups, but ten of these exited the exercise before its completion due to restructuring. Using these data, we calculate a ratio of the group's capital shortfall to its risk-weighted assets (shortfall to RWA) as of September 2011. This ratio is truncated at zero for banks with a capital surplus.

Secondly, we use a unique data set of the monthly balance sheets of individual monetary financial institutions (MFIs) collected by the Eurosystem for the purpose of conducting more in-depth analyses on the transmission mechanism of monetary policy during the sovereign debt crisis. This data set covers 247 MFIs, or "banks," which were selected from the total population of euro-area MFIs in order to create a sample that would be representative of euro-area bank-lending activity. For example, the sample includes the 150 largest MFIs (by main assets) as well as most of the banks that report to the European Central Bank's (ECB's) Bank Lending Survey. MFIs from all euro-area countries are included in the data set, which consists of monthly stock and flow data for twenty-four balance sheet items beginning (for the majority of banks) in August 2008. These balance sheet items were selected in order to allow for the analysis of bank lending to the non-financial private sector (firms and households) as well as the funding activity of banks. Credit to the general government sector and banks' holdings of sovereign debt is also covered.

Finally, we use daily CDS prices and stock prices for all large European banking groups. We consider five-year maturity modify-to-modify CDS contracts, which are generally viewed as the most standard and liquid contracts. CDS price series over the period of interest are available for forty-two banking groups in the EBA sample; stock prices are available for only forty-one of them. We take this information from Bloomberg and use it to test whether the effect of the capital exercise on bank lending can be explained by information revealed about the creditworthiness of European banks at the time of the first EBA releases.

3.2 Preparation of Data Set

The first step of our analysis consists of a mapping of individual banks (IBSI data set) and banking groups (EBA data set). This allows us to divide the IBSI data set into three categories: (i) banks in banking groups identified as having a capital surplus; (ii) banks in banking groups identified as having a capital shortfall; and (iii) banks that were not part of banking groups included in the capital exercise. Using information on banking groups in the IBSI data set, we are also able to identify whether banks in the third category are stand-alone banks or members of a group. Since the data at hand does not allow for a full reconstruction of group-level balance sheets (and therefore we cannot compute the share of each credit insitution in total lending by its banking group), we must assume that an identified capital shortfall at the group level has a uniform impact on the lending growth of all entities within the group (conditional on their measurable characteristics). Such an assumption implies two important but quite standard hypotheses: (i) bank credit policy is set at the group level, and (ii) internal capital markets exist within banking groups.[14]

Of the 247 banks in the IBSI data set, 14 fall out of the sample, as they are part of the ten groups that exited the EBA exercise. We also exclude twenty-four banks that had loan books that were less than 5 percent of total assets in September 2011, seven non-resident banks in Luxembourg and Ireland, and four banks with omitted data points over the period of the capital exercise.[15] Following this stage of data cleaning, we are left with a sample of 198 banks (see table 2) in 118 banking groups, 50 of which are banking groups subject to the capital exercise. The list of the 118 selected banking groups is detailed in table 14 in the appendix. Note that the banking groups monitored by the EBA are headquartered in the European Union, while the observed individual banks are resident in the euro area.[16]

Table 3 presents data on the distribution of bank lending in the euro area, the percentage of total bank credit captured by our sample, the number of banks in our sample, and the proportion of these banks that are part of a banking group with a capital shortfall. For the latter three categories, we present figures for our baseline sample (124 banks that were part of banking groups subject to the capital exercise) and for the larger sample containing all banks in the IBSI data set (198 banks). These figures show that our baseline

[14]Many empirical studies vindicate the hypothesis that internal capital markets matter, so that the holding company is the appropriate level of observation: Ashcraft (2008), Ehrmann and Worms (2004), and Houston, James, and Marcus (1997), to quote a few.

[15]We exclude the following banks resident in Luxembourg: BGL BNP Paribas, ING Luxembourg S.A., Société Générale Bank & Trust, Deutsche Bank Luxembourg S.A., UniCredit Luxembourg S.A., and DZ Privatbank S.A. Other non-resident banks in Luxembourg fall out of the sample, as their loans-to-assets ratios were less than 5 percent in September 2011. We also exclude Depfa Bank AS, which is resident in Ireland.

[16]This explains the presence of, e.g., UK groups (country label: GB), like Barclays or HSBC, which may have subsidiaries located, for instance, in France or Germany.

Table 2. Count of EBA Groups and IBSI Banks

Banking Groups in Capital Exercise	61
IBSI Banks	247
– of which in EBA	142
– of which not in EBA	105
Mapped but No EBA Data	(14)
Mapped but No IBSI Data	(4)
IBSI with Small Loan Books	(24)
Non-Resident Banks in Luxembourg and Ireland	(7)
Sample of Banks	198
– of which in EBA	124
– of which not in EBA	74
Sample of Bank Groups	118
– of which in EBA	50
– of which not in EBA	68

sample of 124 banks covers 46 percent of total bank lending in the euro area, while this rises to 60 percent when we include all 198 banks. Of these 124 banks, 66 (53 percent) showed a capital shortfall. While this proportion varies across countries, only five small euro-area countries (excluding Greece) have no resident banks with a capital shortfall. Importantly, even in the smaller sample that we consider for our baseline regression, both shortfall and non-shortfall banks are present in most countries, making it possible to identify country-specific demand effects.

Finally, a nice feature of the IBSI data set is that we can observe "true" net flows of bank credit instead of approximating them with the changes in credit outstanding at the start and the end of the capital exercise, as is typical in most comparable studies using bank balance sheet data.[17] These credit flows represent changes in credit stocks corrected for various sources of statistical noise, including write-offs, exchange rate effects, reporting changes, and reclassifications. Note that these corrections are basically the same as those implemented by Eurosystem statisticians when computing the growth rates of credit aggregates at the country level.

[17] A noticeable exception is Bridges et al. (2014), which also uses "clean" growth rates of credit.

Table 3. Representativeness of the Sample of Selected Individual Banks

Country	% EA Loans	% Smpl. Loans		No. Banks		% Shortfall Banks	
		EBA	All	EBA	All	EBA	All
AT	3	25	38	4	8	100	50
BE	2	52	77	6	9	33	22
CY	0	46	55	2	4	100	50
DE	23	38	49	29	56	55	29
EE	0	92	92	4	4	0	0
ES	17	30	67	9	23	78	30
FI	2	48	48	5	6	0	0
FR	19	56	68	22	28	68	54
GR	2	—	—	—	—	—	—
IE	2	67	73	9	10	0	0
IT	15	43	53	14	23	57	35
LU	1	13	18	1	2	0	0
MT	0	74	82	2	4	0	0
NL	8	81	90	5	8	40	25
PT	3	70	70	5	5	100	100
SI	0	48	58	4	5	75	60
SK	0	55	55	3	3	67	67
Euro Area	**100**	**46**	**60**	**124**	**198**	**53**	**33**

Notes: Countries are the euro-area countries where individual banks are located. Note that the country of nationality of the banking groups to which these individual banks belong can be different and that all EBA banking groups are headquartered in the European Union but not necessarily in the euro area. Columns 3, 5, and 7 refer to banks in EBA groups. Columns 4, 6, and 8 refer to all selected banks.

We then calculate lending growth rates based on stock and adjusted flow data. The one-month growth rate of loans (I^1) is calculated as follows:

$$I_t^1 = \frac{F_t^M}{L_{t-1}}, \tag{1}$$

where F^M represents the one-month adjusted flow of lending and L represents the outstanding stock of loans.

We clean these monthly growth rates for the impact of eighty-four identified mergers and acquisitions and nine identified securitization operations over the full IBSI sample (August 2007 to June 2013) and winsorize the remaining data at the 2nd and 98th percentiles. We then calculate annualized nine-month growth rates using the following formula, based on the methodology described in the ECB's Monthly Bulletin:

$$I_t^9 = \left[\left(\prod_{i=0}^{8} \left(1 + \frac{F_{t-i}^M}{L_{t-1-i}} \right) \right)^{\frac{12}{9}} - 1 \right]. \tag{2}$$

Table 4 presents some summary statistics for the banks in our sample as of September 2011, i.e., immediately prior to the announcement of the capital exercise. These summary statistics are presented at the aggregate level (for all 198 banks in the sample) as well as for the three groupings of banks. These figures show that we have a large range of bank sizes in our sample.[18] The average annualized loan growth during the period of the capital exercise was quite small, reflecting the generally subdued economic environment during this period. The average figure is smaller for those banks in banking groups with a capital shortfall. The range for this figure is large for all three groups of banks. The incidence of very high interbank-liabilities-to-assets ratios probably reflects the fact that some banks were highly reliant on Eurosystem liquidity at this time (central bank borrowings are included in the interbank liabilities figure). Note also that the capital variable in the IBSI data set is very broadly defined and encompasses tier 1 and tier 2 capital as

[18]These figures are converted to logs when used in our regression analysis.

Table 4. Summary Statistics of Banks in Sample (September 2011, in percent unless otherwise stated)

	Mean	SD	p10	p90
All Banks (N = 198)				
Main Assets (Millions)	84,797	131,795	5,860	218,047
Loan Growth – EBA Exercise	1.46	7.53	−7.55	9.71
Loans/Assets	47.44	21.68	17.55	71.78
Capital/Assets	7.80	4.80	2.58	12.82
Liquid Assets/Assets	16.92	17.35	2.48	37.98
Deposits/Assets	35.16	24.15	0.58	67.95
Interbank Liabilities/Assets	0.20	0.19	0.02	0.44
Deposits/Loans	0.90	1.48	0.02	1.34
Sov. Bonds/Assets	0.05	0.06	0.00	0.14
Shortfall Banks (N = 66)				
Main Assets (Millions)	117,276	163,319	10,149	371,538
Loan Growth – EBA Exercise	0.43	8.01	−8.05	11.08
Loans/Assets	46.73	22.02	16.29	74.85
Capital/Assets	8.08	4.04	2.82	13.26
Liquid Assets/Assets	17.03	12.73	3.85	34.54
Deposits/Assets	29.79	22.73	0.16	62.90
Interbank Liabilities/Assets	0.28	0.24	0.07	0.68
Deposits/Loans	0.67	0.52	0.01	1.32
Sov. Banks/Assets	0.06	0.06	0.00	0.14
Surplus Banks (N = 58)				
Main Assets (Millions)	98,100	150,171	5,192	320,733
Loan Growth – EBA Exercise	2.12	7.24	−7.83	10.37
Loans/Assets	42.60	23.77	13.17	79.65
Capital/Assets	7.91	6.83	1.13	14.13
Liquid Assets/Assets	20.91	23.35	1.14	69.48
Deposits/Assets	31.58	24.19	1.68	65.84
Interbank Liabilities/Assets	0.18	0.18	0.01	0.43
Deposits/Loans	1.14	2.32	0.06	1.62
Sov. Bonds/Assets	0.04	0.05	0.00	0.14
Non-EBA Banks (N = 74)				
Main Assets (Millions)	45,403	53,377	4,915	103,566
Loan Growth – EBA Exercise	1.86	7.31	−5.92	9.13
Loans/Assets	51.86	18.90	21.41	69.72
Capital/Assets	7.45	3.33	3.54	11.23
Liquid Assets/Assets	13.69	14.81	2.48	27.70
Deposits/Assets	42.76	23.71	1.49	73.78
Interbank Liabilities/Assets	0.15	0.13	0.02	0.29
Deposits/Loans	0.93	1.17	0.12	1.30
Sov. Banks/Assets	0.06	0.05	0.01	0.13

Table 5. Summary Statistics of the Fifty EBA Banking Groups in Sample (Sept. 2011)

	Mean	SD	Min.	Max.
Number of Banks in Group	2.4	1.9	1	10
Number of Countries of Location	1.7	1.2	1	6
Shortfall to RWA:				
All Fifty Selected Groups	−0.3	3.8	−14.8	7.1
Twenty-Four Groups with Positive Shortfall	2.4	1.8	0.2	7.1

well as some additional reserves, which explains why the average capital-to-assets ratio displayed in table 4 is much higher than usual measures of raw leverage based on tier 1 capital.

Last but not least, a comparison between shortfall and surplus banks within the sample of banks belonging to EBA groups shows that the average institution has a similar balance sheet profile in both groupings. This suggests that there is limited scope for selection bias in the treatment group that we cannot control for by simply adding relevant bank-specific covariates in our regression.[19]

Table 5 finally presents some summary statistics on the fifty EBA banking groups in our sample, including the number of banks in each group and the number of countries that the group is present in. The heterogeneity in terms of capital positions in September 2011 is remarkably large, as the least-capitalized group shows a shortfall of 7.1 percent while the best-capitalized one enjoys a surplus of close to 15 percent of RWA. For the twenty-four banking groups with a capital shortfall that we keep in our sample, the average shortfall amounts to 2.4 percent of RWA. On average, the selected banking groups are linked to 2.4 IBSI subsidiaries which are present in 1.7 countries.

[19]In the terms of the matching literature, these descriptive statistics suggest that the "treatment" and "control" groups share a common support. This would not be the case if shortfall banks had, for instance, low deposit-to-assets ratios while surplus banks had high deposit ratios. In such a situation, identifying the effect of the capital exercise on lending conditional on banks' deposit ratio would not be feasible.

3.3 Methodology

The aim of our analysis is to test whether banks that were obliged to increase their capital buffers as part of the capital exercise (treatment group) exhibited significantly different lending behavior over the recapitalization period (October 2011 to June 2012) compared with banks that were not obliged to increase their capital buffers (control group).[20] For our baseline analysis, we restrict these two groups to only include banks that were part of banking groups subjected to the capital exercise, i.e., 124 banks. In our robustness analysis, we will explore whether any difference in behavior can be observed when we expand the control group to include banks in banking groups that were not subject to the capital exercise and, therefore, did not face a higher capital requirement.

Our baseline model is as follows:

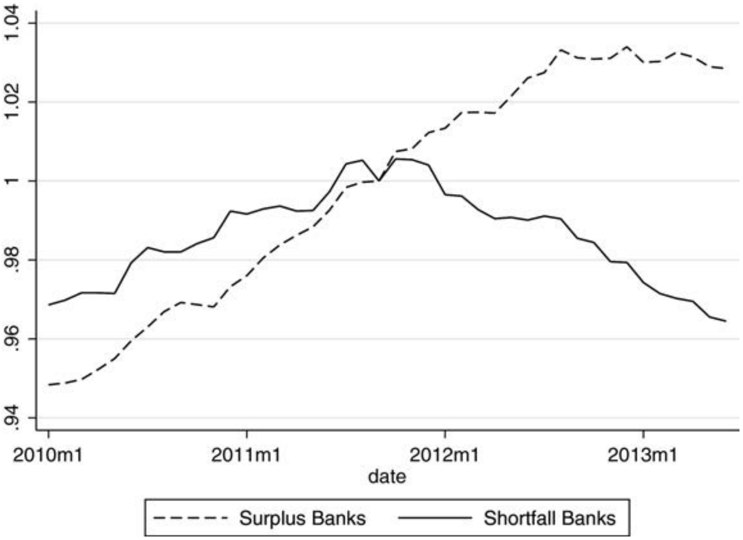
$$Y_{i,j,k} = \alpha + \beta_1 Shortfall_j + \beta_2 X_{i,j,k} + S_k + \epsilon_{i,j,k}. \qquad (3)$$

$Y_{i,j,k}$ is the annualized growth of total (domestic) loans for bank i belonging to banking group j and located in country k, over the nine-month period from September 2011 (before the exercise) to June 2012 (completion of the exercise).[21] $Shortfall_j$ is the ratio of the capital shortfall (in euros) to the group's risk-weighted assets (equal to zero for banks in our control group), X_i is a matrix of bank characteristics, S_k is a variable that controls for loan demand at the level of country k, and $\epsilon_{i,j,k}$ is the residual. The results of our regressions are presented in the next section.

[20]Although the EBA did not publish finalized capital shortfall/surplus figures until December 8, 2011, it is possible that banking groups were able to predict their results at the time of the announcement of the capital exercise (October 26, 2011) and start adjusting their balance sheet at that time. We therefore set the adjustment period as being equal to the entire length of the capital exercise.

[21]We examine the change in credit supplied by individual banks between these two dates, therefore collapsing the time dimension instead of, for instance, running a panel regression on monthly growth rates over the two years 2011–12. This has the advantage that the standard errors associated with our estimator of the "treatment" are robust to the problems of autocorrelation of the residuals pointed out by Bertrand, Duflo, and Mullainathan (2004) when the regressor of interest is very persistent (like a step variable).

Figure 1. Total Loans Outstanding (Sept. 2011 = 100): Cumulated over Control vs. Treated Groups



4. Results

Figure 1 provides an intuition for our results. It shows the evolution of the adjusted stock of loans for our control group (banks in "surplus" EBA banking groups) and our treated group (banks in "shortfall" EBA banking groups), indexed at the value of one in September 2011.[22] This graphical analysis shows that the evolution of lending was broadly similar for the two groups prior to the announcement of the capital exercise in October 2011. There is a sharp divergence following the announcement, however, with banks in the control group continuing to increase their stock of loans during and following the capital exercise, while banks in the treated group started to reduce their stock of loans almost immediately after the announcement of the exercise.

[22]We calculate the adjusted loan stock figures using the actual loan stock at the start of the IBSI sample (August 2007) and adding on a cumulated monthly flow figure derived from our monthly growth rates. These adjusted stock figures therefore reflect the data cleaning described in section 3.2 and are consistent with our subsequent regression analysis.

This relationship is borne out in a multivariate regression analysis. Table 6 shows the results from our baseline regressions. Column 1 is a simple regression of annualized loan growth during the capital exercise on the truncated shortfall-to-RWA ratio. Columns 2 and 3 add alternative control measures for credit demand at the country level: a dummy that takes the value of one for "stressed" euro-area countries and a variable equal to the unemployment rate in the bank's country of residence in September 2011, in order to proxy for the degree of slack in domestic economic activity.[23] Columns 4 and 5 add a number of bank characteristics to the specifications contained in columns 2 and 3. The inclusion of such variables allows for a better control of the bank characteristics that may have contributed to lending behavior over this period.

In column 6 of table 6 we first add the variable *Truncated Surplus-to-RWA*, which measures the intensity of the capital surplus for banks in the control group. This variable is included in order to investigate whether banks in the control group changed their lending behavior as a result of the capital exercise. Evidence of such a change in behavior would violate the assumption that the control group would have the same behavior in the counterfactual of no treatment event. Second, we also control for the possible bias which may be associated with the presence of banks from groups which only narrowly passed the July 2011 stress tests. In our selection of banking groups, this is the case for nine individual banks belonging to seven different EBA groups.[24] Among these nine banks, eight show a "capital shortfall" as of September 2011 under the definition of the capital exercise. Such banks may have started to adjust their capital ratio (and therefore may have started to deleverage) before the launch of the capital exercise. Furthermore, part of the adjustment they underwent over the period of the capital exercise may in fact be due to the consequences of the stress tests, not of the capital exercise per se. In column 6, we thus add a dummy for banks belonging to

[23] We define seven euro-area countries as having been stressed at the time of the capital exercise: Cyprus, Greece, Ireland, Italy, Portugal, Slovenia, and Spain.

[24] These seven EBA groups are Marfin popular bank (CY), Norddeutsche Lbk (DE), HSH Nordbank (DE), Banco Popular (ES), BCP (PT), Espirito Santo (PT), and Nova Ljubljanska banka (SI).

Table 6. Impact of EBA Capital Exercise on Annualized Lending Growth: Oct. 2011–June 2012 (baseline estimates)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Shortfall/RWA	−1.48**	−1.06*	−1.36**	−1.19**	−1.23**	−1.43**	−1.61*
	(0.58)	(0.59)	(0.54)	(0.53)	(0.47)	(0.54)	(0.83)
Stressed		−0.04**		−0.01			
		(0.01)		(0.02)			
Unemployment			−0.25**		−0.05	−0.04	
			(0.11)		(0.12)	(0.12)	
Size				0.00	0.00	0.00	
				(0.00)	(0.00)	(0.00)	
Liquid Assets/Assets				0.10	0.10	0.10	
				(0.06)	(0.06)	(0.06)	
Deposits/Assets				0.03	0.03	0.03	
				(0.03)	(0.03)	(0.03)	
Loans/Assets				0.03	0.03	0.03	
				(0.04)	(0.04)	(0.05)	
Sov. Bonds/Assets				0.46***	0.47***	0.47***	0.69***
				(0.14)	(0.14)	(0.13)	(0.16)
Dom. Sov. Bonds/ Assets * Stressed Country				−0.55*	−0.61***	−0.62***	−0.77**
				(0.32)	(0.20)	(0.20)	(0.37)
Surplus/RWA						0.04	
						(0.41)	
July '11 ST Fringe						0.03	
						(0.02)	
Country FEs	No	No	No	No	No	No	Yes
N	124	124	124	124	124	124	124
R^2	0.06	0.12	0.09	0.23	0.23	0.23	0.35

Notes: This table presents the results of OLS regressions at the level of individual banks, where the dependent variable is the annualized rate of growth of loans to customers over the nine-month period of the capital exercise, from September 2011 to June 2012. *Shortfall/RWA* is the consolidated capital shortfall, truncated at zero, as measured by the EBA at the banking-group level in September 2011. *Unemployment* is the rate of unemployment in the country of location in September 2011. *Stressed* is a dummy variable indicating whether the bank is located in a country under financial stress in 2011–12 (GIIPS countries, plus Cyprus and Slovenia). All other bank controls are measured at the unconsolidated level of the individual banking institutions at end-September 2011. Definitions are detailed in table 13 in the appendix. *Surplus/RWA* is the consolidated capital surplus, truncated at zero. *July '11 ST Fringe* is a dummy variable which takes the value of one if the bank belongs to one of the seven banking groups that nearly failed the July 2011 EBA stress tests (with a CT1 ratio under stress between 5 and 6 percent). Column 7 replaces the country control measures with country fixed effects, while only retaining the bank characteristics that were statistically significant in columns 4–6. A constant is included but not shown. Standard errors (in parentheses) are clustered at the level of banking groups. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

these seven "fringe" groups.[25] The coefficients associated with both this dummy and the *Truncated Surplus-to-RWA* variable are close to zero and not significant, while the main coefficient of interest is still negative and significant.

Finally, column 7 replaces the credit demand proxies with country fixed effects while retaining the bank characteristics that are statistically significant in the specifications of columns 4 and 5.[26] All specifications use clustering methods to correct standard errors for possible correlation of innovations for banks belonging to the same banking group.

In all of these specifications, the coefficient for the variable *Truncated Shortfall-to-RWA* is statistically significant. We view the results of column 4 as coming from our best-identified specification, and take it as our baseline. This leads us to conclude that a shortfall-to-RWA ratio of 1 percentage point was associated with an annualized nine-month rate of loan growth that was 1.2 percentage points lower than for banks in the control group.

As intuition would suggest, banks resident in "stressed" countries also tended to have lower lending growth. Of the bank characteristics included in the regression, only the two variables describing the bank's holdings of sovereign bonds are significant. This is perhaps unsurprising, given that exposure to euro-area sovereigns was one of the drivers of the level of the capital shortfall, via the "sovereign buffer." It is interesting to note that none of the other bank characteristics included in the regression are statistically significant, highlighting similarities in the business models of banks included in the EBA's capital exercise. Also of note, the coefficient on the variable *Truncated Surplus-to-RWA* is not significant, indicating that banks in the control group did not change their behavior as a result of the capital exercise.

Overall, these results suggest a limited impact of a reduction in leverage on lending growth in the short term, with a coefficient that

[25] We also ran the baseline regressions on a reduced sample where we excluded the nine fringe banks. Again, the results are qualitatively unchanged and look even slightly stronger across all specifications, which might reflect the fact that one bank within a fringe group with a capital shortfall was an outlier that showed a relatively strong credit expansion.

[26] Note that the lower degrees of freedom due to the inclusion of country fixed effects implies that the coefficient of interest is less precisely estimated.

is at the lower end of the range of estimates from the existing literature, as mentioned above in the Introduction section. A number of factors may have dampened the magnitude of the impact in the present study, however. Most significantly, as discussed in section 2, the EBA and national supervisors exerted pressure on banks to increase their capital ratios mainly through measures targeting their liabilities. Banks in a number of countries were also subject to other forms of "moral suasion" not to reduce lending at this time, notably from national politicians. The ECB also undertook exceptional liquidity-providing measures during this period (the LTROs), possibly reducing deleveraging pressure on banks.

Interpreting our results as indicating that the tightening in capital requirements induced the reduction in lending requires that we first qualify an alternative reading related to potential information revelation by the EBA about the credit status of surveyed banks. Indeed, one may suppose that the main effect of the disclosure of detailed bank information by the EBA was to shed light on the fragility of some institutions, thus deterring potential investors and increasing the funding stress faced by these institutions. We provide evidence that this was not the case.

First, as previously stated, the banking groups included in the capital exercise were a sub-sample of the European banking groups already subject to the EBA stress tests in 2010 and 2011. In particular, the 2011 stress tests, the conclusions of which were communicated to the public in the summer of 2011, already revealed most of the relevant information, including detailed exposures of participating institutions to sovereign debt holdings.

More formally, we conduct a small event study of the variation in CDS spreads and stock returns of EBA banking groups over the day of the EBA disclosure on December 8, 2011, when the EBA first published bank-level results based on balance sheet data from end-September 2011. We find evidence that the market largely foresaw the degree of capital constraints faced by banks. More precisely, we calculate the shortfall-to-RWA ratio using data released on this date and use this as the independent variable in a regression explaining the change in banks' CDS spreads or banks' stock returns over a window of two days around the event date. The results, presented in table 7, show that this announcement had a statistically significant impact on CDS spreads but no visible impact on equity returns. The

Table 7. Event Study: Impact of EBA Announcement on Bank CDS Spreads and Equity Returns on a Two-Day Window around December 8, 2011

	CDS	CDS	Equity	Equity
Shortfall to RWA	2.26***	2.15***	−0.04	−0.11
	(0.66)	(0.56)	(0.15)	(0.19)
Stressed Country		6.72		1.66
(Headqu.)		(6.43)		(1.14)
Constant	22.48***	20.18***	−1.62***	−2.30***
	(3.01)	(2.98)	(0.36)	(0.57)
N	42	42	41	41
R^2	0.18	0.21	0.01	0.11

Notes: This table presents the results of OLS regressions, where the dependent variable is either the change in CDS price (columns 1–2) or the stock return of individual banking groups (columns 3–4). *Stressed Country (Headqu.)* is a dummy which takes the value of one if the country where the banking group is headquartered is under financial stress in 2011. Included banking groups are the sample banking groups for which these market prices were available. Changes in CDS and stock prices are computed over a window of two days surrounding the event (from December 7 to December 9, 2011). Changes to CDS prices are expressed in basis points; changes to stock returns are expressed in percentage points. Robust standard errors are in parentheses. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

magnitude of the impact on CDS spreads is quite limited, however. While the CDS spread of the average banking group in the sample increased by 23 basis points over the three days following the announcement, a bank with a shortfall-to-RWA ratio of 2.4 percentage points (the average for shortfall groups) saw its CDS rise by just 5.4 basis points more. This confirms that the relevant story is not one of information about the situation of banks being revealed, and the markets penalizing these banks, but one where some banks faced a heightened regulatory capital constraint and adjusted their balance sheet accordingly over a short period.

5. Robustness Tests

In this section, we present the results of a number of robustness tests. The aim of these tests is twofold: firstly, to check the statistical robustness of our baseline results and, secondly, to determine whether the observed difference in loan growth rates between our two groups is really driven by the capital exercise.

A fundamental assumption of models such as ours is that outcomes for the treated and the control groups would have been the same in the absence of the treatment.[27] In our case, we can state this hypothesis as follows: banks in groups identified as having capital shortfalls would not have had lower average loan growth over the period of the capital exercise if they had not been subject to higher regulatory capital requirements as part of this exercise. It is, of course, impossible to test whether this hypothesis is true, as we cannot observe the counterfactual for treated groups. However, the robustness tests that we undertake in this section, such as a placebo test and a change to our definition of the control group, provide evidence that this is indeed the case.

Our first robustness test is what is commonly referred to as a *placebo test.* Such a test undertakes the same regression specifications but on a different (non-overlapping) period in the sample in order to test whether the model identifies a statistically significant relationship during this period. Such a relationship would be difficult to interpret and would undermine the validity of our baseline results. Indeed, while the lower level of lending growth observed for our treated group may be due to deleveraging on the part of banks required to meet a higher regulatory capital requirement, it is also possible that weakly capitalized banks would have undertaken necessary deleveraging even if the EBA exercise had not taken place. We look at the nine-month window prior to the announcement of the capital exercise (January 2011–September 2011). The results of this regression (displayed in table 8, which has the same structure as table 6) show that the coefficient on the truncated shortfall-to-RWA ratio is not significant for this period. In contrast, a number of bank characteristics (the deposit-to-assets ratio and the ratio of sovereign bond holdings to assets) do have a statistically significant relationship with lending growth during this period. While the coefficient on the variable *Truncated Surplus-to-RWA* is significant in the results shown in column 6, this is not the case in the specification using

[27]This assumption is often called the "parallel trends" hypothesis. See, e.g., Angrist and Pischke (2009, section 5.2).

Table 8. Placebo: Impact of EBA Capital Exercise on Annualized Lending Growth: Jan. 2011–Sept. 2011

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Shortfall/RWA	−0.67	−0.45	−0.61	−0.44	−0.47	−0.44	−1.20
	(0.49)	(0.56)	(0.48)	(0.54)	(0.50)	(0.61)	(0.79)
Stressed		−0.02		−0.00			
		(0.02)		(0.03)			
Unemployment			−0.23*		−0.12)	−0.10	
			(0.14)		(0.18)	(0.18)	
Size				−0.00	−0.00	−0.01	
				(0.01)	(0.01)	(0.01)	
Liquid Assets/Assets				0.01	0.02	0.00	
				(0.07)	(0.08)	(0.08)	
Deposits/Assets				0.05*	0.04	0.04	0.02
				(0.02)	(0.03)	(0.03)	(0.02)
Loans/Assets				−0.04	−0.03	−0.05	
				(0.06)	(0.06)	(0.07)	
Sov. Bonds/Assets				0.19	0.20*	0.17	0.08
				(0.14)	(0.11)	(0.12)	(0.15)
Dom. Sov. Bonds/ Assets * Stressed Country				−0.25	−0.25	−0.22	
				(0.47)	(0.33)	(0.31)	
Surplus/RWA						−0.68**	−0.36
						(0.32)	(0.40)
July '11 ST Fringe						−0.04*	
						(0.02)	
Country FEs	No	No	No	No	No	No	Yes
N	120	120	120	120	120	120	120
R^2	0.01	0.03	0.03	0.10	0.10	0.15	0.27

Notes: This table presents the results of OLS regressions at the level of individual banks, where the dependent variable is the annualized rate of growth of loans to customers over the nine-month period prior to the capital exercise, from December 2010 to September 2011. *Shortfall/RWA* is the consolidated capital shortfall, truncated at zero, as measured by the EBA at the banking-group level in September 2011. *Unemployment* is the rate of unemployment in the country of location in December 2010. *Stressed* is a dummy variable indicating whether the bank is located in a country under financial stress in 2011–12 (GIIPS countries, plus Cyprus and Slovenia). All other bank controls are measured at the unconsolidated level of the individual banking institutions at end-December 2010. Definitions are detailed in table 13 in the appendix. *Surplus/RWA* is the consolidated capital surplus, truncated at zero. *July '11 ST Fringe* is a dummy variable which takes the value of one if the bank belongs to one of the seven banking groups that nearly failed the July 2011 EBA stress tests (with a CT1 ratio under stress between 5 and 6 percent). Column 7 replaces the country control measures with country fixed effects, while only retaining the bank characteristics that were statistically significant in columns 4–6. A constant is included but not shown. Standard errors (in parentheses) are clustered at the level of banking groups. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

country fixed effects (column 7). Overall, the results of our placebo test support the hypothesis that the extra deleveraging observed by banks in our treatment group during the period of the capital exercise was due to the higher capital requirements imposed by this exercise.

Our second robustness test changes the composition of banks in our control group. In our baseline regression, we only include banks in banking groups that were subject to the capital exercise. However, it can be argued that banks in banking groups that were not subject to the capital exercise should exhibit similar lending behavior to banks in "surplus" groups, as neither were subject to a regulatory capital adjustment. Table 9, which repeats our baseline regression specifications using this increased sample, shows that this was indeed the case, with the coefficient on the variable *Shortfall-to-RWA* remaining of a similar order of magnitude. Moreover, a dummy variable indicating whether a bank is in a banking group subject to the capital exercise is not statistically significant (in columns 4–7), suggesting that the use of this enlarged control group is justified. Overall, these regressions show that our baseline results are robust to the size and composition of the control group.

Given the wide range of bank sizes in our sample, it is possible that our baseline regression results are skewed by the growth rates of small banks. We use weighted OLS analysis in order to test whether the results are robust to small banks being given a lower weight. Table 10 presents the results of this regression specification, with the size of the banks' loan books used as the weighting factor. While the size of some of the coefficients for the shortfall-to-RWA ratio change, they remain of a similar order of magnitude. Moreover, the statistical significance of the coefficient does not change, indicating that our results are robust to the size of banks in the sample.

Our final robustness test attempts to correct for the possibility of correlation between the observations for banks in the same banking group. In our baseline analysis, we account for the possibility of such correlation by correcting our standard errors using clustering methods. Another method is to average observations at a group level. We therefore collapse our data set into 118 groups by averaging the variables in our regression specification. We also construct a variable, *Lending to Stressed Countries,* corresponding to the proportion of each group's lending in "stressed" euro-area

Table 9. Impact of EBA Capital Exercise on Annualized Lending Growth: Oct. 2011–June 2012 (all IBSI banks)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Shortfall/RWA	−1.36**	−1.02**	−1.25***	−1.13**	−1.20**	−1.45***	−0.98*
	(0.53)	(0.51)	(0.46)	(0.50)	(0.46)	(0.49)	(0.56)
Stressed		−0.04***		−0.01			
		(0.01)		(0.02)			
Unemployment			−0.31***		−0.14*	−0.14	
			(0.07)		(0.09)	(0.09)	
Size				0.00	0.00	0.00	
				(0.00)	(0.00)	(0.00)	
Liquid Assets/Assets				0.05	0.05	0.05	
				(0.06)	(0.06)	(0.06)	
Deposits/Assets				0.08***	0.08***	0.08***	0.08***
				(0.03)	(0.03)	(0.03)	(0.03)
Loans/Assets				−0.02	−0.02	−0.01	
				(0.04)	(0.04)	(0.05)	
Sov. Bonds/Assets				0.26**	0.28**	0.28**	0.37**
				(0.12)	(0.12)	(0.12)	(0.17)
Dom. Sov. Bonds/				−0.24	−0.31**	−0.31**	−0.31
Assets * Stressed Country				(0.25)	(0.15)	(0.15)	(0.33)
EBA Banking Group				0.01	0.01	0.01	
				(0.02)	(0.02)	(0.02)	
Surplus/RWA						−0.04	
						(0.41)	
July '11 ST Fringe						0.03	
						(0.02)	
Country FEs	No	No	No	No	No	No	Yes
N	198	198	198	198	198	198	198
R^2	0.04	0.10	0.09	0.19	0.20	0.20	0.27

Notes: This table presents the results of OLS regressions at the level of individual banks, where the dependent variable is the annualized rate of growth of loans to customers over the nine-month period of the capital exercise, from September 2011 to June 2012, and the sample is extended to include all selected IBSI banks. *Shortfall/RWA* is the consolidated capital shortfall, truncated at zero, as measured by the EBA at the banking-group level in September 2011. *Unemployment* is the rate of unemployment in the country of location in September 2011. *Stressed* is a dummy variable indicating whether the bank is located in a country under financial stress in 2011–12 (GIIPS countries, plus Cyprus and Slovenia). All other bank controls are measured at the unconsolidated level of the individual banking institutions at end-September 2011. Definitions are detailed in table 13 in the appendix. *EBA Banking Group* is a dummy variable which takes the value of one if the bank belongs to a banking group monitored by the EBA. *Surplus/RWA* is the consolidated capital surplus, truncated at zero. *July '11 ST Fringe* is a dummy variable which takes the value of one if the bank belongs to one of the seven banking groups that nearly failed the July 2011 EBA stress tests (with a CT1 ratio under stress between 5 and 6 percent). Column 7 replaces the country control measures with country fixed effects, while only retaining the bank characteristics that were statistically significant in columns 4–6. A constant is included but not shown. Standard errors (in parentheses) are clustered at the level of banking groups. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

Table 10. Impact of EBA Capital Exercise on Annualized Lending Growth: Oct. 2011–June 2012 (weighted OLS)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Shortfall/RWA	−2.57***	−1.56**	−2.20***	−1.76***	−1.86***	−2.14***	−1.62**
	(0.59)	(0.65)	(0.66)	(0.64)	(0.65)	(0.73)	(0.78)
Stressed		−0.05***		−0.03			
		(0.01)		(0.02)			
Unemployment			−0.20		0.03	0.02	
			(0.14)		(0.14)	(0.12)	
Liquid Assets/Assets				0.04	0.04	0.06	
				(0.06)	(0.06)	(0.07)	
Deposits/Assets				0.08*	0.09**	0.09**	0.05
				(0.04)	(0.04)	(0.04)	(0.03)
Loans/Assets				−0.01	−0.02	−0.02	
				(0.06)	(0.06)	(0.06)	
Sov. Bonds/Assets				0.45***	0.49***	0.51***	0.31***
				(0.12)	(0.12)	(0.12)	(0.11)
Dom. Sov. Bonds/ Assets * Stressed Country				−0.31	−0.71***	−0.67***	−0.20
				(0.30)	(0.23)	(0.24)	(0.30)
Surplus/RWA						0.10	
						(0.37)	
July '11 ST Fringe						−0.04*	
						(0.02)	
Country FEs	No	No	No	No	No	No	Yes
N	124	124	124	124	124	124	124
R^2	0.21	0.31	0.23	0.41	0.40	0.42	0.52

Notes: This table presents the results of weighted OLS regressions at the level of individual banks, where the dependent variable is the annualized rate of growth of loans to customers over the nine-month period of the capital exercise, from September 2011 to June 2012. Individual bank observations are weighted according to the bank's outstanding amounts of customer loans. *Shortfall/RWA* is the consolidated capital shortfall, truncated at zero, as measured by the EBA at the banking-group level in September 2011. *Unemployment* is the rate of unemployment in the country of location in September 2011. *Stressed* is a dummy variable indicating whether the bank is located in a country under financial stress in 2011–12 (GIIPS countries, plus Cyprus and Slovenia). All other bank controls are measured at the unconsolidated level of the individual banking institutions at end-September 2011. Definitions are detailed in table 13 in the appendix. *Surplus/RWA* is the consolidated capital surplus, truncated at zero. *July '11 ST Fringe* is a dummy variable which takes the value of one if the bank belongs to one of the seven banking groups that nearly failed the July 2011 EBA stress tests (with a CT1 ratio under stress between 5 and 6 percent). Column 7 replaces the country control measures with country fixed effects, while only retaining the bank characteristics that were statistically significant in columns 4–6. A constant is included but not shown. Standard errors (in parentheses) are clustered at the level of banking groups. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

countries.[28] The results of these regressions are shown in table 11 and indicate that our results are robust to correlation among banks in groups. However, while the coefficient on our *Shortfall-to-RWA* variable remains significant, its magnitude decreases somewhat.

6. Looking for Aggregate Effects

The results presented in section 4 indicate that the increase in regulatory capital requirements as part of the EBA's capital exercise led to lower rates of loan growth during the period of the exercise for banks identified as having a capital shortfall. It is possible, however, that this reduced rate of loan growth by shortfall banks was compensated for by other banks, resulting in little or no impact on overall loan growth at the country or euro-area level. We investigate this hypothesis by collapsing our data set at the country level and constructing the variable *Weighted Shortfall-to-RWA*, which is equal to the weighted average of banks' shortfall-to-RWA ratios (weighted by the size of banks' loan books) during the period of the capital exercise and zero otherwise. We compute credit growth rates as the country equivalent of the "clean" growth rates we computed for individual banks present in a given country.[29]

The results of this analysis are presented in table 12. Column 1 is a simple regression of monthly growth rates of credit at the country level on the weighted shortfall to RWA and lagged unemployment. Column 2 adds (lagged) aggregated bank characteristics (at the country level), while column 3 adds a lag of the dependent

[28] It is important to note our data set does not allow us to recreate consolidated group balance sheets by aggregating constituent banks' balance sheets. This is due to the fact that the IBSI data set does not necessarily contain data for all banks in a banking group.

[29] More precisely, we sum clean loan flows over all banks in a country and divide by the sum of all loan stocks to get clean monthly growth rates at the country level. An alternative could be to look at aggregate growth rates of domestic credit to the non-financial private sector from country-level monetary statistics releases. As banks in our sample form the bulk of credit in most countries, the results would be qualitatively unchanged.

Table 11. Impact of EBA Capital Exercise on Lending Growth: Oct. 2011–June 2012 (group averages)

	(1)	(2)	(3)
Shortfall/RWA	−1.21***	−0.70*	−0.71*
	(0.42)	(0.40)	(0.38)
Exposure to Stressed Countries		−0.04***	−0.02
		(0.01)	(0.01)
Size			−0.00
			(0.01)
Liquid Assets/Assets			0.05
			(0.09)
Deposits/Assets			0.11**
			(0.05)
Loans/Assets			−0.12*
			(0.07)
Sovereign Bonds/Assets			−0.02
			(0.15)
July '11 ST Fringe			0.01
			(0.02)
EBA Banking Group			−0.01
			(0.01)
N	118	118	118
R^2	0.05	0.14	0.29

Notes: This table presents the results of OLS regressions at the level of banking groups, where the dependent variable is the annualized rate of growth of loans to customers over the nine-month period of the capital exercise, from September 2011 to June 2012. Individual bank observations have been averaged at the banking-group level. *Shortfall/RWA* is the consolidated capital shortfall, truncated at zero, as measured by the EBA at the banking-group level in September 2011. *Exposure to Stressed Countries* is the proportion of groups' lending activity in euro-area countries under financial stress in 2011–12 (GIIPS countries, plus Cyprus and Slovenia). All other bank controls are measured at the unconsolidated level of the individual banking institutions at end-September 2011. Definitions are detailed in table 13 in the appendix. *July '11 ST Fringe* is a dummy variable which takes the value of one if the group nearly failed the July 2011 EBA stress tests (with a CT1 ratio under stress between 5 and 6 percent). *EBA Banking Group* is a dummy variable which takes the value of one if the group is monitored by the EBA. A constant is included but not shown. Robust standard errors are in parentheses. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

Table 12. Impact of Shortfall Banks on Country-Level Loan Growth: Jan. 2010–Dec. 2012

	(1)	(2)	(3)
Weighted Shortfall/RWA	−1.04**	−1.30***	−1.47***
	(0.46)	(0.33)	(0.33)
Unemployment	−1.08**	−0.68*	−0.83*
	(0.37)	(0.36)	(0.41)
Size		−0.02	−0.01
		(0.08)	(0.08)
Liquid Assets/Assets		0.19	0.22
		(0.15)	(0.14)
Deposits/Assets		0.85**	0.86*
		(0.40)	(0.42)
Loans/Assets		−0.58**	−0.55*
		(0.27)	(0.29)
For. Sov. Bonds/Assets		0.58	0.66
		(0.67)	(0.71)
Dom. Sov. Bonds/Assets		−0.67	−0.67
		(0.69)	(0.75)
Lagged Dep. Var.			−0.12*
			(0.06)
Country FEs	Yes	Yes	Yes
Date FEs	Yes	Yes	Yes
N	548	548	548
R^2	0.39	0.42	0.43

Notes: This table presents the results of country-level OLS regressions, where the aggregate annualized one-month loan growth is the dependent variable. *Weighted Shortfall/RWA* is the average shortfall to RWA of the group of each individual bank resident in the country weighted by the size of the banks' outstanding customer loans. *Unemployment* is the rate of unemployment in the country of location, lagged by one month. Individual bank balance sheet items have been summed at the level of the country of residence, and balance sheet ratios are computed using these collapsed bank data. All these bank balance sheet controls are lagged by one month. A constant is included but not shown. Robust standard errors are in parentheses. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

variable.[30] All three specifications use country and time fixed effects, while standard errors are clustered at the banking-group level as a straightforward way to correct for possible correlation (including autocorrelation in the time dimension) between observations in the same country. The coefficients for the variable *Weighted Shortfall-to-RWA* are significant across all three specifications and are also of a similar magnitude as at the micro level, indicating that the capital exercise did indeed have a negative impact on country-level lending growth over the horizon of the exercise.

7. Conclusions

We use the EBA's recapitalization exercise of 2011–12 as a quasi-natural experiment to test the impact of a regulatory shock tightening bank capital requirements on lending to the real economy. For this purpose, we exploit a new data set of monthly balance sheets of some 250 individual banks (representative of credit provision at both the euro area and member states' levels) and map it onto data for the banking groups monitored by the EBA. Controlling for individual bank characteristics and demand at the level of country of residence, we find that forcing a banking group to increase its core tier 1 capital by 1 percent of risk-weighted assets was associated with a decrease of 1.2 percentage points (annualized) in credit supplied by banks in the same group over the nine-month period of the capital exercise. We also collapse our data set at the country level in order to assess aggregate effects and find that banks that were not constrained to recapitalize did not substitute for more constrained lenders. This confirms that the capital exercise had procyclical macroeconomic effects on credit supply. At the same time, the magnitude of the effects that we find are at the lower range of the effects of regulatory capital shocks on credit supply found in the empirical literature. This may be accounted for by the expansionary measures implemented by the Eurosystem over the same period of time. Also, this may suggest that moral suasion by supervisors and governments

[30]The presence of both lagged dependent variables and fixed effects causes a well-known bias in the coefficient of the lagged dependent variable. However, since we include more than thirty monthly observations and as our sample of countries is small, standard fixed effects remains preferable to generalized method of moments (GMM). Besides, preliminary checks showed that monthly credit growth rates are barely autocorrelated at the country level (with correlation coefficients between 0 and 0.3). Cf. Judson and Owen (1999) for a formal justification.

was indeed instrumental in convincing major banking groups with a capital shortfall to limit their shedding of risk-weighted assets.

Two words of caution are nevertheless of the essence when interpreting these results. First, we emphasize that our study only documents the *short-run* contractionary effect of an *unexpected* tightening of capital requirements on bank lending. Second, we confirm that the EBA capital exercise was badly timed and therefore procyclical, as it took place in a context of depressed activity and declining lending trends. However, our findings should not be interpreted as pointing to permanent contractionary effects of heightened capital requirements or as suggesting that even short-run effects would be as large if the tightening was imposed during more benign times. At the same time, our findings tend to strengthen the case for a gradual implementation of stricter bank regulations, thus allowing banks to meet heightened capital ratios mostly by the accumulation of retained earnings. Lastly, comparing the EBA exercise to the Supervisory Capital Assessment Program (SCAP) of the U.S. Federal Reserve in 2009 (as a result of the stress tests), we can also view our results as highlighting the potential benefits of bank recapitalization programs that are targeted at capital levels (or in "euros") rather than at capital ratios, especially when this equity adjustment has to happen in crisis times.[31]

Last but not least, our study sheds some useful light on decisions facing the ECB in its new role as the euro area's Single Supervisory Mechanism (SSM). Indeed, demanding that banks hold capital against their sovereign assets, as outlined recently by the new head of the SSM, amounts to a regulatory tightening that is very similar to the EBA exercise. To the extent that these new capital weights lead to capital requirements in excess of the capital buffer already held by banks, and supposing that monetary policy remains as accommodative as it currently is, our estimates could provide an upper bound of the expected short-run negative effects on credit supply in the euro zone.

[31]The case for recapitalization objectives targeted at "dollars" of capital instead of capital ratios is made by Hanson, Kashyap, and Stein (2011). They notably point out that in the few months following the release of the SCAP results, the banks involved were able to raise over $125 billion of new equity, without apparent negative impact on credit supply. As they emphasize, the tough hand of the regulator, which left no room for discretionary action, made this issuance easier for banks by removing the usual moral hazard problem à la Myers and Majluf (1984).

Appendix. Data

Table 13. Definition and Sources of Bank Variables

Statistic	Description
Size	Total assets of banks (in euros). These figures are converted to logs when used in our regression analysis.
Annualized Loan Growth (Recap. Period)	Annualized nine-month loan growth over the period of the capital exercise (Oct. 2011 to June 2012).
Loans to Assets	Total loans to the real economy (sum of loans to households and loans to non-financial corporates) divided by total assets.
Capital to Assets	Capital divided by total assets. The capital figure in the IBSI data set is a broad measure of banks' capital, including equity capital raised, undistributed profits, and provision against loans and other types of assets.
Liquid Assets	Interbank assets divided by total assets. Interbank assets include liquidity deposited with the Eurosystem.
Deposits to Assets	Real-economy deposits (sum of deposits from households and deposits from non-financial corporates) divided by total assets.
Interbank Liabilities to Assets	Borrowings from other banks (interbank loans) divided by total assets. Interbank loans include borrowing from the Eurosystem.
Deposits to Loans	Total deposits from the real economy (sum of deposits from households and deposits from non-financial corporates) divided by total loans to the real economy (sum of loans to households and loans to non-financial corporates). We report the inverse of the more commonly used loans-to-deposits ratio due to the presence of non-deposit-taking banks in our sample.
Sovereign Bonds to Assets	Sum of domestic and foreign sovereign bond holdings divided by total assets.

Table 14. List of Banking Groups in Sample

Nationality	Head ID Code	EBA ID Code	Bank Group Name	No. Banks
AT	AT14000		BAWAG P.S.K. Bank für Arbeit und Wirtschaft und Österreichische Postsparkasse Aktiengesellschaft	1
AT	AT15000		Oberbank AG	1
AT	AT20100	AT001	Erste Group Bank (EGB)	3
AT	AT31000	AT002	Raiffeisen Zantralbank Österreich (RZB)	2
AT	AT32000		Raiffeisenlandesbank Niederoesterreich-Wien AG	1
AT	AT34000		Raiffeisenlandesbank Oberösterreich Aktiengesellschaft	1
BE	BEARSPBE22		N.V. Argenta Spaarbank	1
BE	BEARTEBEBB		Belfius Banque SA	1
BE	BEKREDBEBB	BE005	KBC BANK	2
CY	CY110002	CY007	Bank of Cyprus Public Company Ltd	1
CY	CY110003		Co-operative Central Bank Ltd (CY110003) and Co-operative Credit Institutions [aggregated]	1
CY	CY110005		Hellenic Bank Public Company Ltd	1
CY	CY 110010	CY006	Marfin Popular Bank Public Co Ltd	1
DE	DE00001	DE017	Deutsche Bank Aktiengesellschaft	7
DE	DE00003	DE018	Commerzbank AG	3
DE	DE00091		Oldenburgische Landesbank Aktiengesellschaft	1
DE	DE00316	DE019	Landesbank Baden-Wuerttemberg	1
DE	DE00317	DE021	Bayerische Landesbank	2
DE	DE00319	DE026	Landesbank Hessen-Thüringen Girozentrale	2
DE	DE00320	DE022	Norddeutsche Landesbank-Girozentrale	3
DE	DE00325		Nassauische Sparkasse	1
DE	DE00561		Stadtsparkasse Muenchen	1
DE	DE00637	DE027	Landesbank Berlin AG	2
DE	DE00724		Sparkasse Hannover	1
DE	DE00835		Stadtsparkasse Essen	1
DE	DE00897		Sparkasse KölnBonn	2

(continued)

Table 14. (Continued)

Nationality	Head ID Code	EBA ID Code	Bank Group Name	No. Banks
DE	DE01094		Sparkasse Suedholstein	1
DE	DE01108		Die Sparkasse Bremen AG	1
DE	DE01109		Hamburger Sparkasse AG	1
DE	DE01121	DE020	DZ Bank AG Dt. Zentral-Genossenschaftsbank	3
DE	DE01127	DE029	WGZ Bank AG Westdt. Geno. Zentralbk, Ddf	2
DE	DE01135		Deutsche Apotheker- und Ärztebank eG	1
DE	DE01244		Volksbank Pforzheim eG	1
DE	DE01291		Volksbank Stuttgart eG	1
DE	DE01364		Muenchner Bank eG	1
DE	DE01400		Berliner Volksbank eG	1
DE	DE01436		Frankfurter Volksbank eG	1
DE	DE01521		Hannoversche Volksbank eG	1
DE	DE01776		Sparda-Bank Suedwest eG	1
DE	DE03249		Deutsche Pfandbriefbank AG	1
DE	DE03250		Muenchener Hypothekenbank eG	1
DE	DE03402		Volkswagen Bank Gesellschaft mit beschränkter Haftung	1
DE	DE03472		Aareal Bank AG	1
DE	DE05695		Landeskreditbank Baden-Wuerttemberg – Foerderbank	1
DE	DE05740		NRW. Bank	1
DE	DE05749	DE025	HSH Nordbank AG	1
DE	DE06261		Ostsaechsische Sparkasse Dresden	1
DE	DE06273		Stadt- und Kreissparkasse Leipzig	1
DK	DK003000	DK008	Danske Bank	4
ES	ES0049	ES059	Banco Santander S.A.	6
ES	ES0075	ES064	Banco Popular Español, S.A.	1
ES	ES0081		Banco de Sabadell, S.A.	1
ES	ES0128		Bankinter, S.A.	1
ES	ES0182	ES060	Banco Bilbao Vizcaya Argentaria, S.A.	1

(continued)

Table 14. (Continued)

Nationality	Head ID Code	EBA ID Code	Bank Group Name	No. Banks
ES	ES1000		Instituto de Crédito Oficial	1
ES	ES2048		Liberbank, S.A.	1
ES	ES2085		Ibercaja Banco, S.A.	1
ES	ES2095		Kutxabank, S.A.	1
ES	ES2100		CaixaBank, S.A.	1
ES	ES2103		Unicaja Banco, S.A.	1
ES	ES2108		Banco de Caja España de Inversiones, Salamanca y Soria SA	1
ES	ES3058		Cajas Rurales Unidas	1
ES	frob		FROB	4
FI	FI01999207	FI012	OP-Pohjola Group	2
FI	FI21817028		Aktia Bank Abp (FI21817028) and Savings Banks [aggregated]	1
FR	FR10278		Targobank AG & Co. KGaA	1
FR	FR11808		Banque Fédérative du Crédit Mutuel	3
FR	FR12548		AXA Bank Europe SA	1
FR	FR16188	FR015	BPCE	10
FR	FR19460		Sofax banque	1
FR	FR20041		La Banque Postale	1
FR	FR30003	FR016	Societe Generale	4
FR	FR30004	FR013	BNP Paribas	5
FR	FR30006	FR014	Credit Agricole	6
GB	GB0570	GB090	Barclays plc	4
GB	GB1805	GB089	HSBC Holdings plc	2
GB	GB2600	GB088	Royal Bank of Scotland Group plc	2
IE	IEAIBPLC	IE037	Allied Irish Banks PLC	1
IE	IEANGLOI		Irish Bank Resolution Corporation Limited	1
IE	IEBKIREL	IE038	The Governor and Company of the Bank of Ireland	2
IE	IEIRPERM	IE039	Irish Life and Permanent PLC	1
IT	IT01030	IT042	Banca Monte dei Paschi di Siena Spa	2
IT	IT02008	IT041	Unicredit Banca Spa	4

(continued)

Table 14. (Continued)

Nationality	Head ID Code	EBA ID Code	Bank Group Name	No. Banks
IT	IT03032		Credito Emiliano Spa	1
IT	IT03069	IT040	Intesa Sanpaolo Spa	4
IT	IT03111	IT044	Unione di Banche Italiane SCPA (UBI Banca)	2
IT	IT05035		Veneto Banca Holding Società Cooperativa per Azioni	1
IT	IT05387		Banca Popolare dell'Emilia Romagna	1
IT	IT05584		Banca Popolare di Milano	1
IT	IT05696		Banca Popolare di Sondrio Societa Cooperativa per Azioni	1
IT	IT05728		Banca Popolare di Vicenza Societa Cooperativa per Azioni	1
IT	IT06055		Banca delle Marche Spa	1
IT	IT06175		Banca Carige Spa – Cassa di Risparmio di Genova e Imperia	1
IT	IT10631		Mediobanca – Banca di Credito Finanziario Spa	1
LU	LUB00001	LU045	Banque et Caisse d'Epargne de l'Etat, Luxembourg	1
LU	LUB00009		Banque Raiffeisen	1
MT	MTCIAPSB		APS Bank Ltd	1
MT	MTCILBMA		Lombard Bank Malta plc	1
MT	MTCIVALL	MT046	Bank of Valletta plc	1
NL	NL120		F. van Lanschot Bankiers N.V.	1
NL	NL149	NL049	ABN Amro Bank N.V.	1
NL	NL163	NL047	ING Bank NV	6
NL	NL399		Achmea Bank Holding N.V.	1
NL	NL512		The Bank of Tokyo – Mitsubishi UFJ Ltd	1
NL	NL578	NL050	SNS Bank N.V.	1
NL	NL600	NL048	Rabobank Nederland	4
NL	NL680		Bank Nederlandse Gemeenten N.V.	1

(continued)

Table 14. (Continued)

Nationality	Head ID Code	EBA ID Code	Bank Group Name	No. Banks
PT	PT10	PT056	Banco BPI, SA	1
PT	PT33	PT054	Banco Comercial Português, SA	1
PT	PT35	PT053	Caixa Geral de Depósitos, SA	1
PT	PT7	PT055	Banco Espírito Santo, SA	1
SE	SE11102	SE085	Skandinaviska Enskilda Banken AB (publ) (SEB)	2
SE	SE11123	SE086	Svenska Handelsbanken AB (publ)	1
SE	SE11145	SE084	Nordea Bank AB (publ)	2
SE	SE11200	SE087	Swedbank AB (publ)	1
SI	SI5026024		AbankaVipa D.D.	1
SI	SI5860571	SI057	Nova Ljubljanska Banka D.D., Ljubljana	1
SI	SI5860580	SI058	Nova Kreditna Banka Maribor D.D.	1

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Discussion of "Did the EBA Capital Exercise Cause a Credit Crunch in the Euro Area?"*

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1. Introduction

The impact of capital regulation on bank lending is an area of permanent interest for academics, industry commentators, and regulators. New changes in capital regulation and continued macroprudential efforts to regulate banks across the globe following the 2007–9 financial crisis have spurred a wave of research into the effects of changes in regulatory capital on bank lending. Since banks play a central role in the economy by facilitating business through financial intermediation, it is important that they remain well capitalized enough to continue lending and operating as viable institutions during a crisis. Regulators then use minimum capital requirements to reduce banks' excessive risk taking and to ensure the solvency of the banking sector, in an effort to avoid the negative externalities caused by bank failures and the costs to the economy of their financial collapse.

There is, however, a trade-off between the need for enhanced capital regulation and the potentially detrimental effects on the real side of the economy caused by excessive regulation. These effects, of course, could lead to restricted credit availability and thus could impose unnecessary costs on economic activity. Finding the precise balance between the benefits and the costs of new capital regulation is therefore essential, which is why academics and regulators must seek to better understand the magnitude of the impact of regulatory changes, and their implications for bank lending in anticipation of those changes.

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The empirical literature on the effects of regulatory capital on bank credit supply has found that changes in minimum capital requirements reduce bank lending.[1] Work in this literature usually faces some identification challenges, such as separating how much of the change in bank credit is demand or supply driven or identifying the extent to which a lending contraction is indeed caused by changes in capital regulation. For example, regulatory changes could be announced well in advance, giving banks enough time to preemptively respond to the new regulation. The paper by Jean-Stéphane Mésonnier and Allen Monks (this issue) contributes to our understanding of the relationship between capital requirements and the lending behavior of large banks in Europe by analyzing the banks that were subject to the capital exercise implemented by the European Banking Authority (EBA) in 2011.

Unlike previous stress tests, the EBA capital exercise was a one-off exercise aimed at restoring confidence in the European banking sector. The capital exercise was announced in October 2011 and required banks to raise their core tier 1 capital ratio to 9 percent by June 2012. The capital exercise was implemented in the context of adverse developments in European capital markets, brought about by the sovereign debt crisis. The novelty in the EBA capital exercise was the explicit account of a capital buffer against bank exposures to sovereign debt. Furthermore, the capital exercise came as a somewhat remedial action following the EBA stress test in July 2011. This stress test was widely criticized in Europe because it did not account for sovereign debt exposures and because it gave passing marks to some large banks that, a few months later, failed or had to be recapitalized (for example, the Dexia Group). The EBA capital exercise was thus aimed at restoring investor confidence and reassuring markets that banks had enough capital to withstand the financial storm associated with the sovereign debt crisis.

The paper by Mésonnier and Monks is both interesting and timely. The authors exploit monthly balance sheet data for about 250 banks from the Eurosystem. These banks belong to about sixty of the largest banking groups that were subject to the EBA capital

[1] See, for example, Brinkmann and Horvitz (1995), Peek and Rosengren (1995, 1997), Gambacorta and Mistrulli (2004), and more recently, Aiyar, Calomiris, and Wieladek (2014).

exercise. The paper provides empirical evidence of a contractionary effect associated with the tightening of regulatory capital ratios in the EBA exercise. In particular, the paper finds that an increase in the tier 1 capital by 1 percent of risk-weighted assets is associated with a 1.1 percent decrease in bank lending. This result is consistent with previous findings for banks in other latitudes.[2] More importantly, the paper's results suggest a short-term response of bank loan supply to changes in regulatory capital ratios. As mandated by the EBA capital exercise, banks had a short time span—about nine months—to increase their capital positions and fulfill the requirement.

In this discussion, I raise some confounding factors in the explanation of bank lending. Some of these have been already addressed by the authors and some others may be potential avenues for future research. For example, the revised paper addresses an important issue with this type of analysis, which is whether the capital exercise was indeed exogenous and truly unanticipated. I also emphasize other factors affecting the supply of bank credit, such as the role of bank lending standards and the potentially mitigating effects of the liquidity provision by the European Central Bank (ECB), that would need to be accounted for to ensure that the impact of the capital exercise is indeed accurately measured.

2. The Effect of the EBA Capital Exercise on Bank Lending

2.1 Anticipated or Unexpected Change?

One possible explanation for the contraction seen in European bank lending is that it merely reflected preemptive actions by the banks to adjust their balance sheets before the exercise was implemented. This is a salient concern because immediately after the results of the July 2011 stress tests were released, the EBA explicitly recommended that national supervisory authorities in participating

[2]See, for example, Francis and Osborne (2009) for UK banks and Berrospide and Edge (2010) for U.S. large bank holding companies. These papers find a positive impact of capital on loan growth, indicating that banks with surplus capital tend to lend more. The implication of this result is that raising capital requirements relative to existing capital ratios would lower lending, all else equal.

countries take remedial actions (i.e., to increase capital) regarding banks with core tier 1 capital ratios below 5 percent and with significant sovereign debt exposures. Thus, it is possible that by October 2011, four months later, some of these banks might have taken the necessary steps to reduce their exposures by increasing their capital positions or cutting their lending.

Moreover, the press release that followed the publication of the capital exercise results in October 2012 stated that "in line with the recommendation, capital strengthening had not led directly to a significant reduction in lending into the real economy. A deleveraging process had already started before the capital exercise and will need to continue in an orderly fashion to ensure long term repair of banks' balance sheets" (EBA 2012). This statement again suggests that the credit supply reduction started before the capital exercise. Thus, the extent to which the loan contraction identified in the paper is the result of the remedial actions would make the authors erroneously attribute the loan contraction to the increased capital requirements mandated by the capital exercise.

One way to address this concern is to link the information on bank capital from previous stress tests to the capital exercise results. The capital exercise used almost the same banks that were subject to the stress test in July 2011; of the ninety banking groups involved in the July stress tests, about sixty of them were subject to the capital exercise. In the revised paper, the authors followed this approach and identified the banks with capital shortfalls in the July stress-test exercise (e.g., banks with core tier 1 capital below 5 percent under stress scenarios) or with capital positions above but close to the minimum capital requirement. The authors then verified that these banks, either having or close to having a preexisting capital shortfall, maintained capital shortfalls by the time the October capital exercise was conducted. Finding that banks that participated in the stress test maintained their capital positions at the beginning of the capital exercise is favorable evidence that the exercise was in fact unanticipated, which further bolsters the paper's findings.

2.2 Other Explaining Factors

Another possible factor that could explain the lending contraction identified in the paper is the tightening of bank lending standards.

To control for this possibility, the authors could have used data from the quarterly ECB Bank Lending Survey, which covers 124 banks in the euro area.[3] For example, the January 2012 Bank Lending Survey shows a significant tightening of lending standards (from 16 percent to 35 percent for loans to non-financial corporations) during the fourth quarter of 2011, precisely when the capital exercise was undertaken. Furthermore, since the results of the Bank Lending Survey are available by country, it would have been possible to include an explicit measure of lending standards in the country-level loan growth regressions.

Mésonnier and Monks acknowledge a potential mitigating factor: the fact that the ECB liquidity injections before and during the period they analyze may have reduced the deleveraging pressures experienced by banks. More specifically, the authors refer to the potential mitigation effect of the two three-year long-term refinancing operations (LTROs) conducted in December 2011 and in February 2012 for a total of about EUR 1 trillion.

Although there is no publicly available information on the liquidity injections received by individual banks, there is information at the country level (e.g., see van Rixtel and Gasperini 2013). Therefore, one way to account for the mitigation of the LTROs would have been to use country-level data of the uptake of ECB liquidity injections by country, and then to examine whether the countries that received the liquidity support were also those with banking sectors experiencing the largest capital shortfalls. This would have added support to the idea that liquidity injections moderated the impact of the capital exercise. Table 1 shows that this could indeed have been the case. The global and sovereign debt crisis in Europe increased the dependence of banking sectors on central bank liquidity, particularly in Spain and Italy, which had banks with the largest capital shortfalls at the time of the capital exercise.

Finally, potential future work in this area may exploit the multinational nature of the capital exercise in order to measure the impact

[3]See, for example, Ciccarelli, Maddaloni, and Peydró (2013), who use the euro-area Bank Lending Survey at the country level to identify the transmission of monetary policy shocks through the credit channel. These authors identify different transmission channels by looking at detailed information from the survey, such as bank lending conditions and borrowers' creditworthiness and net worth.

Table 1. Capital Shortfall and the ECB's Liquidity Provision by Country

Country	Number of Banks	Overall Capital Shortfall Euros (billion)	ECB LTRO Amounts Euros (billion)[a]
Austria	2	3	0
Belgium	1	0	40
Cyprus	2	4	0
Denmark	4	0	0
Finland	1	0	0
France	4	7	173
Germany	12	13	74
Hungary	1	0	0
Ireland	3	0	67
Italy	5	15	273
Luxembourg	1	0	0
Malta	1	0	0
Netherlands	4	0	0
Norway	1	2	0
Poland	1	0	0
Portugal	4	7	51
Slovenia	2	0	0
Spain	4	25	329
Sweden	4	0	0
United Kingdom	4	0	0
Total	61	75	1,007

Source: EBA website, EU capital exercise, available at http://www.eba.europa.eu/risk-analysis-and-data/eu-capital-exercise. [a]Taken from van Rixtel and Gasperini (2013).

of the tightening of capital regulation on cross-border lending. It may be interesting to try to identify the cross-country spillover effects of capital shocks, such as the capital exercise, along the lines of the work in the literature on the international transmission of global shocks (e.g., Cetorelli and Goldberg 2012). Another potential avenue for further research would be to study whether European banking groups are a source of strength or weakness for foreign affiliates in the face of regulatory capital shocks, along the lines of the capital integration and multi-national banking literature (e.g., De Haas and van Lelyveld 2010).

3. Concluding Remarks

The paper by Mésonnier and Monks (this issue) addresses an interesting and timely topic. Consistent with previous work on the impact of bank capital on lending, the paper provides empirical support for a contractionary effect on bank lending resulting from the tightening of regulatory capital ratios mandated by the EBA capital exercise. More importantly, the paper identifies a short-term response of loan supply to changes in capital regulation and finds this response in a very difficult environment. At the time when the capital exercise was undertaken, the euro area was shaken by market disruptions brought on by the sovereign debt crisis.

As key discussion points, I highlighted the need for the empirical analysis to provide evidence that the capital exercise was indeed unanticipated and recommended using bank data on previous stress tests for that purpose. I also suggested other loan supply determinants, such as the role of bank lending standards and the effects of the ECB liquidity provision, that would need to be accounted for in assessing the effects of the EBA capital exercise on bank lending.

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The Road to Financial Stability: Capital Regulation, Liquidity Regulation, and Resolution*

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Prior to the 2007–9 financial crisis, regulations addressing risk taking in the financial system were woefully inadequate. In this essay, I summarize the regulatory changes implemented over the past five years and come to three conclusions. First, as a result of the new Basel III standards, the global financial system is now substantially safer than it was, but probably not yet safe enough. Second, the costs of increasing capital requirements have been much smaller than we originally thought. And third, we are best advised to shy away from time-varying discretionary regulatory policies.

JEL Codes: E58, G28.

1. Introduction

We can think of the financial system as having two distinct, but related, parts: institutions that do screening and monitoring, and have balance sheets; and markets where prices are determined and resources are allocated through trading. Both are essential for the smooth and efficient operation of the system. And, for the system to remain stable and support strong, stable, and balanced growth, we need resilient institutions and resilient markets. That is, both must be designed to withstand substantial stress and continue to operate. I will leave the discussion of market resilience for another day. Here,

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I will take the lead from the papers in this issue and discuss what it is that we need to ensure resilience of institutions.

As is always the case with any economic analysis of regulation, the first step is to identify the externality that the regulation is designed to address. In the case of financial institutions, this is relatively straightforward. As a consequence of limited liability and government guarantees (both explicit and implicit), banks engage in too much credit transformation, too much liquidity transformation, and too much maturity transformation. That is, they hold assets that are too risky, too illiquid, and too long term relative to what would be socially optimal. And the reason is that when banks are under stress, and especially when they fail and even when they are illiquid, it damages other parts of the financial system.

Banking regulation is designed to control this risk taking, reducing the spillovers that come from the failure of an individual institution. Capital requirements are designed to address the externality associated with the incentive to engage in too much credit and maturity transformation. The bulk of my comments will be about this aspect of financial regulation—the level of capital requirements, the possibility of making them time varying, and the transitional macroeconomic impact of increases. But first, a few words about liquidity requirements and resolution.

2. Liquidity Requirements

Their ability to tap the central bank as a source of liquidity, as a lender of first resort when the system is under stress, leads commercial banks to issue too many short-term, liquid liabilities to fund long-term, illiquid assets. The liquidity requirements embodied in Basel III are designed to constrain both of these. The first, the liquidity coverage ratio (LCR), is intended to limit liquidity transformation, while the second, the net stable funding ratio (NSFR), is aimed at controlling the level of maturity transformation. I will briefly describe each of these.

To help understand the LCR, it is useful to quote from the agreed international standard itself:[1]

[1]See Basel Committee on Banking Supervision (2013).

> The objective of the LCR is to promote the short-term resilience of the liquidity risk profile of banks. It does this by ensuring that banks have an adequate stock of unencumbered[2] high-quality liquid assets (HQLA) that can be converted easily and immediately in private markets into cash to meet their liquidity needs for a 30 calendar day liquidity stress scenario. The LCR will improve the banking sector's ability to absorb shocks arising from financial and economic stress, whatever the source, thus reducing the risk of spillover from the financial sector to the real economy.

Reading this, we can see that the idea behind the LCR is to compel banks to hold an amount of liquid assets (like U.S. Treasury securities) that can be easily sold to meet deposit outflows and the takedown of loan commitments that might occur during a crisis. The goal is to ensure that banks can meet their obligations without relying on fire sales of their assets—something that has a negative impact on everyone else—or on borrowing from the central bank.

It would take too long (and be too tedious) to describe the details of the implementation of the LCR. Suffice it to say that the definition of what constitutes a high-quality liquid asset is complex, as is the computation of "liquidity needs for a 30 calendar day liquidity stress scenario." But in the end, the idea is to constrain the degree to which banks can use liquid liabilities to finance illiquid assets.[3]

Turning to the NSFR, again I quote from the rules text:[4]

> The NSFR will require banks to maintain a stable funding profile in relation to the composition of their assets and off-balance sheet activities. A sustainable funding structure is intended to reduce the likelihood that disruptions to a bank's regular sources of funding will erode its liquidity position in a way that would increase the risk of its failure and potentially lead to broader systemic stress. The NSFR limits overreliance on short-term wholesale funding, encourages better assessment of

[2] The term "unencumbered" means that the assets have not been pledged as collateral for a loan.

[3] For a discussion of the economics of liquidity regulation, especially its relationship to central bank lending, see Stein (2013).

[4] See Basel Committee on Banking Supervision (2014).

funding risk across all on- and off-balance sheet items, and promotes funding stability.

The purpose of the NSFR is to limit the extent of this maturity mismatch, requiring banks with long-term assets to have long-term liabilities, and only allowing those with short-term assets to issue short-term liabilities. Again, the details of the computation are complex, but the idea is fairly simple: banks should not do what they did prior to the crisis, which was to rely on short-term interbank or repo funding to support large volumes of long-maturity securities.

3. Resolution[5]

In a market-based financial system, the right to succeed is the right to fail. The orderly entry and exit of firms, combined with an appropriate relationship between risk and return, means that risk takers that stand to profit also stand to lose. And what's true for restaurants or technology companies must be true for banks. None can threaten the entire economic or financial system if they go out of business.

We remain a long way from achieving a sound global cross-border resolution regime. However, a number of jurisdictions are implementing national reforms that enhance their resolution powers. This process has been facilitated by the Financial Stability Board's (2011) release of the *Key Attributes of Effective Resolution Regimes for Financial Institutions*, which sets out new international standards for the resolution of distressed financial institutions. These measures are complementary to, not substitutes for, higher loss absorption capacity.

In the end, I believe that the solution to the very real problem posed by our inability to resolve large global financial institutions can only be met with plans for automatic (or rules-driven administrator-assisted) recapitalization in bad times—what Kim Schoenholtz and I have called a *phoenix plan*. In such an arrangement, the capital structure of a bank's long-term liabilities must be clearly stated and strictly honored. That is, think of the bank as having a hierarchy of long-term debt ranging from the most senior

[5]This section is based in part on Cecchetti and Schoenholtz (2014b).

(call it tranche A) to the most subordinated (tranche Z for zombie!). Whenever a bank's capital position is deficient—defined in an objective, widely observable fashion (say, on the basis of market equity prices)—the resolution authority automatically converts debt into equity, starting with the Z tranche and then climbing up the alphabet until there is sufficient capital to return the bank to the regulatory minimum. Provided that there is sufficient long-term debt to absorb the losses, the concern remains a going one. [The resolution authority also would be required to replace management and shut down risky activities in an effort to prevent a serial failure.]

Safeguarding the financial system will still require rules and enforcement. Above all, each systemic intermediary must issue an adequate supply of long-term debt in good times to absorb its potential losses in bad times. Were it instead to issue short-term debt, the intermediary would be vulnerable to a run. In addition, rules must prevent other leveraged intermediaries from owning this systemically risky long-term debt, which is a close substitute for equity capital. Otherwise, losses incurred by the holders of the converted debt can transmit one intermediary's insolvency to the broader financial system.

4. Capital Regulation

Turning to capital regulation, I organize the remainder of my discussion around three questions:

(i) What is the right steady-state level of capital?
(ii) How should we think about the move to implement discretionary, time-varying capital requirements?
(iii) Once we decide on a level of required capital, how should it be implemented?

4.1 The Level of Capital

Starting with the basics, capital requirements are stated as a minimum ratio of capital to risk-weighted assets. Changes to these can influence the numerator (the definition of capital), the denominator (the computation of risk-weighted assets), or the ratio itself. Basel III made three changes: it changes the computation of the

Table 1. Comparing Basel III and Basel II Capital Requirements (Share of Risk-Weighted Assets) for the Largest Systemic Banks: Impact of Basel III Capital Definition

Basel III Range	8% to 10%
Basel II Baseline	4%
Adjustment for Hybrid Capital	−2%
Adjustment for Goodwill, Intangibles, Deferred Tax Assets, etc.	−1%
Adjustment for Changes in Risk Weights	$-\frac{1}{4}\%$
Effective Basel II Converted to a Basel III Basis	$< -\frac{3}{4}\%$

Source: Basel Committee on Banking Supervision (2010b) and authors' calculations.

numerator in an effort to ensure that capital includes only what is truly loss absorbing; it changes the computation of the denominator, including all of a bank's activities as well as providing a more realistic assessment of relative risk; and it changes the required ratio, increasing it from 4 percent to 7 percent. Large, systemically important institutions are subject to surcharges over and above this 7 percent.[6]

But because of changes in the definition of capital and the computation of risk-weighted assets, the Basel II and Basel III required ratios are not directly comparable. This leads to the following important question: If we use the Basel III definition of capital and risk weights, what is the effective increase in capital requirements? The answer is in table 1.

Here is a rough accounting. First, under Basel II, capital was not just common equity, but included items that had the attributes of both debt and equity. Since debt has a tax shield, it is cheaper than

[6]Beyond simply requiring additional capital, authorities have also moved to restrict the activities that banks can undertake. For example, the Vickers Report in the United Kingdom proposes ring-fencing traditional retail banking business activities. The Volcker rule in the United States includes restrictions on proprietary trading by banks and limits on owning and investing in hedge funds. And the Liikanen Report for the European Union looks to ring-fence risky activities in a bank's subsidiaries.

equity, but it also is less reliable than equity as a loss absorber. This alone cut the equity requirement virtually in half.

Next comes a change in what counted as an asset. Under Basel II, banks could count things like goodwill, intangible assets, and deferred tax assets in their computation of capital. The last of these arises from the fact that a bank that is losing money can carry the loss forward to reduce future tax payments. But this is something that is only valuable if the bank becomes profitable! These cut the requirement virtually in half again.

Finally, there is the change in the risk weights. The Basel Committee on Banking Supervision (BCBS) estimates that this reduced assets by roughly a quarter of 1 percentage point.

Putting this all together, we find that if we were to use the Basel III capital and asset definitions, the Basel II requirement of 4 percent would in fact be something between $\frac{1}{2}$ percent and $\frac{3}{4}$ percent. As the authorities were fond of saying, Basel III increased capital requirements by a factor of 10. (For systemically important banks, the increase is even bigger.) Is this enough? Almost surely not.[7]

So, what is the correct answer? At one extreme, narrow banking advocates call for depository institutions to finance anything but riskless assets with 100 percent equity capital. Admati and Hellwig (2013) argue that banks should have equity capital of 20 percent to 30 percent of their total assets, unadjusted for risk.

Needless to say, the BCBS required an answer to this question. Balancing the benefits of reduced frequency and severity of financial crises against the increased costs of financial intermediation, the BCBS (2010a) concluded that risk-weighted capital requirements should be in the range of 10 percent to 12 percent. By contrast, using a calibrated dynamic general equilibrium model, Clerc et al. (this issue), suggest that capital should be in the range of 10 percent on an unweighted basis—that is, just one-half of the Admati and Hellwig lower bound. To understand how wide the implied range is, I note that the ratio of risk-weighted assets to total assets ranges from 30 percent for continental European banks to 60 percent for

[7]It is worth noting that the Basel III calibration was done with the understanding that there would be a liquidity requirements. As Pierret (this issue) notes, the two interact. The implication is that capital requirements can be lower in the presence of liquidity requirements.

U.S. banks, with UK and Japanese banks somewhere in between.[8] So, converting everything to the risk-weighted measures, this means the range is from the Basel Committee's 7 percent to Admati and Hellwig's 100 percent.

That is obviously too big a spread to be practical. And it explains why we are having such a hard time engaging the various parties in a productive dialogue. What can we do? I will make several points. First, the right level of capital is not 0 percent and it is not 100 percent (unweighted). Furthermore, to avoid having banks load up on risky assets, it is important to retain a measure of risk sensitivity.[9]

One way out of this impasse is to adopt an approach similar to that advocated by Orphanides and Williams (2002) for monetary policy. Noting the substantial uncertainties over the level of the equilibrium real interest rate and the size of the output gap, they proposed the use of monetary policy rules based on *changes* in economic activity, rather than on its *level*. The analog, where we lack knowledge about the relative costs and benefits of higher capital requirements, is for regulators to ratchet up the level until the trade-off between banking efficiency and financial safety shifts appreciably in favor of the latter. Importantly, as capital levels rise, we will be able to measure the costs, in terms of increased lending spreads, reduced loan volumes, and shifts of activity to less-regulated shadow banks.[10] Over time, these responses will give us the information we need to determine the desirable level of capital requirements. And, during this transition, the safety of the financial system will be on the rise.

4.2 Time-Varying Capital Requirements

Next I turn to my second question. Under the rubric of "macroprudential policy," Clerc et al. (this issue) consider the efficacy of discretionary time-varying capital requirements. This raises a number of very difficult policy issues, some theoretical and some practice.

[8]See Bank for International Settlements (2013, chart V.2, p. 55).

[9]For a discussion of the problems with narrow banks, see Cecchetti and Schoenholtz (2014d). On the need for risk-sensitive measures, see Cecchetti and Schoenholtz (2014a). On the desirable level of capital requirements, see Cecchetti and Schoenholtz (2014c).

[10]See Pozsar et al. (2010) for a discussion of shadow banking.

As a matter of theory, the mechanisms through which time-varying capital requirements influence real economic activity are nearly identical to what we normally think of as the monetary policy transmission mechanism.[11] They influence financial conditions, changing loan supply, borrower net worth, and asset prices. Put differently, capital requirements influence banks' cost of doing business in a way that is nearly indistinguishable from interest rates. So, in considering macroprudential regulations, we have to start by asking to what extent macroprudential policy aimed at reducing the reinforcing feedback between the financial system and the real economy (procyclicality) short-circuits the monetary policy transmission mechanism.

On a more practical level, discretionary macroprudential policy raises all of the issues associated with the debate of rules versus discretion and more. There are information and recognition lags. How will authorities be able to tell when the financial system is vulnerable so action is needed? There are response and decision lags. Will policymakers be able to make timely decisions and take quick enough action? And there will be implementation and transmission lags. How long will it take to increase capital requirements and then have an impact on lending, asset prices, and the like?

These are the traditional problems with discretion. In the case of macroprudential policy, there are also issues of governance and political resistance. Who has the authority to raise capital requirements from one day to the next? In some jurisdictions, like the United Kingdom, this is clear. But in the United States, where there are numerous regulatory agencies with overlapping responsibilities, it is far more difficult.[12] As for the politics, where is the constituency in favor of higher capital requirements?

How can we overcome these challenges? One answer is to make the financial system sufficiently robust so that it can weather occasional booms and busts. This suggests a combination at all times (good and bad) of high capital requirements and effective stress tests implemented in a rules-based framework.[13]

[11] Cecchetti and Kohler (2014) discuss the correspondence between time-varying capital requirements and traditional interest rate policy in a simple macroeconomic model.

[12] See Cecchetti and Schoenholtz (2014f).

[13] See Cecchetti and Schoenholtz (2014e).

4.3 Implementation

During the financial regulatory reform process that followed the 2007–9 financial crisis, there was a very legitimate worry that higher capital standards would reduce bank lending at a time when economies were just starting to recover. The ultimate response to this was a slow phasing in of the new higher standards, a decision that was informed by a macroeconomic assessment.[14] That exercise, performed by the Macroeconomic Assessment Group (MAG), was a meta-analysis of the results collected from modelers in eighteen jurisdictions plus the International Monetary Fund. The MAG concluded that a 1-percentage-point increase in required capital implemented over a $4\frac{1}{2}$-year horizon would reduce economy-wide lending volumes by roughly 1.4 percentage points.

The paper by Mésonnier and Monks (this issue) addresses this same question by examining the impact on lending volumes of the unannounced 2011–12 European Banking Authority (EBA) capital exercise. Using bank-level data, they are able to estimate the behavior of the banks that were capital constrained and compare it with the behavior of those that were not. The authors conclude "that banks in a banking group that had to increase its capital by 1 percent of risk-weighted assets tended to have annualized loan growth (over the nine-month period of the exercise) that was 1.2 percentage points lower than that of banks in groups that did not have to increase their capital ratio."

At first glance, this result appears quite consistent with those of the MAG. It is not. In fact, what Mésonnier and Monks find is a substantially weaker effect. This is for three reasons. First, the EBA exercise was completely unexpected. Second, banks had nine months to meet the new requirements. And third, the Mésonnier and Monks result is for banks that were constrained. The implication is that a well-planned phase-in of higher capital requirements over a period of several years should have only a minor impact on lending that can easily be offset by slightly more accommodative monetary policy.

[14] See Macroeconomic Assessment Group (2010).

5. Conclusion

A safe, stable financial system requires resilient markets and resilient institutions. Institutional resilience, in turn, requires strong capital and liquidity requirements, combined with an effective resolution regime. The papers in this conference further our understanding of how to formulate and implement a financial stability policy framework that can provide the foundation for strong, stable, and balanced growth.

As I consider the challenges for financial and monetary policymakers raised in the work presented here, I draw three main conclusions. First, to promote a robust financial system, we need significantly higher capital requirements than those currently in place. Basel III may have been a tenfold improvement over Basel II, but that is because the latter was so woefully deficient. But we remain uncertain about the share of equity capital in bank finance that balances social costs and benefits. A pragmatic solution to address this lack of knowledge, a way for authorities to limit the risk of going too far, is to raise substantially, but gradually, the required level of capital, monitoring the system as we go.

My second conclusion is that the costs of the transition to higher capital requirements in terms of bank lending likely will be quite small, smaller than we originally thought.

And finally, I conclude that we are best advised to shy away from time-varying discretionary regulatory policies. This is true for two reasons: first, since we don't know the welfare implications of raising and lowering capital requirements from the desirable steady state, and second, since the transitional cost of increasing bank equity appears to be small (aside from the key risk of spurring shadow banking), the elasticity of aggregate activity with respect to capital also must be small. This implies that the benefits of time-varying discretion must be small as well.

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Large Banks, Loan Rate Markup, and Monetary Policy*

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A large body of empirical evidence suggests that bank loan margins are countercyclical. We develop a model where a countercyclical spread arises due to the strategic interaction between large intermediaries—i.e., banks whose individual behavior affects macroeconomic outcomes–and the central bank. We uncover a new mechanism related to market power of banks which amplifies the impact of monetary and technology shocks on the real economy. The level of the spread is positively connected to the level of entrepreneurs' leverage, and the amplification effect is stronger the more aggressive the central bank's response to inflation.

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1. Introduction

A large body of empirical evidence suggests that bank loan markups tend to move countercyclically along the business cycle (Angelini

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and Cetorelli 2003; Corbae and D'Erasmo 2013; Dueker and Thornton 1997; Mandelman 2011). This relation has been typically attributed to the cyclical properties of borrowers' riskiness, which tends to increase the cost of external finance during recessions (e.g., Bernanke, Gertler, and Gilchrist 1999). Some papers, however, have provided evidence in support of a countercyclical behavior of price-cost margins *independent* of borrowers' riskiness (Olivero 2010). On theoretical grounds, this relation has usually been explained by the existence of sunk or switching costs, sluggish interest rate setting, horizontal product differentiation, the existence of a small number of dominant banks, and a fringe of smaller competitors (Aliaga-Díaz and Olivero 2010b; Andrés and Arce 2012; Corbae and D'Erasmo 2013; Gerali et al. 2010; Mandelman 2011; Olivero 2010).

In this paper we build a model in which countercyclical markups arise due to the presence of a finite number of *large* banks. This new mechanism relies on the strategic interaction between the banks—which internalize the negative aggregate demand effects of their actions in their loan-pricing decisions—and the central bank—which sets the policy rate corresponding to the banks' funding cost. In this setup, market power—and therefore the bank loan margins—depends on the elasticity of the *aggregate loan demand* and of the *policy rate* to changes in the loan rate.[1] These elasticities, in turn, crucially depend on the degree of borrowers' leverage, which affects the responsiveness of aggregate investment and output to a rise in the lending rate. Since leverage is countercyclical in the model, this channel generates a negative relation between GDP and the loan spread.

The strategic interaction between the banks and the monetary authority amplifies the impact of exogenous shocks on the economy, bringing forth a new type of *financial accelerator*, which is crucially related to the presence of non-atomistic banks.[2] This new

[1]When there are n oligopolistic banks, the equilibrium loan rate elasticity of demand faced by each bank is a function of n, since they take into account the effect of loan rate changes on the aggregate loan rate (see, e.g., Cetorelli and Peretto 2012; Corbae and D'Erasmo 2013). In this paper, banks internalize the effect of their decisions not only on the aggregate loan rate but also on the policy rate, thereby strategically interacting with the central bank.

[2]This result is in line with the literature that, ever since the influential empirical work of Kashyap and Stein (2000), has pointed out the importance of bank market structure in the monetary transmission mechanism.

accelerator *adds up* to the standard financial accelerator discussed in the literature on the credit channel (Bernanke and Gertler 1989; Bernanke, Gertler, and Gilchrist 1999; Kiyotaki and Moore 1997), which is also at work in our model due to the presence of borrowing-constrained agents.

More in detail, the model builds on a baseline New Keynesian model with borrowing constraints and a concentrated banking sector. The economy is populated by a small number n of intermediaries, each with a size of $1/n$, so that atomistic banks are embedded as a special case (for $n \to \infty$). Banks choose the level of their individual loan interest rate and, under perfect rationality, internalize the aggregate effects of their decisions. As an intuition, consider the case in which a (large) bank decides to increase the loan rate, with the aim of increasing its profits (the story is symmetric in the case of a reduction in the loan rate). The bank anticipates that such an increase would (proportionally) augment the aggregate interest rate on loans and, as a consequence, reduces the amount of credit that borrowers can obtain (because of the collateral constraint). Because of the credit restriction, entrepreneurs reduce investment and capital accumulation, pushing down the price of capital and the marginal cost of goods-producing firms. This effect is stronger the higher the initial leverage of the borrowers. Moreover, due to the optimal price-setting behavior in the goods market, the decline in marginal costs reduces inflation, triggering a loosening of the monetary stance proportional to the systematic response to inflation. As the policy rate in the model corresponds to the deposit rate paid to households by banks, both a higher leverage and a tougher central bank in stabilizing inflation will offer greater incentives to the bank to raise the loan rate—and thus the spread—by reducing its marginal costs to a larger extent.

The mechanism outlined in the paper bears a number of empirical implications, which constitute potential testable predictions for the model. First, the equilibrium (aggregate) level of the loan spread is positively related to the number of banks, which proxies for the level of concentration in the economy and determines the degree of strategic interaction; this effect, however, would tend to disappear for $n \to \infty$, suggesting that it should be a characteristic of highly concentrated banking markets. Many empirical works have shown that there is a positive relation between market power and the degree of concentration in banking (e.g., Bikker and Haaf 2002; Claessens and Laeven 2004, among others; see section 2 for further details). Second, the level of the spread and the degree of amplification are positively related to the level of entrepreneurs' leverage, reflecting the fact that a higher leverage implies a greater elasticity of the policy rate to changes in loan rates, which in turn increases banks' market power. Entrepreneurs' leverage (defined as the ratio of price-sensitive assets to net worth) is countercyclical in the model, as net worth tends to fall (increase) more than assets after shocks that negatively (positively) affect output. Empirical evidence overall supports the hypothesis of countercyclical firm leverage (e.g., Adrian and Shin 2010; Chugh 2009; see section 2). Third, we find that the loan spread depends on the design of the monetary policy rule. For simplicity, we limit the analysis to the simple case in which monetary policy sets the short-term interest rate based on a rule that only responds to deviations of inflation from the steady state. We find that the spread is higher the more aggressive the response to inflation, as measured by the parameter determining the systematic response in the simple rule. In addition, the inflation coefficient in the Taylor rule also interacts with the financial accelerator described above: amplification is stronger the more aggressive the central bank.

Large banks' behavior assumed in the paper is consistent with the major intermediaries' practice to regularly produce forecasts on the behavior of monetary policy. Examples can be found in research newsletters, press articles, CEO interviews, and corporate websites of the major global banks.[3] In these analyses, conditions in the

[3]For example, Deutsche Bank's *Focus Europe* newsletter regularly discusses future European Central Bank (ECB) decisions; Barclays' *Global Economics Weekly* does the same for the Bank of England, and JP Morgan's *Global Data Watch* and Bank of America–Merril Lynch's *Global Economic Weekly* do the same for the Federal Reserve. Similarly, one can easily find large bank CEOs' or other executives' interviews or website statements about future policy decisions. See, for example, for the United States, JP Morgan (http://fortune.com/2014/04/10/jamie-dimon-says-fed-stimulus-exit-will-be-easy/) and Goldman Sachs (http://blogs.wsj.com/moneybeat/2014/03/21/fed-not-seen-boosting-rates-until-2016-goldman-sachs/); for the euro zone, BNP Paribas (http://video.cnbc.com/gallery/?video=3000252516); for Sweden, Nordea (http://cbonds.it/news/item/608543); and for Switzerland, UBS (http://www.ubs.com/global/en/about_ubs/media/switzerland/releases/news-display-media-switzerland.html/en/2011/02/09/ubs_outlook_switzerland_q1_2011.html).

credit market are often mentioned as an important driver for the prospected central bank decisions. Also, the effects of monetary policy decisions on bank funding costs are sometimes explicitly considered.[4] Indeed, conditions on the credit markets *are* one of the crucial things that most central banks look at when deciding monetary policy stance.[5] In this context, it is interesting to explore, in a theoretical context, the possibility that the anticipated reaction of monetary policy weighs in the decision to change lending rates by banks that have a substantial share of the domestic credit market.[6] The rationality assumptions required in this framework are the same as those employed—as mentioned—in the literature about wage-setting behavior by non-atomistic unions (e.g., Lippi 2003; Soskice and Iversen 2000) and, more broadly, are fully consistent with the rational expectations framework.

Obviously, the existence of large and complex financial institutions not only affects competition in the banking sector. The literature assessing the influence of big banks has also focused on issues of systemic risk, interconnectedness, and "too big to fail" (e.g., Bianchi 2012). Here, we offer an alternative model for the study of large banks based on the macro literature that emerged after the recent financial crisis and that made significant progress in terms of incorporating loan spreads and studying loan-rate-setting behavior by banks (e.g., Andrés and Arce 2012; Curdia and Woodford 2010; Gerali et al. 2010). In particular, we focus on the strategic interaction between large banks and the central bank, which allows us to exploit an established theoretical framework employed for studying wage-setting behavior by non-atomistic unions (see Calmfors 2001 and Cukierman 2004 for a survey of this voluminous literature).

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[4]For example, Deutsche Bank, in the June 6, 2014, issue of *Focus Europe*, proposes a quantification of the impact of the ECB's targeted LTRO auctions on the funding cost of banks from the main euro-zone countries. The estimated impact is a reduction in cost ranging between 75 basis points in Germany and 195 in Italy.

[5]Credit market conditions are regularly mentioned in the ECB's introductory statement or the Federal Open Market Committee's press release following the central banks' meetings.

[6]For example, Bank of America, Barclays, and UBS loan market shares are well above 10 percent.

Our paper is related to a number of other recent works that have studied the role of banking in business-cycle fluctuations. Christiano, Motto, and Rostagno (2010), Gertler and Karadi (2011), and Meh and Moran (2010) are among the first works to incorporate banking into general equilibrium New Keynesian models. These models feature perfect competition in banking and focus on the impact on the aggregate economy of shocks originating in the banking sector. Andrés and Arce (2012) and Olivero (2010) model competition using the Salop (1979) spatial model of horizontal product differentiation, with a finite number of banks competing in the price dimension. In their models, markups are countercyclical because the interest rate elasticity of loans is proportional to aggregate credit demand: therefore, during good (bad) times, banks lower (raise) loan rates in order to compete more aggressively and capture new borrowers. Aliaga-Díaz and Olivero (2010b) and Gerali et al. (2010) assume that banks operate in a standard regime of monopolistic competition with atomistic agents. Loan spreads are countercyclical in both models due to, respectively, switching costs for borrowers and sluggish interest rate setting by banks. Mandelman (2011) models imperfect competition by assuming that entrants must incur large sunk entry costs in highly segmented markets and incumbents adopt limit-pricing strategies (i.e., setting loan rates lower during booms) aimed at deterring entry into retail banking niches. Finally, Corbae and D'Erasmo (2013) analyze a Stackelberg environment where a small number of dominant banks choose their loan supply strategically before a large number of small banks make their loan choice. In contrast to all these papers, we model a strategic interaction between banks and the central bank. In our model, this interaction is the source of countercyclical markups and of the associated financial accelerator.

The remainder of the paper is organized as follows. Section 2 discusses theoretical and empirical evidence on the existence and the cyclical properties of loan markups. Section 3 describes the model. Section 4 shows the implications of the strategic interaction between large banks and monetary policy and its impact on the model's steady state. Section 5 illustrates the dynamic properties due to the link between the endogenous behavior of banks and the general equilibrium properties of the economy. Section 6 concludes.

2. Competition in Banking and Countercyclical Loan Markups

In this section we first provide theoretical and empirical support for our assumption about the structure of competition in the banking sector. Subsequently, we discuss evidence about the cyclical properties of bank loan markups.

2.1 Competition in Banking

One crucial assumption in the model is that banks have market power in the loan market while they operate competitively on the funding side. As regards lending, there is a wide consensus in the literature about the failure of perfect competition.[7] From a theoretical perspective, market power is often associated with the existence of switching costs. These typically arise because asymmetric information over borrowers' creditworthiness gives informational advantages to incumbent banks, generating a hold-up effect for customers and creating entry barriers for other banks (Dell'Ariccia 2001; Dell'Ariccia, Friedman, and Marquez 1999; Kim, Kliger, and Vale 2003; von Thadden 1995). Switching costs might also arise due to the presence of pure "menu costs," like costs associated with moving from one bank to another or fees incurred when applying for a loan or renegotiating the terms of an outstanding debt (Vives 2001). Other studies highlight the importance of regulatory restrictions and market contestability as a determinant of market power (Demirguc-Kunt, Laeven, and Levine 2004). The existence of market power is confirmed by a wide number of empirical analyses which, using both bank-level and aggregate data, show that most banking markets worldwide can be classified as monopolistically competitive (e.g., Bikker and Haaf 2002; Claessens and Laeven 2004; De Bandt and Davis 2000).[8]

[7]See Carletti (2008) for a comprehensive review of competition in banking, and Freixas and Rochet (2008) for a classical treatment of competition in banking.

[8]Berger et al. (2004), Claessens and Laeven (2004), and Degryse and Ongena (2008) provide extensive surveys of the empirical literature on market power in banking.

Assuming that banks' market power does not extend to the funding market (where intermediaries are competitive), we follow Aliaga-Díaz and Olivero (2010b) and Olivero (2010), in which banks price securities competitively and, at the same time, the loan market is not competitive. Asymmetric information problems vis-à-vis banks are likely to be less severe than in the loan markets, thanks to regulation and public guarantees on deposits. Competition for time and saving deposits and for wholesale funds is based on their risk-return profile, as they provide no liquidity services, unlike demand deposits (Corvoisier and Gropp 2002); these instruments must pay the same yield as instruments of comparable risk (Fama 1985). Empirical evidence is not conclusive about the impact of industry concentration on deposit rates: while most studies find a negative relation, the magnitude of the effect varies substantially across samples and specifications (Degryse and Ongena 2008).

As a by-product of the way in which we model imperfect competition in the loan market, we implicitly postulate a direct relation between the degree of concentration (proxied by the inverse of the number of banks) and market power. This assumption is consistent with the so-called structure-conduct-performance (SCP) paradigm, which predicts that competition is less intense in more concentrated markets because collusion is easier (Degryse and Ongena 2008).[9] Despite the fact that after the 1990s this paradigm evolved past this simple framework, recent empirical evidence overall supports a positive relation between concentration and market power.[10] For example, Bikker and Haaf (2002) estimate the Panzar and Rosse (1987) H-statistic for twenty-three industrialized countries over a period of roughly ten years and relate these measures to various measures of concentration (various k-bank concentration ratios, the Herfindahl

[9]It is important to note that the relation between concentration and market power in our case is relevant not because of collusion but because large banks realize that they can affect aggregate outcomes, thus exploiting the strategic interaction with the central bank.

[10]Since the 1990s, it became customary to model market structure as endogenous and measure the degree of competition via more direct measures (Berger et al. 2004). In the new paradigm, the main hypothesis is that efficiency drives the structure (efficiency-structure hypothesis), because more efficient banks will gain market share, therefore margins would be larger in more concentrated markets due to greater efficiency (e.g., Demsetz 1973).

index, and the absolute number of banks), finding evidence that higher concentration is associated with weaker competition and more market power. Claessens and Laeven (2004) reach similar conclusions for a sample of fifty countries between 1994 and 2001. Maudos and Fernandez de Guevara (2004), estimating the determinants of bank margins in the five main European countries between 1993 and 2000, find a positive effect of the Herfindahl index on bank margins, consistently with the results obtained using the Lerner index (which is a more direct measure of market power). Corvoisier and Gropp (2002) find that concentration does affect interest margins on loans.

2.2 Countercyclical Markups

A number of papers provide evidence for the existence of a negative correlation between GDP and bank markups (Angelini and Cetorelli 2003; Corbae and D'Erasmo 2013; Dueker and Thornton 1997; Mandelman 2011). A negative correlation with GDP, however, could just reflect the cyclical properties of borrowers' riskiness, which tends to increase the cost of external finance during recessions (e.g., Bernanke, Gertler, and Gilchrist 1999). Olivero (2010) provides evidence in support of a countercyclical behavior of bank cost margin *independent* of borrowers' riskiness. First, based on a large sample of bank-level data in a number of OECD countries, she shows that banks' (earned) net interest margin (a measure of bank markup which is independent of riskiness, as defaults are already accounted for) is negatively related to GDP. Second, using aggregate data from the International Monetary Fund International Financial Statistics database, she shows that a negative correlation holds for the majority of countries also when controlling for the cyclicality of credit risk in a VAR framework. In a related paper, Aliaga-Díaz and Olivero (2010a) confirm the results using quarterly Call Report data for U.S. banks between 1984 and 2005.

From a theoretical point of view, countercyclicality of bank margins (independently of credit riskiness) has been linked to the competitive structure of the banking industry. Mandelman (2011) highlights the role of entry barriers (like sunk costs). During recessions, when credit demand is low, incumbent banks may exploit their monopoly power to increase margins. During booms, however, the expansion of the financial system allows potential entrants to operate at an efficient scale, forcing incumbents to lower interest rates (and thus margins) so as to deter entry. Aliaga-Díaz and Olivero (2010b) emphasize the role of the borrower's "hold-up" effect and switching costs, which increase during recessions when borrowers' perceived riskiness increases. As a consequence, incumbent banks may charge higher interest rates, giving rise to countercyclical margins.

As a final remark, as will be explained in section 3, in the model the countercyclicality of banks' markup reflects that of firms' leverage.[11] A countercyclical behavior of leverage is consistent with a passive management of capital structure of the firm: since the market value of net worth increases in good times, and debt ratio is not actively managed, leverage would decline during expansions and increase in good times. Adrian and Shin (2010) and Chugh (2009) show that this is the case for non-financial firms in the United States, although the correlation between leverage and GDP is only mildly negative. Levy and Hennessy (2007), considering a model where all firms face financial frictions, find that also the book leverage ratio (i.e., constructed using the book rather than the market value of equity) is countercyclical for firms with less stringent constraints.

3. The Model

The economy is populated by two groups of agents of equal mass, households and entrepreneurs. Households work, consume, and save in the form of bank deposits. Entrepreneurs buy physical capital from capital goods producers, then combine that physical capital with labor to produce homogenous intermediate goods, consume, and borrow from banks. Due to the existence of financial frictions (modeled along Iacoviello 2005), lending is collateralized with physical capital. The banking sector comprises a finite number n of *large* banks, which operate in a regime of imperfect competition in the loan market and internalize the effects of their loan rate decisions on the aggregate economy.[12] In addition to entrepreneurs, there are two

[11] As will be explained below, a higher firms' leverage increases the elasticity of the policy rate to changes in bank loan rates, generating a positive correlation with banks' markup.

[12] The way in which the banking sector is modeled is based on Gerali et al. (2010). The main departure from their framework is that we allow for fully flexible rates, and banks are assumed to be non-atomistic.

other producing sectors: retailers, who buy intermediate goods from entrepreneurs in a competitive market, differentiate and price them subject to nominal rigidities, and resell them with a markup over marginal cost; and capital goods producers, who are introduced so as to derive a market price for capital. Monetary policy is conducted according to a simple rule, whereby the (gross) nominal interest rate is set in response to endogenous variations in (gross) inflation ($\pi_t \equiv P_t/P_{t-1}$), as follows:

$$R_t^{ib} = R^{ib} \pi_t^{\phi_\pi} \exp(\varepsilon_t^{R^{ib}}), \qquad \phi_\pi \geq 0, \tag{1}$$

where R_t^{ib} is the gross nominal interest rate, R^{ib} is the steady-state level of R_t^{ib}, and $\varepsilon_t^{R^{ib}}$ is a (white noise) monetary policy innovation with zero mean and variance $\varsigma^{R^{ib}}$.

3.1 Households and Entrepreneurs

Household h solves the following problem:

$$\max_{\left\{c_t^P(h),\ l_t^P(h),\ d_t^P(h)\right\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_P^t \left[\log(c_t^P(h)) - \frac{l_t^P(h)^{1+\phi}}{1+\phi}\right] \tag{2}$$

subject to the budget constraint:

$$c_t^P(h) + d_t^P(h) \leq w_t l_t^P(h) + R_{t-1}^{ib} d_{t-1}^P(h) + J_t^f(h) + J_{t-1}^b(h), \tag{3}$$

where $c_t^P(h)$ is current consumption; $d_t^P(h)$ is bank deposits in real terms, which are remunerated at a rate equal to the policy rate R_t^{ib}; w_t is real wage; $l_t^P(h)$ is labor supply; and $J_t^f(h)$ and $J_{t-1}^b(h)$ are the real (lump-sum) profits, respectively, by the retailers and by the banks.[13] The parameters ϕ and β_P denote the inverse of the Frisch labor supply elasticity and the households' discount factor.

[13]Though it is not critical to our central message here, credits and debts are assumed to be indexed to current inflation; this removes the so-called nominal credit/debt channel from the model. This channel, which implies that changes in the price level have real effects on the aggregate economy because they redistribute real resources between borrowers and lenders, is quite important in Gerali et al. (2010) and in many papers with a collateral channel (e.g., Iacoviello 2005); however, it is possible to show that introducing the nominal credit/debt channel would not affect the key strategic mechanisms at work in this paper.

The relevant first-order conditions are the Euler equation

$$\frac{1}{c_t^P(h)} = \beta_P \mathbb{E}_t \frac{R_t^{ib}}{c_{t+1}^P(h)} \tag{4}$$

and the labor-supply decision

$$l_t^P(h)^\phi = \frac{w_t}{c_t^P(h)}. \tag{5}$$

There is a continuum of measure one of entrepreneurs indexed by $i \in [0, 1]$. Entrepreneurs' optimization problem is given by

$$\max_{\{c_t^E(i),\ k_t^E(i),\ b_t^E(i)\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_E^t \log(c_t^E(i)) \tag{6}$$

subject to a budget and a borrowing constraint, respectively:

$$\begin{aligned} c_t^E(i) + R_{t-1}^b b_{t-1}^E(i) + w_t l_t(i) + q_t^k k_t^E(i) \\ \leq \frac{y_t^E(i)}{x_t} + b_t^E(i) + q_t^k(1-\delta^k)k_{t-1}^E(i), \end{aligned} \tag{7}$$

$$R_t^b b_t^E(i) \leq \mathbb{E}_t m^E q_{t+1}^k k_t^E(i)(1-\delta^k). \tag{8}$$

In the equations above, $c_t^E(i)$ is entrepreneurs' consumption, $b_t^E(i)$ is the amount of borrowing from banks, R_t^b is the (gross) aggregate interest rate on loans, w_t is real wage, $l_t(i)$ is labor demand, $k_t^E(i)$ is entrepreneurs' stock of capital, q_t^k is the price of capital, y_t^E is the output of intermediate goods produced by the entrepreneurs, x_t is the markup of the retailer sector, and δ^k is the depreciation rate of capital. In the borrowing constraint, m^E is a parameter that can be interpreted as the loan-to-value (LTV) ratio chosen by the banks (i.e., the ratio between the amount of loans issued and the discounted next-period value of entrepreneurs' assets). The parameter β_E is the entrepreneurs' discount factor. As is standard in models with a borrowing constraint, we assume that $\beta_E < \beta_P$.

Production is carried out using the following Cobb-Douglas technology:

$$y_t^E(i) = A_t^E(k_{t-1}^E(i))^\alpha(l_t(i))^{1-\alpha}, \tag{9}$$

where A_t^E is a productivity shock to the neutral technology. The shock follows the process $\log(A_t^E) = \log(A^E) + \varepsilon_t^{A^E}$, where $\varepsilon_t^{A^E}$ is white noise with zero mean and variance ς^{A^E}.

Entrepreneurs' demand for loans is derived as in Gerali et al. (2010). We assume that an entrepreneur seeking an amount of loans $b_t^E(i)$ has to purchase a composite basket of slightly differentiated financial products, supplied by n banks, with elasticity of substitution equal to ϵ^b (with $\epsilon^b > 1$). This constraint can be expressed as

$$b_t^E(i) = \left[\int_0^1 b_t^E(i,j)^{\frac{\epsilon^b - 1}{\epsilon^b}} \mathrm{d}j\right]^{\frac{\epsilon^b}{\epsilon^b - 1}}. \tag{10}$$

Let $\int_0^1 R_t^b(j) b_t^E(i,j)\mathrm{d}j$ denote the total repayment due to the continuum of financial products demanded by entrepreneur i. Demand for real loans $b_t^E(i)$ from entrepreneur i is obtained by minimizing the total repayment over $b_t^E(i,j)$, subject to the constraint (10). Cost minimization implies the set of demand schedules $b_t^E(i,j) = \left(\frac{R_t^b(j)}{R_t^b}\right)^{-\epsilon^b} b_t(i)^E$, for all $i \in [0,1]$ and $j \in [0,1]$. Integrating the latter across entrepreneurs yields the total demand for loans of type j

$$b_t^E(j) = \left(\frac{R_t^b(j)}{R_t^b}\right)^{-\epsilon^b} b_t^E; \qquad b_t^E = \int_0^1 b_t(i)^E \mathrm{d}i, \tag{11}$$

where R_t^b is defined as

$$R_t^b = \left[\int_0^1 R_t^b(j)^{1-\epsilon^b} \mathrm{d}j\right]^{\frac{1}{1-\epsilon^b}}. \tag{12}$$

For the sake of simplicity, I assume that loan demands are equally distributed across banks so that each entrepreneur demands $1/n$ loan types to the same bank.

The maximization of problem (6) yields the following first-order conditions:

$$\lambda_t^E = 1/c_t^E \tag{13}$$

$$\lambda_t^E - \beta_E \mathbb{E}_t R_t^b \lambda_{t+1}^E = \lambda_t^E s_t^E, \tag{14}$$

$$\lambda_t^E s_t^E m^E \mathbb{E}_t \frac{q_{t+1}^k(1-\delta^k)}{R_t^b} + \beta_E \mathbb{E}_t \lambda_{t+1}^E [q_{t+1}^k(1-\delta^k) + r_{t+1}^k] = q_t^k \lambda_t^E, \tag{15}$$

$$w_t = (1-\alpha)\frac{y_t^E}{l_t x_t}, \tag{16}$$

$$r_t^k = \alpha \frac{y_t^E}{k_{t-1}^E x_t}, \tag{17}$$

where λ_t^E and $\lambda_t^E s_t^E$ are multipliers on the constraints (7) and (8), respectively, and r_t^k is the rental rate of physical capital.

The intertemporal choice of an entrepreneur (14) is distorted when the credit constraint is binding, i.e., when $s_t^E > 0$. Under our assumptions about the agents' discount factors and because of the existence of a positive markup between the loan and the policy rate, this is always the case in a neighborhood of the steady state.[14] As a result, in equilibrium, households are net lenders and entrepreneurs are net borrowers.

Equation (15) equates the marginal cost of one unit of capital $q_t^k \lambda_t^E$ to its (expected discounted) marginal benefit. The latter has three components: (i) the expected future price of capital, since capital acquired today can be resold tomorrow to the capital sector at $q_{t+1}^k(1-\delta^k)$; (ii) the return on capital used in the production, r_{t+1}^k; (iii) the shadow value of borrowing, since capital acquired today can be used as collateral in borrowing.

Following Andrés, Arce, and Thomas (2013), we can define entrepreneurs' net worth as follows:[15]

$$nw_t^E \equiv r_t^k k_{t-1}^E + q_t^k \left(1-\delta^k\right) k_{t-1}^E - R_{t-1}^b b_{t-1}^E. \tag{18}$$

[14] In particular, the households' and the entrepreneurs' Euler equations (4) and (14), evaluated at the steady state, are equal to, respectively, $1 = \beta_P R^{ib}$ and $1 - \beta_E R^b = s^E$. Therefore, $s_t^E > 0$ if $\beta_P R^{ib} - \beta_E R^b > 0$. This is the case if $\beta_P/\beta_E > \mathcal{M}^b \equiv R^b/R^{ib}$. As will be shown in section 4, this holds given our baseline calibration.

[15] Defining net worth nw_t^E is convenient also for illustrating the timing of the model. At the end of (any given) period t, (i) entrepreneurs hold nw_t^E; (ii) banks lend b_t^E to entrepreneurs to purchase new capital $q_t^k k_t^E$. At the beginning of period $t+1$, entrepreneurs (i) produce using k_t^E units of capital and obtain a unit return of r_{t+1}^k after paying wages to patient workers; (ii) sell $q_{t+1}^k(1-\delta^k)k_t^E$ to the capital sector; (iii) pay back $R_t^b b_t^E$ to banks. Thus, in equation (18),

Substituting (18) into (15) and (14), we can rewrite entrepreneurs' aggregate consumption, c_t^E, and capital in the next period, k_t^E, as a constant fraction of nw_t^E (see appendix 1 for the derivation of the equations):

$$c_t^E = (1 - \beta_E)\, nw_t^E. \tag{19}$$

$$q_t^k k_t^E = \frac{\beta_E}{1 - b_t^E/(q_t^k k_t^E)} nw_t^E. \tag{20}$$

Before turning to the derivation of the optimal loan interest rate, it is convenient to define the entrepreneurs' debt-to-capital ratio,

$$V_t^E \equiv \frac{b_t^E}{q_t^k k_t^E} \tag{21}$$

and the gross expected change of capital price,

$$\Delta_{t+1} \equiv \mathbb{E}_t q_{t+1}^k / q_t^k. \tag{22}$$

From equation (20) we derive the following relation between the debt-to-capital ratio and the entrepreneurs' leverage (LV_t^E):

$$LV_t^E \equiv \frac{q_t^k k_t^E}{nw_t^E} = \frac{\beta_E}{1 - V_t^E}. \tag{23}$$

3.2 Retailers and Capital Goods Producers

As is standard in this class of models, we assume that there exists another group of agents, the *retailers*, who buy the intermediate goods from entrepreneurs in a competitive market, brand them at no cost, and sell the differentiated good at a price that includes a markup over the purchasing cost.[16] The introduction of retailers is useful for introducing nominal rigidities. In particular, in our model

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$r_t^k k_{t-1}^E + q_t^k (1 - \delta^k) k_{t-1}^E$ denotes the entrepreneur's gross capital return at time t, while $R_{t-1}^b b_{t-1}^E$ is the effective cost of borrowing.

[16]For example, Bernanke, Gertler, and Gilchrist (1999) and Gerali et al. (2010) use the same modeling device.

we assume that retailers face a quadratic adjustment cost parameterized by κ_p whenever they want to change their price (Rotemberg 1982). In particular, retailers maximize the following profit function:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[P_t(i) y_t^E(i) - P_t^W y_t^E(i) - \frac{\kappa_p}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right)^2 P_t y_t^E \right] \tag{24}$$

subject to the demand derived from consumers' maximization,

$$y_t^E(i) = (P_t(i)/P_t)^{-\epsilon^y} y_t^E,$$

where $\epsilon^y > 1$ denotes the elasticity of substitution across brand types, $\Lambda_{0,t} \equiv \beta_P c_0^P / c_t^P$ is the households' stochastic discount factor, c_t^P is current consumption, and $y_t = (\int_0^1 y_t(i)^{(\epsilon^y-1)/\epsilon^y} \mathrm{d}j)^{\epsilon^y/(\epsilon^y-1)}$.

The first-order conditions for $P_t(i)$ yields the familiar New Keynesian Phillips curve:

$$\begin{aligned} 1 - \frac{mk^y}{mk^y - 1} + \frac{mk^y}{mk^y - 1} mc_t^E - \kappa_p(\pi_t - 1)\pi_t \\ + \beta_P \mathbb{E}_t \left[\frac{c_t^P}{c_{t+1}^P} \kappa_p (\pi_{t+1} - 1) \pi_{t+1} \frac{y_{t+1}^E}{y_t^E} \right] = 0, \end{aligned} \tag{25}$$

where $mk^y \equiv \epsilon^y/(\epsilon^y - 1)$, $mc_t^E = 1/x_t$ is the real marginal cost, and $x_t \equiv P_t/P_t^W$.

In addition, we assume that fixed capital creation is carried out by *capital goods producers* (CGPs) and is subject to some adjustment costs. CGPs operate in a perfectly competitive environment. They buy last-period undepreciated capital ($(1-\delta^k)k_{t-1}^E$) from entrepreneurs at (a nominal) price Q_t^k, and I_t units of final goods from retailers at price P_t. Using these inputs, CGPs increase the stock of effective capital $\bar{z}$, which is then sold back to entrepreneurs at the same price, Q_t^k. Old capital can be converted one-to-one into new capital, while the transformation of the final good is subject to quadratic adjustment costs. CGPs therefore choose $\bar{z}_t$ and I_t so as to maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^E (q_t^k \Delta \bar{z}_t - I_t) \tag{26}$$

subject to

$$\bar{z}_t = \bar{z}_{t-1} + \left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t, \tag{27}$$

where $q_t^k \equiv Q_t^k / P_t$ is the real price of capital, $\Lambda_{0,t}^E \equiv \beta_E c_0^E / c_t^E$ is the entrepreneurs' stochastic discount factor, and c_t^E is the current consumption. The first-order condition is

$$1 = q_t^k \left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa_i \left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] + \beta_E \mathbb{E}_t \left[\frac{c_t^E}{c_{t+1}^E} q_{t+1}^k \kappa_i \left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right]. \tag{28}$$

3.3 Banks

The economy is populated by a finite number n of banks (with $n \geq 2$), which collect time deposits from households and issue loans to entrepreneurs. We assume that the deposit market is perfectly competitive while (as mentioned above) the loan market is modeled along Gerali et al. (2010), with a Dixit-Stiglitz type of competition.[17]

Before lending funds to entrepreneurs, each bank observes the entrepreneur's net wealth (18) and takes it as given. Loan types are equally distributed across banks, so that each bank has a share of total loans equal to $1/n$. In other words, $1/n$ can be interpreted as the degree of concentration in the credit market. Loan interest rates are fully flexible and set independently and simultaneously. We assume that each large bank takes as given the loan rates set by the other banks and the effects of loan rate on variables in the

[17] As discussed in section 2, this hypothesis is consistent with previous literature and is justified on theoretical grounds. Assuming the existence of market power also in the deposit market, our results on bank margin (defined as the difference between the rate on loans and deposits) would be reinforced. In that case, the interest rate on deposits would be set as a markdown over the policy rate. Due to the strategic interaction, symmetrically to the case of the rate on loans, the large banks would have an incentive to set the deposit rate below the level set by atomistic banks. The intuition is that this would boost household consumption, aggregate demand, and inflation, thus prompting an increase of the policy rate.

next period. In the interaction with the central bank (and the rest of the economy), banks internalize the general equilibrium effects of their loan rates at time t. In particular, the representative bank u (where $u \in \{1, \ldots, n \geq 2)$ sets the same interest rate $R_t^b(u)$ on all loans provided to entrepreneurs $j \in u$ so as to maximize profits:[18]

$$J_t^b = \int_{j \in u} \left[R_t^b(j) - R_t^{ib} \right] b_t^E(j) \mathrm{d}j \tag{29}$$

subject to the loan demand (11), the budget constraints (3) and (7), the borrowing constraint (8), the New Keynesian Phillips curve (25), the equilibrium condition for the labor market (obtained by combining the labor demand (16) with the households' first-order conditions (4) and (5)),[19] and the interest rate rule (1).

The solution to the banks' problem reads

$$R_t^b = \frac{\epsilon^b(n-1) + \Sigma_{b,t} + \Sigma_{R^{ib},t}}{\epsilon^b(n-1) + \Sigma_{b,t} - n} R_t^{ib} \equiv \mathcal{M}_t^b R_t^{ib}, \tag{30}$$

where $\Sigma_{b,t}$ and $\Sigma_{R^{ib},t}$ are, respectively, the elasticity (in absolute value) of aggregate loans, b_t^E, and the elasticity of policy interest rate, R_t^{ib}, to the aggregate loan rate, R_t^b.

The first-order condition (30) is the key equation for our results.[20] It shows that banks set the loan interest rate as a markup ($\mathcal{M}_t^b$) over the policy interest rate. In standard models with monopolistic competition, this markup (and thus the loan rate) is typically time invariant and depends only on the elasticity of substitution among varieties. In this case, instead, due to the assumption of non-atomistic banks, it depends on the number of banks in the economy and is time varying, according to the elasticities of aggregate loans and of the policy rate to the aggregate loan rate.

[18]For the sake of simplicity, we assume an exogenous distribution of symmetric banks. Corbae and D'Erasmo (2013) focus instead on heterogeneity across the bank size distribution.

[19]In particular, the condition is

$$(1-\alpha) y_t^E(i) mc_t \beta_P \mathbb{E}_t \frac{R_t^{ib}}{c_{t+1}^P(i)} = \left[l_t^P(i) \right]^{1+\phi}.$$

[20]For a complete derivation of this expression and of its components, see appendix 2.

The reason why $\mathcal{M}_t^b$ is endogenously determined by n, $\Sigma_{b,t}$, and $\Sigma_{R^{ib},t}$ is the strategic interaction that the presence of large banks induces among banks and between banks and the central bank.

The number of banks n is relevant because the size of banks is inversely proportional to their number. In turn, the bank's size determines the impact of a change in bank u's loan rate on the aggregate loan rate R_t^b (as shown in appendix 2) by

$$\frac{\partial R_t^b}{\partial R_t^b(u)} = \frac{1}{n}. \tag{31}$$

Note that when bank size tends to zero—i.e., n tends to infinity—the effect of the strategic interaction disappears and the markup converges to the value it assumes in standard models of monopolistic competition:

$$\lim_{n\to\infty} \mathcal{M}_t^b = \frac{\epsilon^b}{\epsilon^b - 1}. \tag{32}$$

$\Sigma_{b,t}$ and $\Sigma_{R^{ib},t}$ appear in the expression of the markup because they affect the incentives of the banks to strategically change the loan rate, which in turn depend on the impact that such changes have on the different components of bank profits (29): loan demand b_t^E and the cost of deposits R_t^{ib}. To understand the intuition, consider the case of an increase in the loan rate (a symmetric argument could be used for the case of reduction in the loan rate). When credit constraints are binding, the increase in R_t^b reduces entrepreneurs' borrowing, according to equation (8). In turn, the reduction in loans lowers banks' profits (for given levels of the interest rates), thus reducing the incentive to increase the interest rate in the first place. The intensity of the reduction in borrowing is proportional to $\Sigma_{b,t}$, which is therefore negatively related to $\mathcal{M}_t^b$. The algebraic expression for $\Sigma_{b,t}$ reveals that, in turn, the intensity of loan reduction is proportional to the level of firms' leverage (as implied by the borrowing constraint):

$$\Sigma_{b,t} \equiv -\frac{\partial b_t^E}{\partial R_t^b}\frac{R_t^b}{b_t^E} = 1 + \Sigma_{LV,t}, \tag{33}$$

where

$$\Sigma_{LV,t} \equiv -\frac{\partial LV_t^E}{\partial R_t^b}\frac{R_t^b}{LV_t^E} = \frac{LV_t^E}{\beta_E} - 1 \tag{34}$$

denotes the elasticity of entrepreneurs' leverage (23) to the aggregate loan rate R_t^b.

The relation between the markup $\mathcal{M}_t^b$ and $\Sigma_{R^{ib},t}$ is somewhat less direct and relies on the impact that a rise in the loan rate has on aggregate demand, via the reduction in borrowing. Indeed, as (borrowers') leverage reduces, entrepreneurs are forced to reduce capital expenditure (through (20)) and consumption. The fall in aggregate demand puts downward pressure on marginal costs and on inflation (via the Phillips curve (25)), prompting a response by the central bank which, as mentioned, is assumed to follow a simple rule targeting deviations of inflation from its (zero) steady state. Banks anticipate that the ensuing cut in the policy rate will lower their financing cost, offering incentives to increase the loan rate in the first place.[21] This effect is proportional to $\Sigma_{R^{ib},t}$, which therefore displays a positive correlation with the bank's markup. The expression for $\Sigma_{R^{ib},t}$ is

$$\begin{aligned}\Sigma_{R^{ib},t} &\equiv -\frac{\partial R_t^{ib}}{\partial R_t^b}\frac{R_t^b}{R_t^{ib}} \\ &= \frac{q_t^k k_t^E mc_t \phi_\pi}{c_t^P \phi_\pi mc_t + y_t^E \Psi[(mk^y - 1)\kappa_p + mk^y mc_t \phi_\pi]}\Sigma_{LV,t},\end{aligned} \tag{35}$$

where $\Psi \equiv (1-\alpha)/[mk^y(\alpha+\phi)]$.

Two things are worth stressing. First, borrowers' leverage plays a significant role also in this case: the elasticity of the policy rate is positively correlated with LV_t^E, reflecting the fact that—other things being equal—the fall in aggregate demand and the ensuing policy response is stronger the higher entrepreneurs' leverage. Second, $\Sigma_{R^b,t}$ also depends on the central bank's inflation coefficient ϕ_π, which determines the intensity of monetary policy response for

[21]This is reminiscent of results obtained in the non-atomistic wage setter literature. For a description of the main strategic effects analyzed in this strand of literature in open and closed economies, see Cuciniello (2011).

a given reduction in aggregate inflation. This result underscores the potential importance of the strategic interaction between large banks and the central bank. In particular, it shows how the design of monetary policy may interact with market power in the banking sector and have an impact on banks' interest rate decisions.[22]

Of course, the mechanism described in this section depends on the assumption that bank profits in our model coincide with the interest rate margin.[23] Moreover, the results about the cyclical properties of profits hinge on the fact that, in the case of an increase in bank loan rates (and symmetrically for a decrease), the fall in the amount of intermediated funds does not compensate the positive impact on the unit interest margin. As shown in section 2, this is consistent with the empirical behavior of bank price-cost margins. In the real world, bank profit-and-loss statements obviously include many other items, such as trading and other non-interest income, operating costs, and loan loss provisions.[24]

4. The Steady State

What are the implications of the mechanism described in the previous section? After discussing the model baseline calibration, we first provide an analysis of the steady-state properties of the model. In the next section, we focus on the dynamic properties of the model with large banks.

Table 1 reports the calibration of the main parameters in the model. The households' discount factor β_P is set at 0.996, which implies a steady-state policy rate of roughly 2 percent (annualized). The entrepreneurs' discount factor β_E has to be smaller than β_P and is set at 0.97, as in Iacoviello (2005).[25] The inverse of the Frisch

[22] As mentioned in the introduction, here we limit the analysis to the interaction between large banks and monetary policy, which is certainly easier to understand. Our framework could, however, be extended to study the interaction with other types of policies, such as credit or macroprudential policy, which could deliver additional interesting results.

[23] See equation (29).

[24] Indeed, if one considers overall bank profits, empirical evidence suggests that they are procyclical (Albertazzi and Gambacorta 2009).

[25] Given this calibration, $\beta_P/\beta_E = 1.02680$, while $\mathcal{M}^b$ ranges between 1.006 (for the case of atomistic banks) and 1.02676 (for the case with $n = 3$). This guarantees that the collateral constraint is binding in the steady state (see footnote 14).

Table 1. Baseline Calibration

	Value	Description
β_P	0.996	Household Discount Factor
β_E	0.97	Entrepreneurial Discount Factor
ϕ	1	Inverse Frisch Elasticity of Labor Supply
α	0.30	Product Elasticity with Respect to Physical Capital
m^E	0.80	Entrepreneurs' LTV Ratio
ϵ^b	161	Elasticity of Substitution of Loans
ϵ^y	6	Elasticity of Substitution of Goods
κ_p	30	Price Stickiness
κ_i	0.4	Investment Adjustment Cost
δ^k	0.01	Depreciation Rate of Physical Capital
ζ^{A^E}	0.01	TFP Standard Deviation Innovation
$\zeta^{R^{ib}}$	0.0025	Monetary Policy Standard Deviation Innovation
ϕ_π	1.5	Strength of Monetary Policy Response to Inflation

elasticity ϕ is set at 1 (Galí 2008). The share of capital in the production function (α) and the depreciation rate of physical capital (δ^k) are set at 0.30 and 0.01, respectively. These values imply that the investment-to-GDP ratio and the entrepreneurs' share in consumption equal 0.13 and 0.09, respectively, similar to Gerali et al. (2010). The parameter governing the investment adjustment cost (κ^i) is set at 0.4 so as to obtain an impact response of asset prices after the shocks considered similar in magnitude to the one in Gerali et al. (2010), where it roughly moves one-to-one with GDP. The degree of price stickiness κ_p is set at 30, corresponding to a Calvo probability of not being able to adjust prices of roughly 66 percent, which implies that adjustment occurs, on average, every three quarters. The elasticity of substitution across goods ϵ^y is set at 6, implying a markup in the goods market of 20 percent. In the Taylor rule, the baseline calibration for the strength of monetary policy response to inflation ϕ_π is set at 1.5.

As regards the parameters related to the financial frictions and the banking sector, we set the LTV ratio m^E at 0.80. This implies that the steady-state debt-to-GDP ratio (at an annual frequency) is equal to 2.5, in line with the average private-sector debt-to-GDP ratio in Europe over the last five years. The debt-to-asset ratio is 0.79, which corresponds to the non-financial private-sector indebtedness of euro-area countries measured as a percentage of financial assets. The elasticity of substitution across loan varieties ϵ^b (which contributes to determining the steady-state loan spread) is set at 161, which implies, in the case of atomistic banks, a steady-state gross markup $\mathcal{M}^b$ of 1.006. This value, in turn, corresponds to a net spread between the loan rate and the policy rate of around 2.5 percentage points in annual terms.[26]

The non-stochastic steady state of the model is derived by setting the shocks to their mean value and assuming a gross inflation rate equal to one. The technology parameter A^E is normalized so that $y^E = 1$. In the zero-inflation steady state, the Phillips curve (25) implies that $mc = 1/mk^y$. From equation (28), the steady-state price of capital, q^k, equals 1. As usual, in the steady state, $R^{ib} = 1/\beta_P$. The steady-state values of R^b, c^P, k^E, and LV^E are obtained by solving simultaneously for the equations below (see appendix 3 for the derivation):

$$R^b = \mathcal{M}^b/\beta_P, \tag{36}$$

$$c^P = 1 - \frac{\alpha(1-\beta_E+\delta^k LV^E)}{[1-(1-\delta^k)LV^E(1-m^E)]mk^y} \tag{37}$$

$$k^E = \frac{\alpha LV^E}{[1-(1-\delta^k)LV^E(1-m^E)]mk^y} \tag{38}$$

$$LV^E = \frac{\beta_E R^b}{R^b-(1-m^E)\delta^k}, \tag{39}$$

where the markup in equation (36) is given by

$$\mathcal{M}^b = \frac{\epsilon^b(n-1)+\Sigma_b+\Sigma_{R^{ib}}}{\epsilon^b(n-1)+\Sigma_b-n} > 1, \tag{40}$$

and

$$\Sigma_{R^{ib}} = \frac{k^E mc\phi_\pi}{c^P\phi_\pi mc+\Psi[(mk^y-1)\kappa_p+\phi_\pi]}\left[\frac{LV^E}{\beta_E}-1\right] \tag{41}$$

$$\Sigma_b = LV^E/\beta_E. \tag{42}$$

[26]In particular, the gross (quarterly) policy rate is $R^{ib} = 1/\beta_p = 1.004$ and the gross loan rate is $R^b = R^{ib}\mathcal{M}^b = 1.01004$. The net annualized spread is therefore $400(R^b - R^{ib}) \simeq 2.4$ percentage points.

Figure 1. Relation between Bank Markup and Entrepreneurs' Leverage, for Different Values of the Number of Banks Operating in the Loan Market

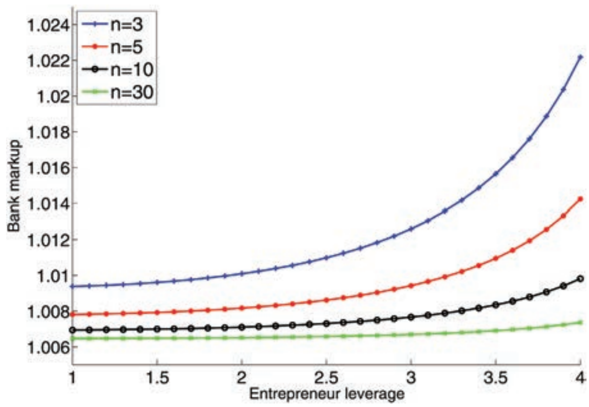
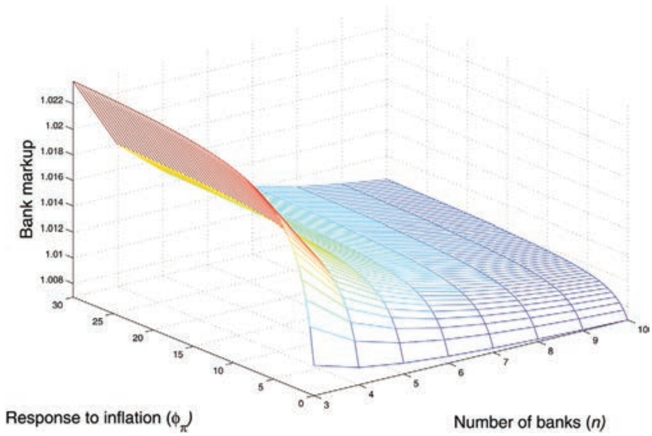


Figure 1 depicts graphically the relation between the steady-state level of the markup and the level of entrepreneurs' leverage (LV^E), under different assumptions regarding the number of banks. In particular, we study the cases in which the number of banks operating in the market equals three (line with + symbols), five (line with closed circles), ten (line with open circles), and thirty (light grey line).

A number of considerations are in order. First, the markup is positively related to the level of borrowers' leverage. In the previous section we commented how the effect of LV^E on $\mathcal{M}^b$ was in principle ambiguous, as it was positively related with both Σ_b and $\Sigma_{R^{ib}}$, which had opposite effects on the markup. The graphical result suggests that, in our calibration, the impact of LV^E on $\Sigma_{R^{ib}}$ prevails. Second, as the number of banks grows, $\mathcal{M}^b$ decreases—for any given value of LV^E—gradually converging to 1.006, which corresponds to the value of $\frac{\epsilon^b}{\epsilon^b - 1}$, that is, the value of the markup with atomistic banks. Moreover, as n increases, the positive relation with leverage also disappears, in line with the irrelevance of strategic interactions.

Figure 2 shows the relation among ϕ_π, n, and the bank's markup $\mathcal{M}^b$ in a tridimensional plot (with the remaining parameters still

Figure 2. Relation between Bank Markup, Degree of Monetary Policy Aggressiveness towards Inflation, and Number of Banks Operating in the Loan Market

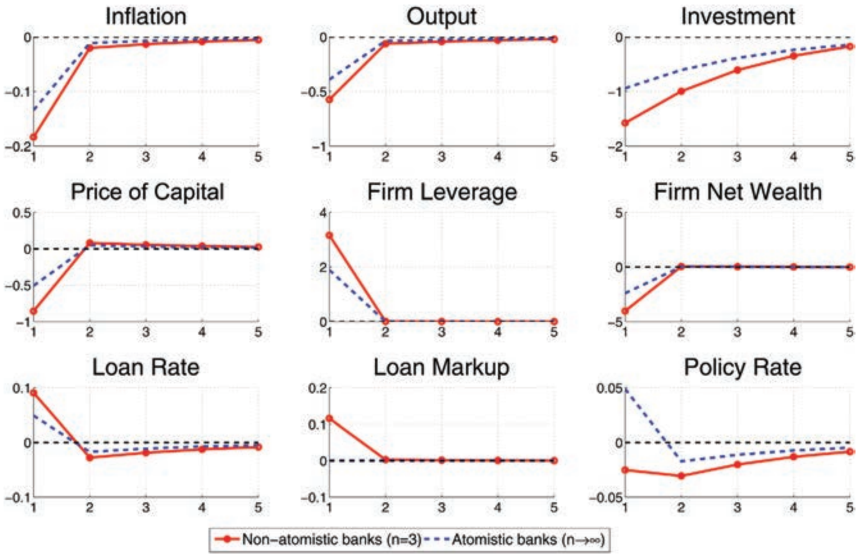


calibrated as in table 1). The value of entrepreneurs' leverage underlying the figure is 3. In this case, we note that the degree of central bank's inflation coefficient is positively related to the markup. Also in this case, note that this result holds as long as the number of banks is not too big (and therefore their size is non-negligible): symmetrically to the previous figure, as n grows, the association between ϕ_π and the markup weakens, with the latter converging to $\frac{\epsilon^b}{\epsilon^b-1} = 1.006$. These results underline a potential trade-off for the central bank regarding the choice of the appropriate degree of aggressiveness towards inflation: a higher ϕ_π stabilizes inflation to a larger extent, but it induces an increase in the degree of monopolistic power of banks in the long run.

5. The Financial Acceleration Markup and the Propagation of Shocks

We now turn to studying the dynamic responses of the model to a monetary shock and a technology shock, showing the impact of different calibrations for n and ϕ_π. We again refer to table 1 for the calibration of the other parameters. Since n and ϕ_π affect the steady state of the model, in the simulations we assume the existence of a

Figure 3. Impulse Response to a One-Standard-Deviation Contractionary Monetary Shock (percent deviation from steady state)



Notes: The figure compares the models with atomistic and large banks.

subsidy Υ (financed with a lump-sum tax) that fully offsets the effect of monopolistic competition in the banking sector, i.e., $\mathcal{M}^b/(1+\Upsilon)=1$, thus generating identical steady states in all models.[27]

We set the serial correlation of the technological and monetary shock equal to zero to help us understand the mechanisms at play. Figure 3 reports the response to a temporary monetary restriction (defined as a shock to $\varepsilon_t^{R^{ib}}$ in equation (1)), calibrating the inflation coefficient ϕ_π at 1.5. The dashed lines correspond to the case of atomistic banks, while the solid lines with circles correspond to the case of large banks with a loan market share of around 30 percent, i.e., $n=3$.

[27]Note that, given the existence of this subsidy, in contrast to footnote 14, the condition $\beta_P > \beta_E$ is sufficient to guarantee that the borrowing constraint is always binding, similarly to Iacoviello (2005).

Qualitatively, the response of the main variables is similar in the two cases. Following the shock, inflation and output drop, reflecting the contraction in consumption and the fall in investment. The price of capital and entrepreneurs' borrowing also fall. Entrepreneurs' leverage, however, increases as net wealth is hit more severely than the reduction in borrowing. This negative correlation between leverage and output is consistent with a passive management of capital structure of the firm and with the findings in Adrian and Shin (2010), Chugh (2009), and Levy and Hennessy (2007) (see section 2).

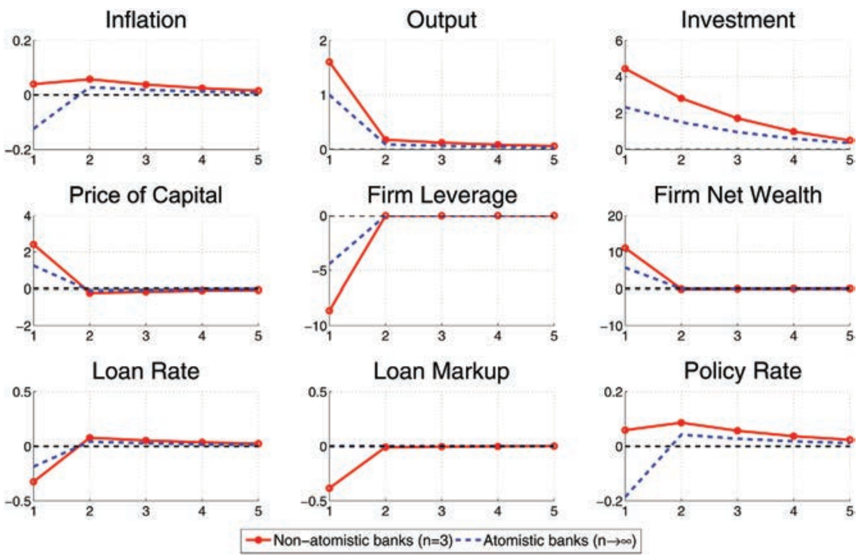
The presence of non-atomistic players, however, makes a significant quantitative difference. In this case, banks' markup is positively related to leverage and therefore increases following the contractionary shock. When banks are atomistic, there is a one-to-one relationship between changes in the loan rate and changes in the policy rate, as the markup is constant. As a consequence of the increase in the markup, the negative dynamics in the model get amplified, bringing about a stronger contraction in output.

This mechanism unveils the existence, in this context, of a new type of *financial accelerator*, which is crucially related to the presence of large banks. This mechanism is different in nature to the standard financial accelerator discussed in the literature on the credit channel (Bernanke and Gertler 1989; Bernanke, Gertler, and Gilchrist 1999; Kiyotaki and Moore 1997) and *adds up* to that channel, which is also at work in the model due to the presence of borrowing-constrained agents.

Figure 4 displays the response of the model to a positive productivity shock (see equation (9)), again comparing the case of atomistic banks and large banks. Also in this case, the presence of non-atomistic banks operates as an amplification mechanism of the fluctuations in the real variables. The size of the response of output and asset prices is roughly twice as large as in the case of atomistic banks. Again, the explanation is that the presence of large banks implies a countercyclical movement in banks' markup, which brings about (in the case considered) a stronger reduction in the loan interest rate. In addition, under our calibration the amplification effect on the demand size is such that inflation turns out to be positive with large banks.

In the previous two exercises, we kept the value of the central bank's inflation coefficient ϕ_π fixed at 1.5. However, as we noted

Figure 4. Impulse Response to a One-Standard-Deviation Expansionary Technology Shock (percent deviation from steady state)

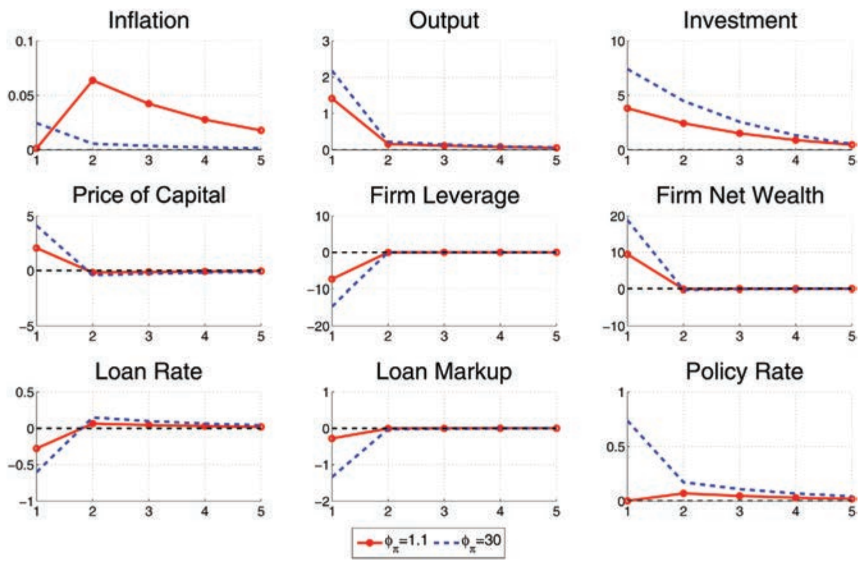


Notes: The figure compares the models with atomistic and large banks.

in section 3, the value of this parameter also has an impact on the dynamic response of the model to the shocks. Figure 5 compares, for the case of non-atomistic banks ($n = 3$), the response of the model to a positive technology shock assuming two different values of the central banks' inflation coefficient: (i) $\phi_\pi = 30$, which can be considered as the (extreme) case of monetary policy following a very strict inflation targeting,[28] and (ii) $\phi_\pi = 1.1$, that is, the case of a "weak" inflation coefficient. The figure shows that the (countercyclical) response of the markup is substantially stronger in the case of the aggressive inflation response. In turn, the increase in output, investment, and asset prices is also more pronounced.

[28] Results are qualitatively similar also assuming more realistic—though still high—values for ϕ_π, like 3 or 5.

Figure 5. Effect of Different Inflation Coefficients with a Positive Technological Shock and $n = 3$ (percent deviation from steady state)



6. Conclusions

In this paper we build a New Keynesian model with financial frictions and large banks, i.e., intermediaries that internalize the aggregate effects of their individual loan-pricing decisions. In the model, due to the strategic interactions between the large banks and the central bank, the bank loan spread is countercyclical. This mechanism generates a new type of financial accelerator, related to the market structure of the banking industry, which adds up to the one discussed in the literature on the credit channel. The loan markup depends positively on the level of borrowers' leverage and on the degree of the central bank's response to inflation in the Taylor rule.

The results identified in this paper are likely to have significant implications, both for the appropriate conduct of monetary policy and for financial stability considerations. For example, optimal monetary policy prescriptions may change once the strategic interaction between the central bank and large financial institutions is taken into account. Moreover, the effectiveness of various monetary and macroprudential policy settings may depend on the interaction of these policies with the behavior of non-atomistic banks. This analysis is left for future research.

Appendix 1. The Derivation of Equations (19) and (20)

From (14) and (15), we obtain

$$q_t^k - m^E q_{t+1}^k / R_t^b = \beta_E c_t^E / c_{t+1}^E \left[r_{t+1}^k + q_{t+1}^k (1 - m^E)(1 - \delta^k) \right]. \tag{43}$$

Using the definition of entrepreneurs' net worth in the text (18), the entrepreneurs' budget constraint can be rewritten as

$$c_t^E = nw_t^E - q_t^k k_t^E + b_t^E. \tag{44}$$

Now, we guess that entrepreneurs' consumption is a fraction $1 - \beta_E$ of net worth as follows:

$$c_t^E = (1 - \beta_E) nw_t^k. \tag{45}$$

Thus, plugging the guess into equation (43) yields

$$q_t^k k_t^E - b_t^E = \beta_E nw_t^E, \tag{46}$$

which corresponds to equation (20) in the text. Finally, in order to verify our initial guess and so equation (19), combine (46) and (44).

Appendix 2. The Bank's *u* Problem Solution

Impact of Bank Loan Rate on Aggregate Loan Rate

The loan rate set by a representative bank u is the same for all the types of loan supplied. We assume that each bank simultaneously sets the loan rate, $R_t^b(u)$, taking the other banks' loan rate as given. Thus, from the aggregate loan index,

$$R_t^b = \left[\int_0^1 R_t^b(j)^{1-\epsilon^b} \mathrm{d}j \right]^{\frac{1}{1-\epsilon^b}}, \tag{47}$$

we have that in a symmetric equilibrium, i.e., when $R_t^b(u) = R_t^b$,

$$\frac{\partial R_t^b}{\partial R_t^b(u)} = \frac{\partial}{\partial R_t^b(u)} \left[\int_{j \in u} R_t^b(j)^{1-\epsilon^b} \mathrm{d}j + \int_{j \notin u} R_t^b(j)^{1-\epsilon^b} \mathrm{d}j \right]^{\frac{1}{1-\epsilon^b}}$$
$$= \frac{1}{n} \left[\frac{R_t^b(u)}{R_t^b} \right]^{-\epsilon^b} = \frac{1}{n}. \tag{48}$$

Note that, because of symmetry, it is also true that

$$\frac{\partial R_t^b}{\partial R_t^b(u)} \frac{R_t^b(u)}{R_t^b} = \frac{\partial R_t^b}{\partial R_t^b(u)} = \frac{1}{n}. \tag{49}$$

Loan Demand and Policy Rate Elasticities to Aggregate Loan Rate Index

Define by

$$\Xi_{Z,t} \equiv \frac{\partial Z_t}{\partial R_t^b} \frac{R_t^b}{Z_t}$$

the elasticity of variable Z_t with respect to R_t^b. Banks' elasticities are computed *taking as given expectations* about variables in the next period.

When the borrowing constraint (8) is binding, we can use equations (21) and (23) and rewrite it as follows:

$$b_t^E = V_t^E LV_t^E nw_t^E.$$

As banks set the interest rate after having observed the entrepreneurs' net wealth (18), they also take the rental rate and price of capital as given. Thus, we can derive the following (perceived) relation

$$\Xi_{b,t} = \Xi_{V,t} + \Xi_{LV,t} = -1 + \Xi_{LV,t} \tag{50}$$

between the elasticity of loans demand and borrowers' leverage, which corresponds to $-\Sigma_{b,t}$ in the text (33).

Similarly, from the equilibrium condition for the labor market (19), the interest rate rule (1), and the production function (9), we obtain

$$\Xi_{y,t} + \Xi_{mc,t} + \Xi_{R^{ib},t} = (1+\phi)\Xi_{l^p,t}, \tag{51}$$

$$\Xi_{R^{ib},t} = \phi_\pi \Xi_{\pi,t}, \tag{52}$$

and

$$\Xi_{y,t} = (1-\alpha)\Xi_{l^p,t}. \tag{53}$$

Now, combining the budget constraint for households (3) and for entrepreneurs (7) yields the clearing condition in the final goods market:

$$y_t^E \left[1 - \frac{\kappa_p}{2}(\pi_t - 1)^2\right] = \frac{c_{t+1}^P}{\beta_P R_t^{ib}} + (1-\beta_E) n w_t^E + LV_t^E n w_t^E - q_t k_{t-1}(1-\delta^k).$$

Differentiate with respect to R_t^b and evaluate at zero net inflation, $\pi_t = 1$, the above resource constraint; using $\frac{\partial Z_t}{\partial R_t^b} = \Xi_{Z,t}\frac{Z_t}{R_t^b}$, it reads

$$y_t \Xi_{y,t} = n w_t^E LV_t^E \Xi_{LV,t} - c_t^P \Xi_{R^{ib},t} \tag{54}$$

and the New Keynesian Phillips curve (25) leads to the following expression:

$$\kappa_p(mk^y - 1)\Xi_{\pi,t} = mk^y mc_t \Xi_{mc,t}. \tag{55}$$

Finally, taking logs of the entrepreneurs' leverage (23) and differentiating with respect to R_t^b yields

$$\Xi_{LV,t} = -\frac{V_t^E}{1-V_t^E} = 1 - \frac{LV_t^E}{\beta_E}, \tag{56}$$

which corresponds to $-\Sigma_{LV,t}$ in the text (34). Expression (35) is derived by solving the system of equations (51)–(55) for $\Xi_{Z,t}$, where $Z \in \{y,\ mc,\ R^{ib},\ l^p,\ \pi\}$.

Banks' First-Order Condition

Taking the derivative of (29) with respect to $R_t^b(u)$ and using (31) yields at the symmetric equilibrium, $R_t^b(j) = R_t^b$,

$$R_t^b - \frac{(n-1)\epsilon^b\left(R_t^b - R_t^{ib}\right)}{n} + \frac{\left(R_t^b - R_t^{ib}\right)\frac{\partial b_t^E}{\partial R_t^b}\frac{R_t^b}{b_t^E}}{n} - \frac{\frac{\partial R_t^{ib}}{\partial R_t^b}R_t^b}{n}. \tag{57}$$

Substituting for $\frac{\partial b_t^E}{\partial R_t^b} = -\Sigma_{b,t}\frac{b_t^E}{R_t^b}$ and $\frac{\partial R_t^{ib}}{\partial R_t^b} = -\Sigma_{R^{ib},t}\frac{R_t^{ib}}{R_t^b}$ yields expression (30) in the text.

Appendix 3. The Steady State

Without loss of generality, we normalize the technology parameter A^E so that $y^E = 1$ in steady state. From the Euler equation (4) and the firms' optimal condition in the capital goods sector (28), we have that $R^{ib} = 1/\beta_P$ and $q = 1$. Thus, in steady state, equations (21), (23), and (20) read

$$V^E = b^E/k^E, \tag{58}$$

$$LV = k^e/nw^E, \tag{59}$$

and

$$LV = \beta_E/(1 - V^E). \tag{60}$$

At zero inflation, the New Keynesian Phillips curve yields $mc = 1/mk^y$ and the resource constraint is given by

$$c^P + nw^E(LV^E - 1) - R^b b^E + \alpha/mk^y + nw^E(1 - \beta_E) = 1. \tag{61}$$

From equations (19), (8), and (18) we have that

$$(l^p)^{1+\phi} = \frac{1-\alpha}{c^P mk^y} \tag{62}$$

and

$$b^E R^b = k^E m^E(1 - \delta^k), \tag{63}$$

$$nw^E + R^b b^E - \alpha/mk^y - k^E(1 - \delta^k) = 0. \tag{64}$$

Equations (37), (38), and (39) are derived by solving the system of equations (58)–(64) for c^p, k^E, LV^E, b^E, nw^E, l^p, and V^E.

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Discussion of "Large Banks, Loan Rate Markup, and Monetary Policy"*

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1. Introduction

Cuciniello and Signoretti (this issue, hereafter CS) provide a New Keynesian dynamic stochastic general equilibrium (NKDSGE) model with imperfect competition in the banking industry and collateral-constrained borrowers to address some important questions. How much does banking industry market structure amplify business cycles? How does strategic interaction between big banks and the central bank affect aggregate outcomes? The idea that bank market structure and real economic outcomes are connected is important, and I think the authors make a nice contribution to the literature.

CS establish some interesting results. First, strategic interaction among a small number (n) of banks generates countercyclical loan markups which depend on (i) the elasticity of substitution between loan types (ϵ^b), firm leverage, and how the central bank responds to inflation (ϕ_π) in its policy rule. Second, countercyclical markups amplify the transmission of monetary and technology shocks on the real economy, which is absent in the perfectly competitive case (i.e., constant markups when $n \to \infty$). Third, the level of the spread is positively related to firm leverage (using the accounting measure of capital assets to net worth). Fourth, amplification of financial (or technology) shocks is weaker (stronger) the more aggressive the central bank's response to inflation.

There is substantial heterogeneity in the banking sector. First, bank market structure varies substantially across countries. For instance, in 2011, the asset market share of the top three banks in

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Table 1. Measures of Competition in Banking

Moment	Value (%)	Std. Error (%)	Corr. with GDP
Net Interest Margin	4.56	0.01	−0.31
Lerner Index	43.11	0.38	−0.21
Markup	90.13	1.42	−0.27
Rosse-Panzar H	50.15	0.87	–

Source: FDIC, Call Reports, and Thrift Financial Reports. Values correspond to the time-series average of the loan-weighted cross-sectional averages. Consistent data available from 1984 to 2010.
Notes: Data correspond to commercial banks in the United States.

the following countries varied between Portugal at 89 percent, Germany at 78 percent, the United Kingdom at 58 percent, Japan at 44 percent, and the United States at 35 percent. While this heterogeneity provides a potentially important source of variation for identification, it is not necessarily exogenous and can vary, for instance, with government policy. Second, even within countries there is substantial heterogeneity among banks. If all banks within a country are symmetric, then asset market share is $1/n$. Symmetry would then imply, for example, that U.S. top three market share should be roughly 3/7000, not 35 percent. Obviously, symmetry is a strong simplifying assumption. Again, this heterogeneity is not necessarily exogenous and can vary, for instance, with government policy and region-specific shocks.

CS cite numerous papers which document countercyclical bank markups. For instance, table 1 (taken from Corbae and D'Erasmo 2013) uses Call Report data on all U.S. commercial banks from 1984 to 2010. Several of these papers provide evidence for imperfect competition in the banking sector including high margins and imperfect pass-through of costs (as measured by the Rosse-Panzar H-statistic). Countercyclical markups in the banking sector provide a new amplification mechanism. For instance, if markups on loans are countercyclical, then loan rates rise in a downturn, choking off investment and further amplifying the downturn. This is apparent in impulse response functions (shown below) for a model with an imperfectly competitive banking sector versus the perfectly competitive case.

This discussion will be organized in the following sections. Section 2 will briefly describe essential parts of CS's model, while section 3 will present some results. Finally, section 4 will discuss questions concerning robustness of the results as well as future directions.

2. Model

2.1 Environment

There are equal masses of two types of agents: (i) households (P) who work, deposit resources in bank, and consume; and (ii) entrepreneurs (E) who produce intermediate goods, accumulate capital, and take loans from banks which must be collateralized. Households discount the future at a lower rate than entrepreneurs (i.e., $\beta_P > \beta_E$), with β_E low enough that the entrepreneurs' collateral constraint always binds.

There are three types of non-financial firms: (i) capital goods producers who operate in a perfectly competitive market at real price q_t^k subject to adjustment costs; (ii) entrepreneurs who produce intermediate goods via a constant-returns-to-scale technology with white-noise aggregate productivity shock A_t^E; and (iii) retailers who differentiate intermediate goods, sell at a markup, and face quadratic price adjustment costs (which delivers a New Keynesian Phillips curve).

There are a finite number $n \geq 2$ of identical banks which collect deposits from households and issue loans to entrepreneurs. The deposit market is assumed to be perfectly competitive, while the loan market is modeled along the lines of Gerali et al. (2010), where loans of different types are aggregated using a Dixit-Stiglitz style aggregator with each bank having a share of total loans equal to $1/n$.

Finally, the central bank sets the interbank rate R_t^{ib} to lean against inflation wind (with sensitivity ϕ_π) according to the following rule:

$$R_t^{ib} = R^{ib} \pi_t^{\phi_\pi} \exp\left(\varepsilon_t^{R^{ib}}\right),$$

where the inflation rate is given by

$$\pi_t = \log(P_t) - \log(P_{t-1})$$

and $\varepsilon_t^{R^{ib}}$ is a white-noise policy innovation.

2.2 Equilibrium

Most of the model environment is familiar from earlier NKDSGE models. The two key differences, which I will highlight here, are the entrepreneur's collateral constraint and, more importantly, the finite number of banks choosing loan rates.

Entrepreneur i chooses consumption, capital, and loans $(c_t^E(i), k_t^E(i), b_t^E(i))$ to maximize the expected present discounted value of log utility subject to a standard budget constraint and an "ex ante" collateral constraint[1]

$$b_t^E(i) \leq \frac{E_t\left[m^E q_{t+1}^k k_t^E(i)(1-\delta^k)\right]}{R_t^b}, \tag{1}$$

where m^E is the "loan-to-value" ratio.

Using sufficient conditions such that the collateral constraint (1) is always binding, the first-order condition of the entrepreneur yields the loan demand decision rule:

$$b_t^E = \frac{\beta_E \chi_t}{q_t(R_t^b - \chi_t)} n w_t^E, \tag{2}$$

where

$$\chi_t \equiv (1-\delta^k) m^E E_t\left[q_{t+1}^k\right]$$

[1]Constraint (1) is used in several DSGE models (e.g., Iacoviello 2005). Its "microfoundations" are, however, different from Kiyotaki and Moore (1997). In Kiyotaki-Moore, there is no aggregate uncertainty, so ex ante is equal to ex post and the constraint makes default sub-optimal. But the ex post condition is what is relevant for the commitment problem. In particular, in period $t+1$, if entrepreneur i does not pay back, he gains $R_t^b b_t^E(i)$ but loses his collateral $q_{t+1}^k k_t^E(i)(1-\delta^k)$. For sufficiently low realizations of q_{t+1}^k, the entrepreneur might default ex post in the current model, which is not accounted for in the ex ante analysis.

and net worth is defined as

$$nw_t^E \equiv r_t^k k_{t-1}^E - R_t^b b_{t-1}^E + q_t^k (1-\delta^k) k_{t-1}^E. \tag{3}$$

After substituting necessary conditions, leverage is given by

$$LV_t = \frac{\beta_E}{\left(1 - \frac{b_t^E}{q_t^k k_t^E}\right)},$$

which yields countercyclical leverage (since $cor\left(Y_t, \frac{b_t^E}{q_t^k k_t^E}\right) < 0$).

An alternative interpretation of CS is that loans of size $b_t^E(i)$ must be "syndicated" according to a "loan production function" whereby entrepreneur i needs loans from banks $j = 1, 2, ..., n$, which solves the following cost-minimization problem:

$$\min_{\{b_t^E(i,j)\}_j} \sum_{j=1}^{n} R_t^b(j) b_t^E(i,j) \tag{4}$$

$$\text{s.t.} \quad \left[\left(\frac{1}{n}\right)^{\frac{1}{\epsilon^b}} \sum_{j=1}^{n} b_t^E(i,j)^{\frac{\epsilon^b - 1}{\epsilon^b}}\right]^{\frac{\epsilon^b}{\epsilon^b - 1}} \geq b_t^E(i). \tag{5}$$

The solution to this problem is given by

$$b_t^E(i,j) = \left(\frac{1}{n}\right)\left(\frac{R_t^b(j)}{R_t^b}\right)^{-\epsilon^b} b_t^E(i), \tag{6}$$

where

$$R_t^b \equiv \left[\frac{1}{n}\sum_{j=1}^{n} R_t^b(j)^{1-\epsilon^b}\right]^{\frac{1}{1-\epsilon^b}}. \tag{7}$$

CS assume that each bank j solves a static profit-maximization problem, choosing loan rate $R_t^b(j)$ to maximize profits:

$$\max_{R_t^b(j)} \prod \equiv \int \left[R_t^b(j) - R_t^{ib}\right] b_t^E(i,j) di, \tag{8}$$

where the demand for syndicated loan $b_t^E(i,j)$ is given by (6). Given a finite number of banks, a bank's choice of interest rate actually affects net worth of entrepreneurs in the future, which is not being taken into account owing to the static profit-maximization assumption.

The first-order condition which solves (8) weighs the costs and benefits to bank j from raising its interest rate:

(A) Direct positive effect of raising own rate on profits:

$$\left(\frac{R_t^b(j)}{R_t^b}\right)^{-\epsilon^b} b_t^E \cdot 1$$

(B) Indirect negative effect of competition from other banks (note that the elasticity of substitution between loans ϵ^b matters directly):

$$-\epsilon^b\left[R_t^b(j) - R_t^{ib}\right] b_t^E \cdot \left(\frac{R_t^b(j)}{R_t^b}\right)^{-(\epsilon^b+1)} \left\{\frac{\overset{(+)}{R_t^b - R_t^b(j)\frac{\partial R_t^b}{\partial R_t^b(j)}}}{\left(R_t^b\right)^2}\right\}$$

(C) Indirect negative effect on overall loan demand:

$$+\left[R_t^b(j) - R_t^{ib}\right]\left(\frac{R_t^b(j)}{R_t^b}\right)^{-\epsilon^b} \cdot \overset{(-)}{\frac{\partial b_t^E}{\partial R_t^b}}\overset{(+)}{\frac{\partial R_t^b}{\partial R_t^b(j)}}$$

(D) Indirect positive effect on central bank policy choice:

$$-\overset{(-)}{\frac{\partial R_t^{ib}}{\partial R_t^b}}\overset{(+)}{\frac{\partial R_t^b}{\partial R_t^b(j)}}\left(\frac{R_t^b(j)}{R_t^b}\right)^{-\epsilon^b} b_t^E$$

Importantly, in a symmetric Nash equilibrium, the solution to the above first-order condition yields the loan markup over the interest it pays depositors (also the central bank policy rate):

$$R_t^b = \frac{\overbrace{\epsilon^b(n-1)}^{B} + \overbrace{\Xi_{b,t}}^{C} + \overbrace{\Xi_{R_t^{ib}}}^{D}}{\underbrace{\epsilon^b(n-1)}_{B} + \underbrace{\Xi_{b,t}}_{C} - \underbrace{n}_{A}} \cdot R_t^{ib} \equiv \mathcal{M}_t^b R_t^{ib}, \qquad (9)$$

where

- $\Xi_{b,t}$ is the absolute value of the elasticity of aggregate loan demand to loan rates, and
- $\Xi_{R_t^{ib}}$ is the absolute value of the elasticity of central bank policy rates to loan rates (i.e., an increase in bank j's rate $R^b(j)$ increases the overall loan rate R^b, which lowers aggregate demand and inflation, which ultimately leads to a decrease in the central bank policy rate R^{ib}).

In a competitive environment where $n \to \infty$, the markup $\mathcal{M}_t^b$ in (9) simply depends on the elasticity of substitution between loans from different banks given by

$$\lim_{n\to\infty} \mathcal{M}_t^b = \frac{1}{1-\frac{1}{\epsilon^b}}$$

so that a higher degree of substitution leads to lower markups. The competitive case also implies that markups do not vary with the cycle.

With a finite number of banks, the cyclical properties of markups depend on many factors. Using the definition of markups in (9), one can compute $\frac{d\mathcal{M}_t^b}{dY}$ to determine the important factors in the cyclical properties of the markup. In particular, markups are countercyclical (i.e., $\frac{d\mathcal{M}_t^b}{dY} < 0$) if

$$\left\{\begin{array}{c} -\left[n+\Xi_{R_t^{ib}}\right]\cdot\frac{d\Xi_{b,t}}{dY_t} \\ +\left[\epsilon^b\cdot(n-1)+\Xi_{b,t}-n\right]\cdot\frac{d\Xi_{R_t^{ib}}}{dY_t} \\ -\left[\epsilon^b+(\epsilon^b-1)\cdot\Xi_{R_t^{ib}}-\Xi_{b,t}\right]\cdot\frac{dn_t}{dY_t}\end{array}\right\}<0, \tag{10}$$

where $\frac{d\Xi_{b,t}}{dY_t} < 0$ since leverage is countercyclical and $\frac{d\Xi_{R_t^{ib}}}{dY_t} < 0$ by an argument similar to that in bullet 2 following (9). Note that in (10) I have also considered how markups would vary in their model if the number of banks also varied with the cycle. Since $\frac{dn_t}{dY_t} = 0$ by assumption in CS's model, markups are countercyclical if the commercial versus central bank strategic impacts (i.e., the second term in (10)) outweigh the leverage effects across the cycle (i.e., the first term in (10)), provided ϵ^b is sufficiently large (which the calibration takes below).

3. Results

There are three key (new) parameters in CS's model: (i) the elasticity of substitution across loan varieties ϵ^b; (ii) the sensitivity of the central bank policy interest rate to inflation in the policy rule ϕ_π; and (iii) the number of banks n or market share $1/n$. Table 1 in CS provides the parameter values. In particular, loan elasticity (which affects the steady-state loan spread) is set at $\epsilon^b = 161$. The parameter is calibrated so that, in the case of atomistic banks (i.e., $n = \infty$), the steady-state gross markup $\mathcal{M}^b$ equals 1.006. This value, in turn, corresponds to a net spread between the loan rate and the policy rate of around 2.5 percentage points in annual terms. The central bank policy rule takes $\phi_\pi = 1.5$. The authors vary market structure (i.e., n) between 3 and infinity (the atomistic case).

Figure 1 below reproduces the impulse response functions under these parameter values for the more standard case where there is an AR1 technology shock process with persistence equal to 0.9 instead of i.i.d. shocks as in CS's figure 4 under both the atomistic ($n = \infty$) case and the non-atomistic ($n = 3$) case. Note that in order to make comparisons between the atomistic and non-atomistic cases, CS use a subsidy which fully offsets the distortion associated with monopolistic competition in the banking sector in the steady state (see section 5 of their paper).[2]

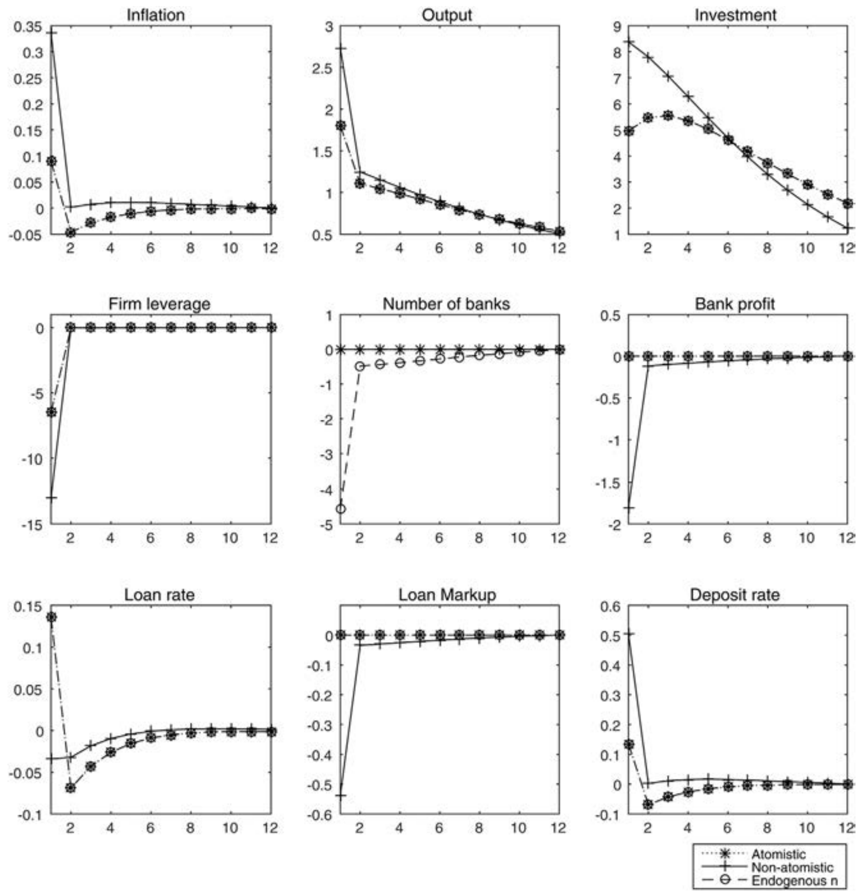
Figure 1 with persistent technology shocks is qualitatively similar to CS's figure 4 with i.i.d. shocks. Figure 1 makes clear that the

[2]In particular, they set Υ so that

$$\frac{\mathcal{M}^b_{ss}}{1+\Upsilon} = 1, \tag{11}$$

which means that the after-tax loan markup is 1. For the atomistic bank case, since $\mathcal{M}^b_{ss} = \frac{\epsilon^b}{\epsilon^b - 1}$, they set $\Upsilon = \frac{1}{\epsilon^b - 1}$. For the non-atomistic case, there is not a closed-form solution for Υ, as $\mathcal{M}^b_{ss}$ depends on Υ. So one must find a fixed point of Υ under which the after-tax markup is 1. CS set $\Upsilon = \mathcal{M}^b_{ss}(\Upsilon) - 1$.

Figure 1. Impulse Response Functions in CS Model



atomistic bank case ($n = \infty$ where loan markups do not vary with the cycle) yields less amplification in key variables than the non-atomistic case ($n = 3$ where loan markups are countercyclical). Here, however, figure 1 shows that the CS model predicts that profits with a finite number of banks are countercyclical in the short run. Empirical papers tend to find procyclical bank profits (see, for example, Albertazzi and Gambacorta 2009). Procyclical profits and countercyclical markups are consistent if loan originations are sufficiently procyclical (a property consistent with data).

4. Robustness

4.1 Exogenous Number of Banks

Obviously, in the very short run, one may want to take the number of banks n as a parameter, but surely in the long-run market share is not exogenous nor invariant to policy experiments as assumed by CS. To see the implications of exogenous market structure, one can use the same parameter values as in table 1 of CS's paper with persistent technology shocks but add a free entry condition.

As a result of the tax policy assumed in CS, steady-state bank profits are zero. Hence, to consider entry into the banking sector, we need to assume entry costs are zero. In that case, the zero-profit condition in a model with bank entry is

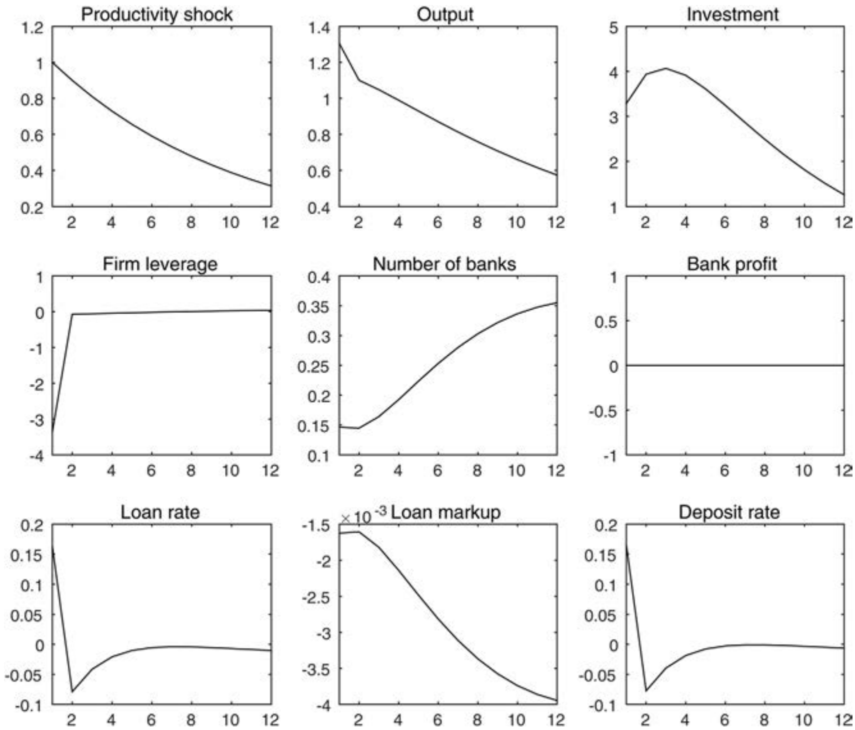
$$\left(\frac{\mathcal{M}_t^b}{1+\Upsilon} - 1\right) R_t^{ib} b_t^E = 0. \qquad (12)$$

Since $b_t^E > 0$, this implies that in the equilibrium with zero entry cost, the after-tax markup should always be 1. Thus the equilibrium allocation is exactly the same as in the case of the atomistic bank case, but (12) pins down the number of banks endogenously (i.e., the "atomistic" and "endogenous n" lines lie on top of one another).

As one can see from our figure 1 (compared with CS's figure 4) there are some key differences between the case with free entry (i.e., "endogenous n") and the baseline model ("non-atomistic") in CS. Free entry implies that the number of banks must actually fall in order to maintain the zero-profit condition, a counterfactual prediction (countercyclical entry in the model while there is procyclical entry in the data). This is related to the countercycical profits in CS's baseline "non-atomistic" case. Ceteris paribus, negative bank profits requires exit in order to be consistent with the zero-profit condition. Countercyclical entry (i.e., $\frac{dn_t}{dY_t} < 0$) in condition (10) is why there is less amplification in the "endogenous n" impulse response functions in figure 1. Thus, the channel between the "financial acceleration markup" and propagation of shocks is not necessarily robust.

There are other ways to generate the link between the "financial acceleration markup" and propagation of shocks. It is possible to write DSGE models with countercyclical markups due to the competitive effects of procyclical entry and countercyclical exit in the

Figure 2. Impulse Response Functions in CI Model



case of a finite number of *symmetric* firms. For instance, Jaimovich and Floettoto (2008) do this in the context of non-financial firms, and it is possible to apply their ideas to the banking industry. Figure 2 graphs the impulse response functions for a case with endogenous bank entry in Corbae and Ino (2015) (hereafter CI) without New Keynesian frictions but with positive entry costs. The figure shows that procyclical bank entry in response to a favorable productivity shock can lead to countercyclical markups even with perfectly flexible prices.[3] Of course, these DSGE models cannot speak to the vast heterogeneity in the bank size distribution due to their simplifying assumption on symmetry.

[3] For this particular parameterization, however, the effects are not large in figure 2.

4.2 Static Bank Optimization

CS assume that banks are "myopic" and choose interest rates not taking into account that their choice of interest rate may in fact alter future borrowing by entrepreneurs (and hence future profits) since each "non-atomistic" bank in their model has market power. It is possible, however, to incorporate forward-looking behavior and structure layers of non-competitive and competitive forward-looking firms (be they financial or non-financial). See, for instance, Gerali et al. (2010) and the appendix in Jaimovich and Floettoto (2008). This will be important if this framework is to be used to understand bank capital and macroprudential policies.

4.3 Symmetry

Ever since Kashyap and Stein's (2000) influential empirical paper, we know the monetary transmission mechanism works differently for big and small banks, but there has been little structural work on that topic. In order to simply the analysis, CS assume that all banks are symmetric, which is obviously inconsistent with the data. It is possible to introduce bank heterogeneity into structural models with imperfect competition and dynamic bank optimization using entry/exit (like that in Jaimovich and Floettoto) to generate countercyclical markups. In a series of papers, Corbae and D'Erasmo (2013, 2014a, 2014b) also generate a "financial acceleration markup" with heterogeneous banks at the expense of computational complexity.

4.4 Binding Collateral Constraints

Not all non-financial firms are collateral constrained in the economy. It may prove useful to apply methods from occasionally binding constraints to this framework (e.g., Guerrieri and Iacoviello 2015). This is also related to the fact that the steady-state debt-to-output level is 10 in CS's model but at most 3 in the data. If one sets $m^E = 0.375$ and $n = 3$, the model produces a steady-state debt level of 3 as opposed to $m^E = 0.8$ and $n = 3$ in CS's benchmark which yields a steady-state debt level of 10. The former case, however, yields a smaller response to technology shocks. In particular, output and investment are nearly half as large in response to a technology shock when the debt-to-output level is at 3 rather than 10.

5. Conclusion

CS take an important step to bring bank market structure into the DSGE framework. Their work provides a simple framework to ask how policy interacts with an exogenous market structure to affect aggregate outcomes and welfare. A particularly interesting and novel part of their analysis is how the strategic interaction between commercial banks with market power and the central bank can amplify shocks in the economy (i.e., term D in (9)).

CS's results are complementary to other papers. For instance, Corbae and D'Erasmo (2013, 2014a, 2014b) also generate a "financial acceleration markup" with an endogenous size distribution of banks through entry and exit affecting competitive market forces. Endogenizing market structure means that policy counterfactuals can affect market structure (i.e., there are no issues with the Lucas critique) as well as market structure affecting policy. I believe this to be a very fruitful avenue of future research.

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Systemic Risk and the Solvency-Liquidity Nexus of Banks*

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This paper highlights the empirical interaction between solvency and liquidity risks of banks that make them particularly vulnerable to an aggregate crisis. In line with the literature explaining bank runs based on the quality of the bank's fundamentals, I find that banks lose their access to short-term funding when markets expect they will be insolvent in a crisis. This solvency-liquidity nexus is found to be strong under many robustness checks and to contain useful information for forecasting the short-term balance sheet of banks. The results suggest that capital not only acts as a loss-absorbing buffer, but it also ensures the confidence of creditors to continue to provide funding to the banks in a crisis.

JEL Codes: G01, G21, G28.

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> "A more interesting approach would be to tie liquidity and capital standards together by requiring higher levels of capital for large firms unless their liquidity position is substantially stronger than minimum requirements. This approach would reflect the fact that the market perception of a given firm's position as counterparty depends upon the combination of its funding position and capital levels. . . . While there is decidedly a need for solid minimum requirements for both capital and liquidity, the relationship between the two also matters. Where a firm has little need of short-term funding to maintain its ongoing business, it is less susceptible to runs. Where, on the other hand, a firm is significantly dependent on such funding, it may need considerable common equity capital to convince market actors that it is indeed solvent. Similarly, the greater or lesser use of short-term funding helps define a firm's relative contribution to the systemic risk latent in these markets." Tarullo (2013)

1. Introduction

The main function of banks is to provide liquidity by offering funding (deposits) that is more liquid than their asset holdings (Diamond and Dybvig 1983). This liquidity mismatch, part of their business model, makes banks vulnerable to runs, as creditors can demand immediate repayment when the bank faces asset shocks. The rationale for studying the solvency-liquidity nexus of banks is based on the literature explaining bank runs based on the strength of the bank's fundamentals. In Allen and Gale (1998), banking panics are related to the business cycle where creditors run if they anticipate that the bank's asset values will deteriorate. Similarly, Gorton (1988) shows that bank runs are systematic responses to the perceived risk of banks.

Theoretical models on the two-way interaction between solvency and liquidity have been more recently developed. Diamond and Rajan (2005) show that bank runs, by making banks insolvent, exacerbate aggregate liquidity shortages. In Rochet and Vives (2004), there is an intermediate range of the bank assets value for which the bank is still solvent but can fail if too many of its creditors withdraw, and the range of the interval decreases with the strength of the bank's fundamentals. Then, Morris and Shin (2008) explain that bank runs come from both the bank's weak fundamentals and the “jitteriness” of its creditors. Therefore, the failure region of the bank would be smaller if both the bank and its creditors held more cash.

An implication of this literature is that systemic risk is likely to play a key role in the solvency-liquidity nexus through the liquidation costs caused by fire sales in a crisis. If the firm fails in isolation, its illiquid assets can be liquidated for a price close to their value in best use (Shleifer and Vishny 1992).[1] In a systemic crisis, however, potential buyers will be unable to find funding to buy the assets of the distressed firm. Creditors will consequently run from banks that are vulnerable to an aggregate shock, as they anticipate these banks will not be able to repay them in a crisis.

While the solvency-liquidity nexus has been well studied theoretically in the economic literature, the interaction between solvency and liquidity risks tends to be omitted in the new capital and liquidity regulatory standards. The liquidity coverage ratio (LCR) of Basel III imposes that financial firms hold a sufficient amount of high-quality liquid assets to cover their liquidity needs over a month of stressed liquidity scenario.[2] However, the liquidity needs according to this standard are essentially a function of the funding mix of the bank and do not depend on other bank’s fundamentals—in particular, on its capital adequacy and asset risks. Similarly, the required capitalization of a bank is not related to its exposure to funding liquidity risk.[3]

[1] Other fire-sale papers also relying on the Shleifer and Vishny (1992) insight include Acharya and Yorulmazer (2008); Acharya and Viswanathan (2011); Allen and Gale (1998, 2000a, 2000b, 2004); and Diamond and Rajan (2005, 2011).

[2] Next to the LCR, Basel III also introduces a net stable funding ratio (NSFR). The NSFR is the ratio of available stable funding to required stable funding over a one-year horizon. The required stable funding is determined based on the institution’s assets and activities (Basel Committee on Banking Supervision 2011).

[3] Funding liquidity risk is only likely to play a modest role via the interconnectedness measure used to derive the additional capital requirement for globally systemically important financial institutions (G-SIFIs). The systemic importance measure is the equally weighted average of the size, interconnectedness, lack of substitutes for the institution’s services, global activity, and complexity (Basel Committee on Banking Supervision 2013b). Interconnectedness is itself based on three indicator measures: intrafinancial system assets, intrafinancial system liabilities, and securities outstanding. Alternatively, some supervisory stress-test models explicitly feature funding liquidity feedbacks from the deterioration of the banks’ fundamentals as in the risk assessment model for systemic institutions (RAMSI) of Aikman et al. (2009) used at the Bank of England.

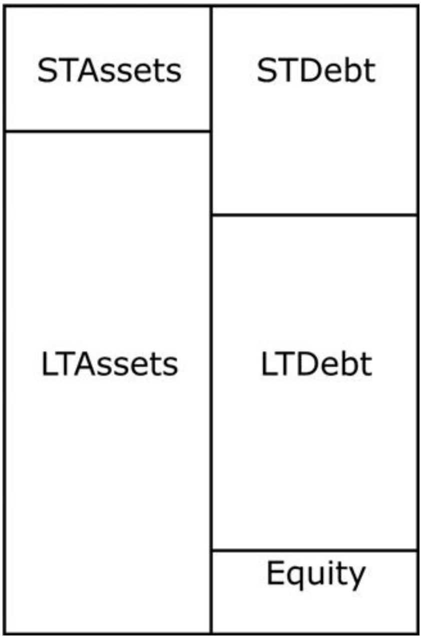
The solvency-liquidity nexus of banks has also not been the center of empirical studies investigating funding liquidity risk of the financial sector.[4] In this paper, I fill this gap in the literature and test whether the solvency-liquidity nexus of banks empirically holds by examining the short-term balance sheet of fifty U.S. bank holding companies over 2000–13. Short-term debt mainly consists of federal funds purchased and repurchase agreements (repos), uninsured deposits, and other short-term borrowings. Short-term assets include cash, federal funds sold and reverse repos, and short-term debt securities.

The difference between short-term debt and short-term assets is used in this paper as a proxy for the exposure of a firm to funding liquidity risk. Funding liquidity risk arises when a financial firm cannot roll over its existing short-term debt and/or raise new short-term debt. When the bank's short-term funding starts drying up, the firm needs a sufficient amount of liquid assets that can be converted into cash to repay creditors. The gap between its short-term debt and short-term assets is called the *liquid asset shortfall*. A negative liquid asset shortfall (liquidity excess) represents the amount of liquid assets that would be left if the bank lost its complete access to short-term funding (see figure 1 for a simplified view of the balance sheet of a bank).

I test for the solvency-liquidity nexus using several measures of solvency risk: regulatory capital ratios, market measures of risk (realized volatility, market beta), and a measure of the expected capital shortfall (*SRISK*) of the bank under aggregate stress defined by Acharya et al. (2010), Acharya, Engle, and Richardson (2012), and Brownlees and Engle (2011). According to *SRISK*, a firm is adequately capitalized to survive a crisis if its ratio of market capitalization to total assets remains larger than 8 percent when the market

[4]Related empirical studies include Das and Sy (2012), who document the trade-off between solvency and liquidity; banks with more stable funding and more liquid assets do not need as much capital to get the same stock return. Gorton and Metrick (2012) find that increases in repo rates are correlated to higher aggregate counterparty risk, whereas increases in repo haircuts are correlated to higher uncertainty about collateral values. Afonso, Kovner, and Schoar (2011) study the federal funds market and find increased sensitivity to bank-specific counterparty risk during times of crisis (both in the amounts lent to borrowers and in the cost of overnight funds).

Figure 1. Simplified Balance Sheet

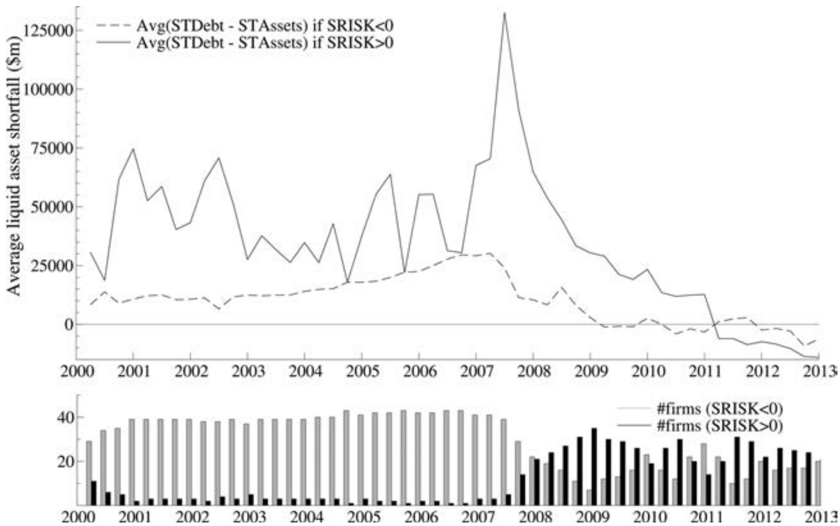


Notes: Liquid asset shortfall$_{it}$ $= STDebt_{it} - STAssets_{it}$. Capital shortfall$_{it}$ $= k * (STAssets_{it} + LTAssets_{it}) - Equity_{it}$. Expected capital shortfall in a crisis $SRISK_{it} = \mathrm{E}\left[k * (STAssets_{it+h} + LTAssets_{it+h}) - Equity_{it+h} | crisis_{t+h}\right] = k * (LTDebt_{it} + STDebt_{it}) - (1-k) * Equity_{it} * (1 + \mathrm{E}(R_{it+h}|crisis_{t+h}))$, where k is the prudential capital ratio (8 percent).

index falls by 40 percent over the next six months. This measure is an alternative to the capital shortfall estimates of regulatory stress tests that is purely based on publicly available market data (and therefore available at a higher frequency than stress-test outcomes).

I document three important results. First, I find that the bank's capital shortfall under stress (*SRISK)* determines how much short-term debt it can raise. This result supports the models of Allen and Gale (1998), Diamond and Rajan (2005), etc. explaining bank runs based on the strength of the bank's fundamentals. The consequences of this solvency-liquidity nexus are particularly severe for banks that are reliant on private short-term funding, in line with the introductory quote of D. Tarullo and some previous evidence that firms with more maturity mismatch have a larger contribution to systemic

Figure 2. Cross-Sectional Average of Liquid Asset Shortfall: Capital-Constrained Banks (Black Line) vs. Adequately Capitalized Banks (Dashed Line)



Notes: Liquid asset shortfall = Short-term debt – Short-term assets ($million). "Adequately capitalized" means $SRISK_{it} \leq 0$.

risk (Adrian and Brunnermeier 2010). Figure 2 illustrates well the solvency-liquidity nexus where capital-constrained banks (i.e., banks with a positive *SRISK*) had a larger average exposure to liquidity risk (measured by the difference between short-term debt and short-term assets) than adequately capitalized banks before the financial crisis. The average liquidity shortfall of capital-constrained banks reached a maximum of $133 billion in the third quarter of 2007. This exposure made them particularly vulnerable to the sudden freeze of short-term funding markets that followed.

Second, I show that not all solvency risk measures predict the short-term debt level of banks. The expected capital shortfall *SRISK* interacts well with the level of short-term funding of the bank compared with other measures of solvency risk because (i) it is a measure of the bank's exposure to aggregate risk, and (ii) it combines both book and market values. Relating to the model of liquidation costs of Shleifer and Vishny (1992), result (i) suggests that a bank with higher solvency risk in isolation does not necessarily get restricted access to short-term funding. What matters most for the suppliers of short-term funding is the vulnerability of the bank to an aggregate crisis. When this crisis occurs, result (ii) suggests that "pure" solvency risk (measured by the tier 1 leverage ratio), amplified by market shocks, explains the bank's access to short-term funding.

Third, the stressed solvency risk measure interacts with the bank's profitability (measured by its net income divided by total assets) in determining its short-term balance sheet. While a more profitable bank has greater access to short-term funding and does not hold as much in liquid assets, profitability does not have this beneficial effect on its short-term balance sheet when the bank is expected to be capital constrained in a crisis. For example, the positive net income of $2 billion of Citigroup in the third quarter of 2007 did not prevent the bank from losing 18 percent of its short-term funding (–$172 billion) the next quarter, as Citigroup was also highly undercapitalized according to *SRISK* ($51 billion expected capital shortfall in 2007:Q3). Therefore, maintaining a certain level of capitalization of the banking sector reduces systemic risk not only by addressing solvency risk problems of banks in a crisis but also by attenuating the solvency-liquidity nexus that makes banks particularly vulnerable to an aggregate crisis.

Finally, the solvency-liquidity nexus appears to be strong under many robustness checks (controlling for government interventions and common factors). Furthermore, out-of-sample forecasting results during the European sovereign debt crisis show that the solvency-liquidity interaction helps improve the forecasts of the short-term balance sheet of banks. Omitting *SRISK* in the model increases the forecasting errors of the liquid asset shortfall considerably, and particularly for capital-constrained banks.

Overall, the results of this paper suggest that the solvency-liquidity nexus should be accounted for when designing liquidity and capital requirements. The paper gives empirical support to the approach advanced by Tarullo (2013) to tie liquidity and capital requirements together by requiring banks with a large exposure to short-term funding to hold an additional capital buffer. The liquid asset buffer of the LCR might be a sufficient requirement from a microprudential perspective. However, the sudden drop in short-term funding for a bank that has a perfectly maturity-matched securities book (including repos and reverse repos) may also result in fire sales and increases the risk of contagion by transferring funding liquidity risk to the bank's customers. The supplementary capital buffer is a preemptive measure that would give creditors the confidence to continue to provide funding to the bank in a period of aggregate stress.

The rest of the paper is structured as follows. In section 2, I describe the short-term balance sheet of banks and their solvency risk measures. I test the solvency-liquidity nexus in section 3. I comment on the out-of-sample forecasting results in section 4, and conclude in section 5.

2. Short-Term Balance Sheet and Solvency Risk Measures

I define solvency risk and (funding) liquidity risk from the simplified representation of a bank's balance sheet in figure 1. A bank will be considered insolvent if it is not sufficiently capitalized to absorb future asset shocks. Solvency risk regulation defines the fraction of assets to be funded with equity such that a bank has a large-enough equity capital buffer to absorb asset losses when asset values deteriorate. As a result, a measure of solvency risk is usually defined as a measure of the bank's equity capital relative to a measure of its assets.

Next to solvency risk, funding liquidity risk is defined in Drehman and Nikolaou (2013) as "the possibility that over a specific horizon the bank will become unable to settle obligations with immediacy." Funding liquidity risk typically arises when the bank does not hold enough liquid assets that can be easily converted into cash to repay short-term creditors when they decide to withdraw. Liquidity regulation therefore ensures that the bank has a large-enough liquid asset buffer to cover all funding outflows over a given horizon.

Funding liquidity risk is related to the maturity mismatch of a bank that invests short-term funding in long-term assets. For the bank depicted in figure 1, a proxy for its maturity mismatch is the difference between its short-term debt and its short-term assets. The gap between the short-term debt and the short-term assets of a bank is called its *liquid asset shortfall* throughout, as I expect a bank with a larger maturity mismatch to be more exposed to funding liquidity risk. On the liability side, short-term creditors will be the first creditors to run, as they can simply decide not to roll over their short-term funding contracts. On the asset side, short-term assets are potentially the largest source of cash of the balance sheet.[5]

2.1 Long-Term vs. Short-Term Balance Sheet and the Liquid Asset Shortfall

The sample considered in this paper is a panel of forty-nine publicly traded U.S. bank holding companies (BHCs) reporting their regulatory accounting data over thirteen years from 2000:Q1 until 2013:Q1 (i.e., fifty-three quarters). This sample of banks corresponds to the intersection between the New York University Volatility Laboratory (V-Lab) sample for its global systemic risk analysis (that will be introduced in the next section), and the bank holding companies reporting under the FR Y-9C schedule (equivalent to the Call Reports of Condition and Income of commercial banks). The names of the BHCs and their market capitalizations are reported in the online appendix (appendix 5) on the *IJCB* website (http://www.ijcb.org).

I construct the short-term debt and short-term asset variables of these BHCs based on items extracted from their FR Y-9C reports from the SNL Financial database. The short-term debt is made up of uninsured time deposits of remaining maturity of less than a year, securities sold under agreements to repurchase (repos), federal funds purchased, and other borrowed money of remaining maturity of less than a year. The short-term assets include debt securities of remaining maturity of less than a year, interest-bearing bank balances (cash), securities purchased under agreements to resell (reverse repos), and federal funds sold. The components of short-term debt and short-term assets are described in appendix 1.

[5]Short-term assets will serve in this chapter as a proxy for liquid assets due to the lack of historical data for the assets included in the high-quality liquid assets (HQLA) definition of Basel III. High-quality liquid assets include cash, reserves at central banks, Treasury bonds, and non-financial corporate bonds and covered bonds with the highest ratings. Additional assets like highly rated residential mortgage-backed securities, non-financial corporate bonds and covered bonds with [A+, BBB–] rating, and common equity shares can be included in the HQLA stock with the appropriate haircuts specified in the LCR revision of 2013 (Basel Committee on Banking Supervision 2013a).

As the panel data set is unbalanced, I will restrict the following analyses to a smaller sample of forty-four banks for which the time-series dimension is larger than thirty observations.[6] I test the stationarity of the balance sheet quantities (in logarithms) in appendix 2, using the panel unit-root test robust to cross-sectional dependence of Pesaran (2007). This test indicates that the permanent impact of a shock on the size (measured by total assets) of a bank comes from shocks in the long-term balance sheet (where the unit-root hypothesis is not rejected), whereas the short-term balance sheet shocks revert to a trend level.[7] This result is consistent with the long-term balance sheet being the core business of the traditional bank that invests insured deposits (part of the long-term debt) in loans (long-term assets).[8]

The evolution of the average balance sheet of banks is shown in figure 3. The average size of the balance sheet (total assets) triples (from $85 billion to $280 billion) over the sample period and follows an increasing trend in the long-term balance sheet. Over this period, and particularly during the financial crisis, salient events include the acquisition of out-of-sample banks by in-sample banks (Golden West Financial sold to Wachovia in May 2006, Bear Stearns sold to JPMorgan in March 2008, Countrywide sold to Bank of America in July 2008, Washington Mutual sold to JPMorgan and Merrill Lynch sold to Bank of America in September 2008) and the acquisition of in-sample banks by other in-sample banks (National City Corp. sold to PNC and Wachovia sold to Wells Fargo in the last quarter of 2008).

For the purpose of testing the solvency-liquidity nexus, this paper focuses on the short-term part of the balance sheet. The acquisition of two major investment banks (Bear Stearns and Merrill Lynch) in 2008 brought a considerable amount of short-term

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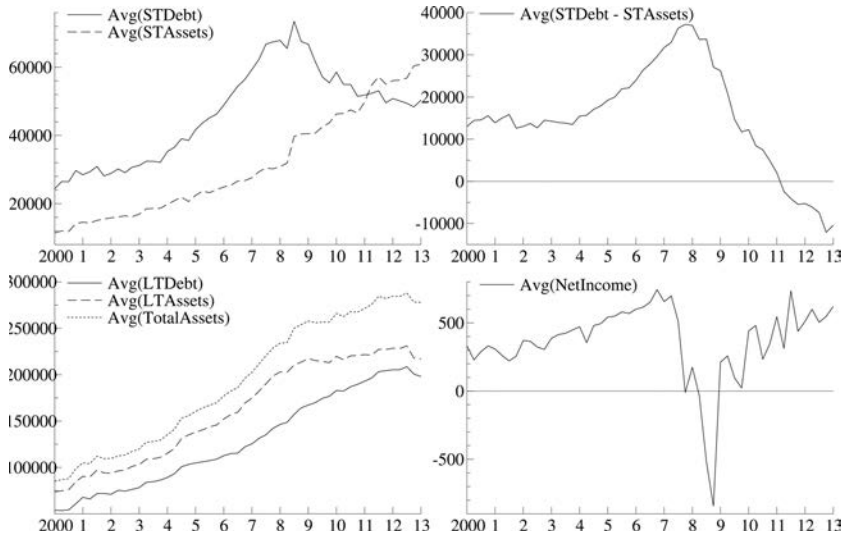
[6] This restriction excludes Goldman Sachs and Morgan Stanley from the sample, as they obtained the status of bank holding company at the end of 2008. The restriction also excludes American Express, CIT Group, and Discover Financial Services.

[7] The trend stationarity of the short-term balance sheet allows for estimating a dynamic panel data model directly on the levels in section 3, by applying standard estimation and inference techniques.

[8] The long-term debt (respectively, assets) is the difference between total liabilities (respectively, assets) and short-term debt (respectively, assets).

Figure 3. Cross-Sectional Averages of the Balance Sheet (in $million)



Notes: Top-left graph: short-term debt and short-term assets. Top-right graph: the difference between short-term debt and short-term assets. Bottom-left graph: total assets and long-term balance sheet. Bottom-right graph: net income.

debt and short-term assets into the banking sector. The increase in the average short-term balance sheet is considerable with the purchase of Bear Stearns (visible on JPMorgan's balance sheet in 2008:Q3). In comparison, the impact of the acquisition of Merrill Lynch (visible on Bank of America's balance sheet in 2009:Q1) on the average short-term balance sheet is attenuated, as several large banks were losing a significant amount of short-term funding at that time.

In contrast to an overall increasing trend in short-term assets, the average short-term debt slowed down in 2007:Q3 with the first signs of a "run on repo" in August 2007 (Gorton and Metrick 2012), visible on the short-term balance sheet of several large banks, including Citigroup, which lost $172 billion (18 percent) of short-term debt from 2007:Q3 to 2007:Q4. The average short-term debt of U.S. BHCs reached a peak in the third quarter of 2008 (with the acquisition of Bear Stearns) and declined afterwards.

The average liquid asset shortfall of the banking sector (the average of the difference between short-term debt and short-term assets) was the largest at the end of 2007 (also shown in figure 3), making banks particularly vulnerable to the sudden freeze in short-term funding markets. The short-term funding freeze was further accentuated by credit risk concerns at the end of 2008 with Lehman Brothers' bankruptcy and the most negative average net income of banks over the sample period (–$850 million).

Since the financial crisis, the average liquid asset shortfall of banks has declined, becoming negative in 2011 (i.e., banks now hold more short-term assets than short-term debt). Several circumstances explain the increase of banks' stock of short-term assets. A first explanation is linked to the persistent effect of the financial crisis on the real economy where the demand for loans has been slowly recovering and has been outpaced by deposit growth. As a result, banks have been investing in securities and (profitable) Treasury products.[9] In order to obtain secured short-term funding, banks also need to hold more short-term liquid assets than before due to stricter collateral requirements (higher haircuts). Then, higher liquid asset holdings by banks respond to precautionary concerns by banks (protecting against anticipated interest rate increase) and the regulator. Banks are encouraged by regulation to hold more short-term liquid assets to comply with both liquidity requirements (Basel III liquidity coverage ratio) and capital requirements (as holding short-term assets usually involves low regulatory capital requirements).

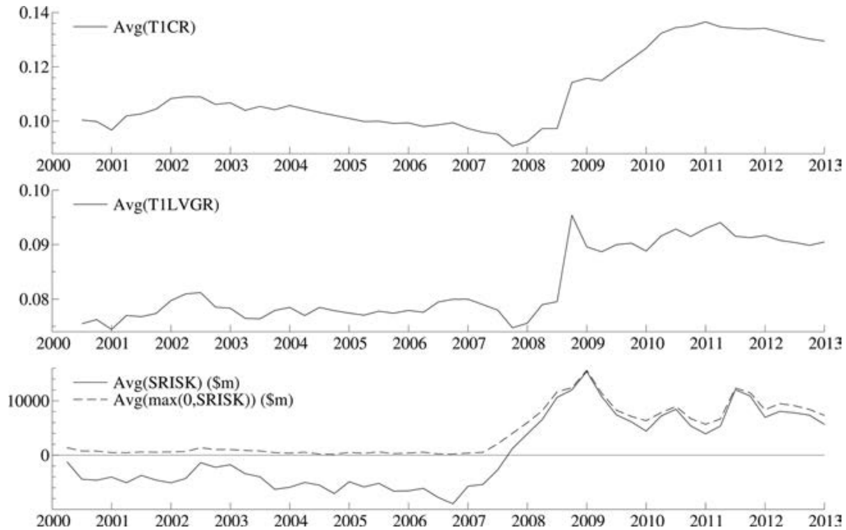
2.2 Solvency Risk Measures

2.2.1 Regulatory Capital Ratios

The regulator usually employs capital ratios to assess the solvency risk of a bank. Figure 4 displays the average regulatory capital ratios: the tier 1 common capital ratio ($T1CR$) and the tier 1 leverage ratio ($T1LVGR$). The tier 1 common capital ratio is the ratio of tier 1 common equity capital to risk-weighted assets, whereas the tier 1 leverage ratio is the ratio of tier 1 capital to total assets. The upward

[9] See "U.S. Banks Brace for Interest Rate Rises," *Financial Times*, February 24, 2011, and "Excess Deposits Demand Novel Responses," *Financial Times*, May 30, 2012.

Figure 4. Cross-Sectional Averages of Solvency Risk Measures



Notes: *T1CR* is the tier 1 common capital ratio (tier 1 common capital divided by risk-weighted assets); *T1LVGR* is the tier 1 leverage ratio (tier 1 capital divided by total assets); *SRISK* is the expected capital shortfall in a crisis.

shift in regulatory capital ratios in the fourth quarter of 2008 indicates a healthier banking system and coincides with the launch on October 14, 2008 of the Capital Purchase Program (CPP) and the Temporary Liquidity Guarantee Program (TLGP) under the Troubled Asset Relief Program (TARP). By purchasing assets and equity from troubled banks from October 2008 on, the TARP led to a significant increase in the average capital ratios. For example, Treasury bought $25 billion of preferred shares of Citigroup in October 2008 and another $20 billion in November 2008 under the CPP.[10]

2.2.2 Expected Capital Shortfalls in a Crisis

Acharya, Engle, and Richardson (2012) define the systemic risk contribution of a firm i to the real economy at time t as "the real social

[10] See http://www.treasury.gov/initiatives/financial-stability/reports/Pages/TARP-Tracker.aspx.

costs of a crisis per dollar of capital shortage(t)$\times$ Probability of a crisis(t) $\times$ $SRISK_{it}$," where $SRISK_{it}$ represents the expected capital shortfall of the firm in a crisis, i.e., when the market equity index drops by 40 percent over the next six months. In these market conditions, *SRISK* is based on the assumption that the book value of the (long-term) debt D_{it} of the bank will remain constant over the six-month horizon, while its market capitalization MV_{it} will decrease by its six-month return in a crisis, called the long-run marginal expected shortfall (*LRMES*). The expected capital shortfall in a crisis of bank i at time t is defined by

$$\begin{aligned} SRISK_{it} &= \mathrm{E}_t[k(D_{it+h} + MV_{it+h}) - MV_{it+h} | R_{mt+h} \leq -40\%] \\ &= kD_{it} - (1-k) * MV_{it} * (1 - LRMES_{it}), \end{aligned} \tag{1}$$

where R_{mt+h} is the return of the market index from period t to period $t+h$ ($h =$ six months), k is the prudential capital ratio (8 percent for U.S. financial firms), and $LRMES_{it} = -\mathrm{E}_t(R_{it+h} | R_{mt+h} \leq -40\%)$. Compared to other market-based measures of systemic risk like the CoVaR of Adrian and Brunnermeier (2010) or the distress insurance premium (DIP) of Huang, Zhou, and Haibin (2012), an interesting feature of *SRISK* is that it is a function of size and leverage, which are two characteristics that the regulator finds particularly relevant when measuring solvency risk of banks. *SRISK* can be written as a function of size, leverage, and risk:

$$SRISK_{it} = MV_{it} \left\{ k(Lvg_{it} - 1) - (1-k)(1 - LRMES_{it}) \right\}, \tag{2}$$

where Lvg_{it} is the quasi-market leverage defined as the ratio of quasi-market assets to market capitalization ($Lvg_{it} = (MV_{it} + D_{it})/MV_{it}$). Therefore, the capital shortfall of a bank will be large if the bank is large, highly leveraged, and highly sensitive to an aggregate shock as measured by $LRMES_{it}$.

These measures (*SRISK* and *LRMES*) are available from the V-Lab website developed at New York University's Stern School of Business.[11] In the global systemic risk analysis of V-Lab, *LRMES* is extrapolated from its short-term counterpart *MES*, which represents the daily return of the bank conditional on a 2 percent decline

[11] See http://vlab.stern.nyu.edu/.

in the daily return of a global market index. The *MES* is derived from a time-varying beta estimated with the dynamic conditional beta model of Engle (2012) that accounts for asynchronous trading around the world when measuring the co-movement of bank returns with a global market index.

By definition, *SRISK* can be negative when a bank is expected to have a capital excess in a crisis. In figure 4, we find two different regimes for the average *SRISK* of banks. Banks were in excess of capital in average (negative *SRISK*) before 2007. The average *SRISK* was the lowest in the third quarter of 2006, then started to increase in 2007. *SRISK* became positive in the fourth quarter of 2007 and reached a maximum average capital shortfall of $16 billion in the first quarter of 2009. The average capital shortfall has remained positive since the financial crisis (reflecting a low market-to-book ratio) and bumped several times afterwards, in particular in the heat of the European sovereign debt crisis in 2011.

3. Testing the Solvency-Liquidity Nexus of Banks

As liquidity risk concerns both sides of the balance sheet, I test for factors affecting both the short-term debt and the short-term assets of the bank. I use an autoregressive model for the logarithm of the short-term balance sheet, as panel unit-root tests indicate that the variables $y_{it} = \ln(STDebt_{it})$ and $z_{it} = \ln(STAssets_{it})$ are trend stationary (see appendix 2). Based on in-sample fit criteria, the model for both elements of $w_{it} = (y_{it}, z_{it})'$ is an autoregressive process of lag order one with bank dummies, and heterogeneous trend and dynamic parameters

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \delta' x_{it-1} + \varepsilon_{it}, \tag{3}$$

where α_i, ϕ_i, and θ_i are (2×1) vectors of parameters specific to bank i, x_{it} is a $(K \times 1)$ vector of stationary bank characteristics (including solvency risk measures), and $\odot$ is the Hadamard product.[12]

[12]The parameters of equation (3) are estimated by ordinary least squares. Judson and Owen (1999) report severe negative bias for the autoregressive parameters of dynamic panel regressions due to the small time-series dimension even when $T = 30$. The potential negative bias of autoregressive parameters has implications

Bank-specific parameters mainly reflect different business models and the resulting differences in aversion for funding liquidity risk.

The solvency-liquidity nexus may appear in different forms; I test for the direct effect of solvency risk on funding liquidity using *SRISK* (section 3.1) and alternative solvency risk measures (section 3.2), and for the interaction between profitability and solvency risk in predicting the short-term balance sheet (section 3.3). Then, I test the robustness of the solvency-liquidity nexus in section 3.4.

3.1 Testing the Solvency-Liquidity Nexus Using SRISK

The estimates of the interaction parameters (δ) of equation (3), where $x_{it} = SRISK_{it}/TA_{it}$, are reported in table 1 (column 1). This table reveals the Granger causality of solvency risk on the short-term balance sheet, where banks with a larger expected capital shortfall hold less short-term debt in the next quarter; the estimates suggest that a positive unit shock on the ratio of *SRISK* to total assets produces a -1.102 percent shock on the short-term funding of the bank.

This result supports the theoretical literature explaining bank runs based on the strength of the bank's fundamentals (Allen and Gale 1998; Diamond and Rajan 2005, etc.) and describing the interaction between liquidity and solvency problems of banks (Diamond and Rajan 2005; Morris and Shin 2008; Rochet and Vives 2004). The results also give empirical support to the recent speeches by Carney (2013) and Tarullo (2013) explaining that the repair of banks' balance sheet (i.e., higher capital levels) gives investors and creditors the confidence to continue to provide funding to banks.

From table 1, we also note that short-term assets do not react to solvency risk or short-term funding shocks, suggesting that banks are not able to adjust their stock of short-term assets to solvency risk or short-term funding conditions in a timely fashion. It also reflects a liquidity hoarding tendency of banks where banks prefer to sell long-term assets to repay short-term creditors. Banks prefer to hold the short-term assets for precautionary reasons or for investing in

for the stationarity of the endogenous variables of the panel regression. Running the regressions in first differences does not, however, qualitatively change the results on the δ parameter estimates.

Table 1. Testing the Solvency-Liquidity Nexus

	(1)		(2)		(3)	
Dep. Variable:	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}
$(SRISK/TA)_{it-1}$	−1.120**	0.074	−1.063**	−0.028	−0.935**	−0.120
	(0.244)	(0.114)	(0.245)	(0.118)	(0.261)	(0.101)
$(SRISK/TA)_{it-1} * s_{it-1}$					−0.408	1.757*
					(0.751)	(0.767)
z_{it-1}	−0.040		−0.038		−0.033	
	(0.023)		(0.023)		(0.022)	
$z_{it-1} * s_{it-1}$					−0.021*	
					(0.008)	
y_{it-1}		−0.003		−0.004		−0.002
		(0.022)		(0.021)		(0.022)
$y_{it-1} * s_{it-1}$						−0.007*
						(0.010)
$(NI/TA)_{it-1}$			2.354	−4.228	9.704**	−7.944*
			(2.278)	(2.331)	(3.290)	(3.716)
$(NI/TA)_{it-1} * s_{it-1}$					−9.902*	6.315
					(4.396)	(5.183)
s_{it-1}					0.347*	0.066
					(0.144)	(0.159)
R^2 (%)	20.811	22.157	20.870	22.318	21.278	22.562
Adj. R^2 (%)	15.430	16.808	15.450	16.997	15.715	17.089

Notes: Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. Column 1: model of equation (4), where $x_{it} = SRISK_{it}/TA_{it}$. Column 2: Model of equation (4), where $x_{it} = (SRISK_{it}/TA_{it}, NI_{it}/TA_{it})'$. Column 3: model of equation (4), where $x_{it} = (SRISK_{it}/TA_{it}, NI_{it}/TA_{it})'$ and with state variable $s_{it} = 1_{\{SRISK_{it}>0\}}$. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$. $(NI/TA)_{it} = NetIncome_{it}/TotalAssets_{it}$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. *SRISK* is the expected capital shortfall of the bank in a crisis. Robust standard errors are in parentheses. * denotes significant parameter at 5 percent; ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks.

fire-sale assets of other financial institutions that are expected to generate high future returns (Acharya, Shin, and Yorulmazer 2009).

"Reverse causality" tests (in appendix 3) indicate that a higher exposure to short-term debt has a positive impact on the capital shortfall *SRISK*. Therefore, the interaction between solvency and the short-term balance sheet is asymmetric; higher solvency risk limits the access of the firm to short-term funding, but a firm with more short-term debt has a higher risk of insolvency in a crisis. The second finding is, however, harder to interpret as a causal relationship, as short-term debt is more likely to be endogenous than solvency risk. I therefore concentrate on the first finding: banks with higher solvency risk are penalized by the market in their access to short-term debt.

3.2 Testing Alternative Solvency Risk Measures

I report the tests of alternative measures of solvency risk to predict the short-term balance sheet (y_{it} and z_{it}) in table 2, controlling for the market-to-book ratio, as the regression includes both accounting and market variables. Columns 1–5 show the individual impact of each measure. From this table, the regulatory capital ratios ($T1CR$ and $T1LVGR$) do not appear to be related to either side of the short-term balance sheet. Market measures of risk like the realized quarterly volatility are significant (at 5 percent) to predict short-term assets, but this result does not hold in the regression including all solvency risk factors (column 6). Then, the sensitivity of the bank's return to market shocks measured by the dynamic conditional beta (DCB) of Engle (2012), and the contribution of the bank to systemic risk measured by the delta CoVaR of Adrian and Brunnermeier (2010) are not significant drivers of the short-term balance sheet either. When all solvency risk factors are included in the regression (column 6), only *SRISK* per unit of asset and the market-to-book ratio are significant at the 1 percent level to predict the short-term debt level of banks.

The results of table 2 suggest that not all solvency risk factors can predict the shocks in the short-term balance sheet of banks. A bank with higher solvency risk in isolation does not necessarily get restricted access to short-term funding. However, banks lose short-term funding when they are expected to be insolvent in a systemic crisis. An explanation for this observation is based on the liquidation

Table 2. Testing Alternative Solvency Risk Measures

Dep. Variable:	(1)		(2)		(3)		(4)		(5)		(6)	
	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}
$T1CR_{it-1}$	0.301	−0.070									0.144	−0.088
	(0.337)	(0.134)									(0.555)	(0.360)
$T1LVGR_{it-1}$			0.508	−0.074							−1.163	−0.141
			(0.491)	(0.305)							(0.880)	(0.834)
$Real\ Vol_{it-1}$					−0.438	0.919*					0.693	0.977
					(0.412)	(0.450)					(0.426)	(0.547)
DCB_{it-1}							−0.046	0.030			−0.015	−0.001
							(0.027)	(0.034)			(0.028)	(0.039)
$\Delta CoVaR_{it-1}$									−0.402	0.188	0.078	0.108
									(0.761)	(0.784)	(0.758)	(0.800)
$(SRISK/TA)_{it-1}$											−1.587**	−0.077
											(0.069)	(0.142)
MB_{it-1}	0.042	−0.014	0.042	−0.014	0.035	−0.001	0.036	−0.011	0.041	−0.015	−0.052**	−0.005
	(0.026)	(0.017)	(0.025)	(0.017)	(0.027)	(0.017)	(0.025)	(0.019)	(0.024)	(0.017)	(0.018)	(0.022)
R^2 (%)	16.621	22.196	16.604	22.192	16.581	22.393	16.645	22.235	16.542	22.194	21.398	22.413
Adj. R^2 (%)	10.955	16.909	10.937	16.905	10.913	17.119	10.980	16.951	10.871	16.907	15.844	16.930

Notes: Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$. *T1CR*: Tier 1 common capital ratio, *T1LVGR*: Tier 1 leverage ratio, *Real Vol*: Realized volatility, *DCB*: dynamic conditional beta, *SRISK/TA* = *SRISK*/Total Assets, *MB*: market-to-book equity ratio. Robust standard are errors in parentheses. * denotes significant parameter at 5 percent; ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks.

costs of a firm's illiquid assets in a crisis. Shleifer and Vishny (1992) show that when a firm is individually in distress, its liquidation costs are not as high because the firm can find buyers in the same industry who value its illiquid assets at a price close to their value in best use. In a crisis, however, the potential buyers in the industry will likely also meet difficulties in obtaining funding and will not be able to buy those assets. The firm will then have to sell its illiquid assets to less specialized buyers outside the industry at a higher liquidation cost.

A bank that is expected to be insolvent in a crisis will be facing high liquidation costs and will consequently not be able to raise cash. Creditors who anticipate this based on publicly available data (such as those used to derive *SRISK*) will run from the bank, as they expect the bank will not be able to repay them. The liquidation costs during the 2008 financial crisis were exacerbated by the huge gap between short-term assets and short-term debt observed in section 2. As a result, banks had no choice but to sell illiquid assets to repay creditors when losing access to short-term funding.

In-sample fit criteria show the higher performance of *SRISK* in table 3 (first column) in predicting short-term funding; the adjusted R^2 is 15.7 percent compared with an adjusted R^2 around 11 percent for the regressions with the alternative solvency risk measures of table 2.[13] In order to identify what works so well in *SRISK* to predict the short-term funding of banks, table 3 also reports the estimates of the different components of *SRISK* highlighted in equation (2). The table shows that the improvement in in-sample fit comes from the ratio of market capitalization to total assets (MV/TA) rather than from the long-run marginal expected shortfall ($LRMES$) or the quasi-market leverage (Lvg). The main difference between Lvg and the ratio MV/TA is a different combination of book and market values; the ratio MV/TA is the product of the book leverage ratio ($T1LVGR_{it}$) and the market-to-book ratio (MV_{it}/BV_{it})

$$\frac{MV_{it}}{BV_{it}} = \frac{BV_{it} * (\frac{MV_{it}}{BV_{it}})}{TA_{it}} \backsimeq T1LVGR_{it} * \left(\frac{MV_{it}}{BV_{it}}\right),$$

[13]Note that all reported R^2 are on the first differences ($w_{it} - w_{it-1}$). The R^2 of levels (w_{it}) are very high (around 90 percent) given the bank-specific constant, trend, and autoregressive parameters.

Table 3. Testing *SRISK* Components

Dep. Variable:	(1)		(2)		(3)		(4)		(5)		(6)	
	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}
$(SRISK/TA)_{it-1}$	−1.439**	0.010										
	(0.105)	(0.100)										
$LRMES_{it-1}$			−0.162	0.205							−0.080	0.195
			(0.096)	(0.111)							(0.110)	(0.117)
Lvg_{it-1}					−0.002	0.001					−0.002	0.000
					(0.001)	(0.001)					(0.001)	(0.001)
$(MV/TA)_{it-1}$							0.930**	−0.002			0.925**	0.002
							(0.051)	(0.049)			(0.052)	(0.046)
$(SMV/TA)_{it-1}$									1.369**	−0.021		
									(0.080)	(0.116)		
MB_{it-1}	−0.048**	−0.014	0.032	−0.002	0.032	−0.007	−0.050**	−0.014	−0.051**	−0.013	−0.060	−0.001
	(0.016)	(0.022)	(0.025)	(0.019)	(0.027)	(0.019)	(0.019)	(0.021)	(0.016)	(0.022)	(0.020)	(0.024)
R^2 (%)	21.110	22.191	16.714	22.443	16.701	22.254	20.725	22.191	21.338	22.192	20.931	22.446
Adj. R^2 (%)	15.749	16.904	11.055	17.173	11.041	16.971	15.338	16.903	15.993	16.905	15.473	17.092

Notes: Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$. *MV*: market capitalization, *TA*: total assets, *Real Vol*: realized volatility, $SRISK/TA = SRISK/$Total Assets, *LRMES*: long-run marginal expected shortfall, *Lvg*: quasi-market leverage, *MB*: market-to-book equity ratio, $SMV/TA = MV * (1 - LRMES)/TA$. Robust standard errors are in parentheses. * denotes significant parameter at 5 percent; ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks.

whereas $Lvg_{it} = 1 + \frac{D_{it}}{MV_{it}}$ is not a function of the book leverage ratio. Market values are expected to reflect liquidity problems of banks, as they incorporate information about both solvency and liquidity risks. Therefore, any measure based on market values is not a "pure" solvency risk measure. The fact that the ratio MV/TA is a function of the book leverage ratio ($T1LVGR_{it}$)—a "pure" solvency risk measure—appears to be a crucial element in predicting short-term funding; it makes this ratio significant in the solvency-liquidity interaction compared with other solvency risk measures like the distance to default, which is an inverse function of market leverage (Lvg) and firms' assets volatility. The results of table 3 indeed suggest that both the book leverage ratio—informing about "pure" solvency risk—and the market-to-book ratio—informing about how fast the market values fall compared with book values—are important factors explaining banks' access to short-term funding. The ratio MV/TA is highly correlated to the book leverage ratio (0.91) and less correlated to the market-to-book ratio (0.44); solvency risk, amplified by market shocks, explains banks' access to short-term funding, and neither the market-to-book or the leverage ratio taken separately, nor their linear combination predict short-term funding.

The modest improvement in fit due to the downside risk of the bank in a crisis *LRMES* (0.66 percent increase of adjusted R^2 from column 4 to column 5, table 3) is consistent with the sample period that contains several episodes of market stress. In a crisis, everything is already a function of the aggregate shock. However, measuring the downside risk is important preemptively; I find increasing out-of-sample forecasting errors when MV/TA is employed in equation (3) instead of *SRISK/TA* for predicting the short-term balance sheet of banks during the European sovereign debt crisis (especially with the dynamic forecasting exercise of section 4).

3.3 Interaction between Solvency and Profitability

In Perotti and Suarez (2011), both liquidity risk and profitability are increasing functions of the short-term debt level of the bank. A bank will indeed demand more short-term funding when it finds profitable investment opportunities. Its liquidity risk will also increase, as its short-term debt will be invested in long-term profitable assets. The impact of the profitability of the bank measured by its net income divided by total assets is found to be positive on short-term debt and negative on short-term assets in table 1 (column 2), but these parameters are not significant at the 5 percent level.

The parameters of equation (3) are, however, expected to vary with the state of the bank and/or the aggregate liquidity conditions. In good times, short-term funding and short-term assets are the result of management decisions and are driven by demand factors. As mentioned, banks with profitable opportunities will demand more short-term funding. In bad times, supply factors determine how much short-term debt a bank can raise, and the short-term assets adjust accordingly. One way to disentangle supply and demand effects on the bank characteristics is to augment equation (3) with a state variable,

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \delta' x_{it-1} + \gamma' x_{it-1} * s_{t-1} + \omega s_{t-1} + \varepsilon_{it}, \quad (4)$$

where the state variable s_t could be a bank characteristic or a common factor. For example, Cornett et al. (2011) use the TED spread (the difference between the three-month LIBOR rate and the Treasury-bill rate) to reflect the change in the management of liquidity risk exposures of banks during the financial crisis.[14] In table 1 (column 3), I show that a good candidate for the state variable is simply a dummy variable equal to one when *SRISK* is positive ($s_{it} = 1_{\{SRISK_{it}>0\}}$), i.e., when the bank is expected to have a capital shortfall in a crisis.

This distinction between states where *SRISK* is positive or negative appears to be important when measuring the effect of the profitability of the bank on its short-term balance sheet. Indeed, a bank with a higher net income has greater access to short-term funding, while it does not hold as much in liquid assets. In table 1, this beneficial effect of the bank's profitability on its short-term balance sheet appears to be true only when the bank's *SRISK* is negative, i.e., when the bank is adequately capitalized to survive a crisis ($s_{it} = 0$). When the bank is expected to be capital constrained in a crisis ($s_{it} = 1$), the effect of profitability on its balance sheet disappears ($\delta + \gamma \simeq 0$), and only solvency risk predicts the short-term

[14]The TED spread is, however, not significant to predict the short-term balance sheet for the sample considered in this paper (cf. appendix 4).

debt of the bank. Therefore, the solvency-liquidity nexus appears to be exacerbated for capital-constrained banks; for these banks, only solvency risk explains access to short-term debt.

3.4 Robustness of the Solvency-Liquidity Nexus

3.4.1 Robustness to the TARP

On October 14, 2008, the U.S. government announced a series of measures—the Troubled Asset Relief Program (TARP)—to restore financial stability. Under the TARP, the Treasury Department launched the Capital Purchase Program (CPP) and the Federal Deposit Insurance Corporation (FDIC) launched the Temporary Liquidity Guarantee Program (TLGP). Treasury injected $205 billion in capital into banks under the CPP by buying warrants, common shares, and preferred shares.[15] Under the TLGP, the FDIC allowed financial institutions to retain and raise funding by giving a guarantee on existing non-interest-bearing transaction accounts and certain newly issued senior unsecured debt. Data on the amount and maturity of total unsecured debt issued by banks and guaranteed by the FDIC are publicly available.[16]

It is possible to derive the hypothetical amount of short-term debt a bank would have had if it had not benefited from government guarantees. The solvency-liquidity nexus estimates hardly change when TLGP funding is not taken into account. It is, however, difficult to project this scenario on the other variables (*SRISK* and short-term assets), as it requires knowing where TLGP funding was invested and how markets would have reacted in this scenario.

3.4.2 Robustness of the Solvency-Liquidity Nexus to Common Factors

The short-term balance sheets of firms are expected to co-move according to the aggregate liquidity conditions. To capture these common effects, I consider the macroeconomic and financial factors that are used in Fontaine and Garcia (2012) to relate to their

[15] See http://www.treasury.gov/initiatives/financial-stability/TARP-Programs/bank-investment-programs/cap/Pages/overview.aspx.

[16] See http://www.fdic.gov/regulations/resources/TLGP/index.html.

factor measuring the value of funding liquidity. The sensitivity of the short-term balance sheet to the common factors is tested in appendix 4.

I test the robustness of the solvency-liquidity nexus to the presence of common factors in

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \lambda' g_{it-1} + \beta' f_{t-1} + \varepsilon_{it}, \qquad (5)$$

where $w_{it} = (y_{it}, z_{it})'$; g_{it} is a $((2 * K + 1) \times 1)$ vector stacking x_{it}, $x_{it} * s_{it}$, and s_{it} in a single column; λ is a $((2 * K + 1) \times 2)$ vector containing the δ, γ, and ω parameters; and f_t is a vector of macroeconomic and financial factors.[17]

Chudik and Pesaran (2013) propose an alternative modeling strategy based on the Common Correlated Effects (CCE) of Pesaran (2006), where the unobserved common factors are proxied by the cross-sectional averages of the dependent variable and the regressors

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \lambda' g_{it-1} + \sum_{l=0}^{1} \varphi_l' \bar{w}_{t-l} + \kappa' \bar{g}_{t-1} + \varepsilon_{it}, \qquad (6)$$

where $\bar{w}_{t-l} = N^{-1} \sum_{i=1}^{N} w_{it-l}$ and $\bar{g}_t = N^{-1} \sum_{i=1}^{N} g_{it}$.

The estimation results of equation (5) and equation (6) are reported in appendix 4 (table A4). The fit improves considerably when common factors are included. The best in-sample performance is found with the CCE model for all elements of w_{it}. However, the CCE model counts a contemporaneous factor (average of the dependent variable), while the model with macro and financial factors only includes lagged factors. The macrofinancial model is therefore more convenient for forecasting, and the loss of in-sample fit is relatively small compared with the CCE model.

The solvency-liquidity nexus holds when I control for cross-sectional dependence. The interaction term between the profitability and *SRISK* is, however, not as important (not significant at the 5 percent level).

[17]Note that common factors do not necessarily need to be lagged, but this allows for the derivation of one-step-ahead forecasts for w_{it} without specifying a model for the common factors.

3.4.3 Short-Term Debt Components and Fixed Effects

The different components of short-term debt (repos, uninsured deposits, commercial papers, etc.) have very different characteristics and may not react to solvency risk with the same magnitude. Table A5 in appendix 4 reports the parameter estimates of equation (3) where the dependent variable in each column is a different component (in logarithm) of the short-term debt available from FR 9-YC reports. *SRISK* predicts most of the components of the short-term debt; it is significant at the 1 percent level for wholesale funding (federal funds, repos, and commercial papers) and at the 5 percent level for retail funding (uninsured time deposits and foreign office deposits).

Finally, an important result is that *SRISK* is only related to the short-term part of the balance sheet and does not predict long-term leverage. Table A6 in appendix 4 shows that the long-term balance sheet is not sensitive to *SRISK*. The long-term debt only reacts to short-term assets and the flows in long-term assets. Other robustness checks (not reported in this paper) show that the interaction between solvency and liquidity remains with homogenous dynamic parameters ($\phi_i = \phi, \forall i$), with homogenous trend parameters ($\theta_i = \theta, \forall i$), without trend ($\theta_i = 0, \forall i$), and when a break in 2008:Q4 is included in the trend. These results tend to confirm the robustness of the solvency-liquidity nexus. In the next section, I test for the out-of-sample forecasting performance of the solvency-liquidity nexus in predicting the short-term balance sheet of banks.

4. Forecasting the Short-Term Balance Sheet

To test for the out-of-sample predictive performance of the solvency-liquidity nexus, I conduct two forecasting exercises. Both exercises are based on a fixed estimation period from 2000:Q1 to 2010:Q4 to forecast the balance sheet of banks over the four quarters of 2011. The information is updated each quarter in the one-step-ahead forecasts ($\hat{w}_{it+1|t}$), while there is no information update in the dynamic forecasts ($\hat{w}_{it+h|t}$). The out-of-sample period corresponds to the European sovereign debt crisis. Funding conditions were not as tight as during the financial crisis in the United States, but the total decline of $161 billion in short-term funding of U.S. banks during this period indicates potential liquidity stress for some banks.

The root mean square forecasting error (RMSFE) of the one-step-ahead forecasting exercise is reported in table 4. In this table, I report the RMSFE of the short-term debt and short-term assets individually (panels A and B), as well as the RMSFE of their difference (panel C). As already mentioned, the liquid asset shortfall is a measure of the exposure of banks to funding liquidity risk; the wider the gap in the short-term balance sheet, the more vulnerable the bank to runs. As this paper studies the liquidity-solvency nexus of banks, I also report the RMSFE of this liquid asset shortfall for capital-constrained banks (panel D) vs. adequately capitalized banks (panel E).

Four models are considered: a univariate autoregressive model (AR), the model of equation (3) with bank characteristics (BC), the model of equation (4) that allows for the interaction of bank characteristics with the state variable $s_{it} = 1_{\{SRISK_{it}>0\}}$ (INT), and the model including all these features together with the macroeconomic and financial factors (equation (5)) (CF).

The assumption on the trend appears to be the most important model characteristic to impact forecasting errors. To check for the robustness of the forecasting results, I report the RMSFE of these models for different trend assumptions (heterogeneous trends, homogenous trend, no trend, and a break in the homogenous trend in 2008:Q4).

For the one-step-ahead forecasts, the best model is the dynamic model that accounts for the interaction of bank characteristics with *SRISK* (INT) and that assumes a break in the trend in the fourth quarter of 2008. When the trend parameters are constant over time, the model with common factors (CF) performs the best for the liquid asset shortfall, as common factors reflect the changing aggregate funding conditions after the financial crisis. In the last three columns of table 4, I report the increase in RMSFE when a particular bank variable is not included in the BC model. This table shows that omitting *SRISK* increases the forecasting errors of the liquid asset shortfall considerably, particularly for capital-constrained banks during 2011. However, the model with bank characteristics (BC) or the interaction with solvency risk (INT) does not improve the forecasts of adequately capitalized banks.

Table 4. Root Mean Square Forecasting Error (RMSFE): One-Step-Ahead Forecasting over 2011

Trend Assumption	AR	BC	INT	CF	ΔRMSFE (*SRISK*)	ΔRMSFE (*NI*)	ΔRMSFE (*STA*)
A. Forecasting the Short-Term Debt (Whole Sample)							
Heterogeneous Trends	18567	16338	16267	**11939**	1871	−236	451
Homogenous Trend	10239	10577	**7943**	10753	813	−519	−198
No Trend	8438	7943	**6801**	9046	1165	−185	−78
Trend Break	10038	8295	**7581**	12986	1252	−43	−148
B. Forecasting the Short-Term Assets (Whole Sample)							
Heterogeneous Trends	**13079**	13817	13596	15011	−113	84	−802
Homogenous Trend	**13477**	13828	13570	14381	45	−127	−228
No Trend	14632	15349	14483	**14176**	370	−192	−651
Trend Break	13235	13108	**12988**	13985	−60	−101	264
C. Forecasting the Liquid Asset Shortfall (Whole Sample)							
Heterogeneous Trends	19834	17374	15673	**13426**	1638	−301	
Homogenous Trend	15737	18475	16891	**15244**	370	−791	
No Trend	15999	17172	15952	**14915**	1629	−576	
Trend Break	14353	14159	**13993**	15782	225	−321	

(continued)

Table 4. (Continued)

Trend Assumption	**AR**	**BC**	**INT**	**CF**	**ΔRMSFE (*SRISK*)**	**ΔRMSFE (*NI*)**	**ΔRMSFE (*STA*)**
D. Forecasting the Liquid Asset Shortfall of Adequately Capitalized Banks ($SRISK_{it} \leq 0$)							
Heterogeneous Trends	7702	6443	6992	**4927**	87	−27	
Homogenous Trend	**5294**	6003	6672	5338	−185	−84	
No Trend	**5297**	6117	6666	5725	−58	−54	
Trend Break	**4431**	5374	5654	5081	−236	−49	
E. Forecasting the Liquid Asset Shortfall of Capital-Constrained Banks ($SRISK_{it} > 0$)							
Heterogeneous Trends	25413	22329	19858	**17267**	2214	−406	
Homogenous Trend	20337	23916	21615	**19658**	536	−1057	
No Trend	20692	22122	20326	**19125**	2226	−774	
Trend Break	18624	18170	**17877**	20439	358	−429	

Notes: Fixed estimation sample (2000–10), information updated each quarter. AR: univariate autoregressive model. BC: autoregressive model with bank characteristics (equation (3)), where $x_{it} = (SRISK_{it}/TA_{it}, NI_{it}/TA_{it})'$. INT: autoregressive model with bank characteristics and interaction with *SRISK* (equation (4)). CF: autoregressive model, with bank characteristics, interaction with *SRISK*, and common factors (equation (5)). ΔRMSFE(x) is the difference in RMSFE when variable x is not included in the BC model. Liquid asset shortfall = *STDebt* – *STAssets*. In bold: minimum RMSFE for each line (trend assumption).

I obtain very similar results for the dynamic forecasts and therefore do not report their RMSFE. Note that the RMSFE of dynamic forecasts are larger than the errors of one-step-ahead forecasts due to the absence of information updates over the forecasting horizon. The model with interaction with *SRISK* (INT) and a break in the trend after the financial crisis is also the preferred model according to the RMSFE of dynamic forecasts. The cross-sectional average dynamic forecasts obtained with this model for the short-term balance sheet levels and flows over 2011:Q1–2013:Q1 are illustrated in figure 5A. It turns out that the model is outstanding at forecasting short-term financing flows but is less successful at forecasting short-term asset flows, which are not sensitive to the factors considered in the model.

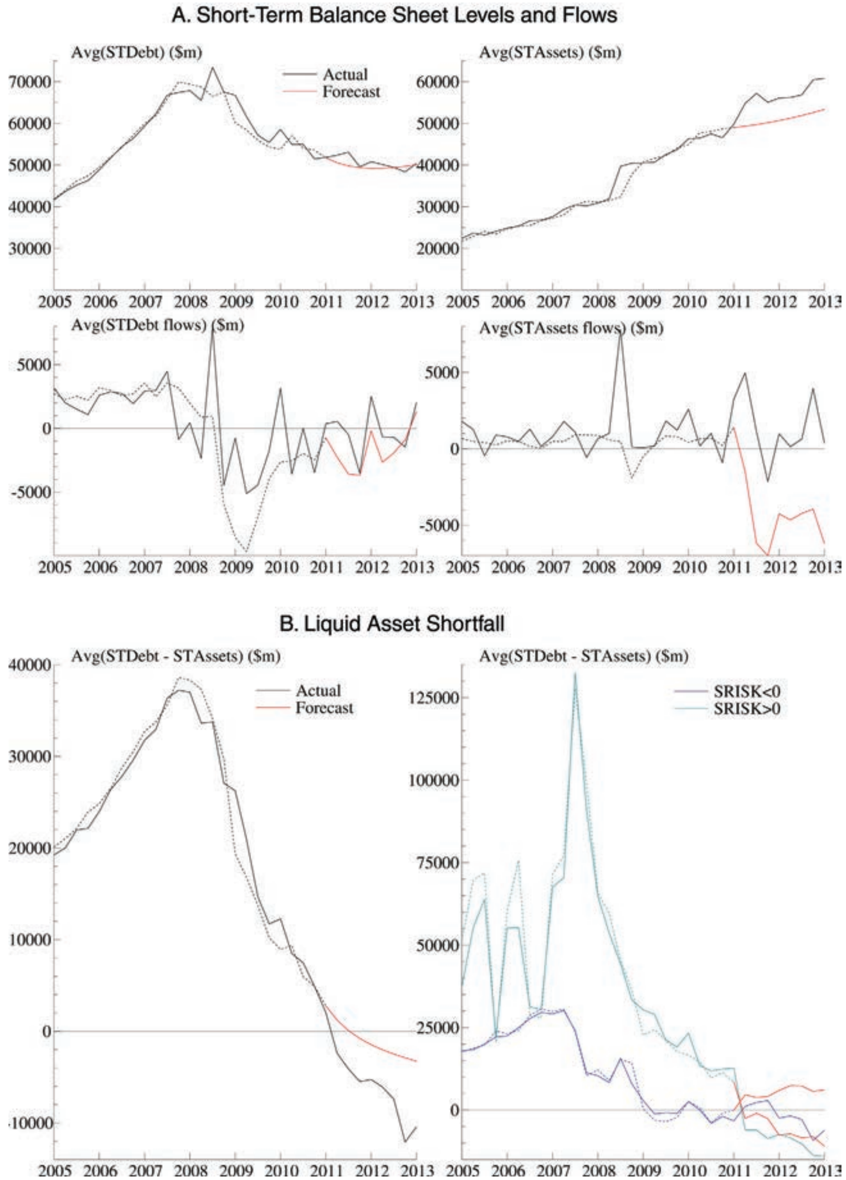
In figure 5B, I show the average dynamic forecasts of the liquid asset shortfall across all banks, as well as for the sub-samples of capital-constrained vs. adequately capitalized banks. As mentioned in the Introduction, the liquid asset shortfall of capital-constrained banks spiked in the first quarters of 2007 and suddenly dropped afterwards due to the sudden freeze of short-term funding markets. In the first quarter of 2011, the average liquid asset shortfall of capital-constrained banks became negative; capital-constrained firms are less exposed to funding liquidity risk than adequately capitalized banks for the first time over the sample period. The model predicts this reversal in the solvency-liquidity nexus and predicts well the average excess of liquidity of capital-constrained banks during this period.

5. Conclusion

This paper reveals the empirical solvency-liquidity nexus of banks. While the interaction between solvency and liquidity has been well studied in the theoretical economic literature, this relationship tends to be omitted in the new capital and liquidity regulatory standards introduced under Basel III. In this paper, I test the solvency-liquidity nexus by examining the short-term balance sheet and the solvency risk measures of a sample of U.S. bank holding companies over 2000–13.

I find that the expected capital shortfall of a bank in a crisis (*SRISK*) predicts how much short-term funding the bank has access to. This result appears to be strong under many robustness checks

Figure 5. Forecasting the Short-Term Balance Sheet over 2011:Q1–2013:Q1



Notes: The figure shows dynamic forecasts over 2011:Q1–2013:Q1—model with *SRISK* as a state variable (equation (4), break in trend).

and supports the theoretical models of the interaction between solvency and liquidity risks and its amplification (aggregate) effects leading to systemic risk.

Importantly, not all solvency risk measures predict the bank's access to short-term debt. The expected capital shortfall *SRISK* interacts well with the level of short-term funding of the bank compared with other solvency risk measures because (i) it is a measure of the bank's exposure to aggregate risk, and (ii) it combines both book and market values. Suppliers of liquidity are mostly concerned with the vulnerability of the bank to an aggregate crisis due to the high liquidation costs the distressed bank will face in the presence of fire sales. When the crisis happens, "pure" solvency risk (measured by the tier 1 leverage ratio) amplified by market shocks explains the bank access to short-term funding.

The expected capital shortfall of the bank under stress also interacts with its profitability in determining its short-term balance sheet. While a profitable bank gets greater access to short-term funding and does not hold as much in liquid assets, the impact of the bank's profitability on its liquidity profile tends to disappear when the bank is expected to be insolvent in a crisis.

The solvency-liquidity nexus provides useful information for forecasting the short-term financing flows during 2011 (European sovereign debt crisis). I show that the forecasting errors of the liquid asset shortfall of banks increase considerably when the stressed solvency risk measure is not included in the regression.

Overall, the results of this paper suggest that the solvency-liquidity nexus should be accounted for when designing liquidity and capital regulations, where macroprudential regulation of funding liquidity risk would be a combination of both liquid assets requirements and capital requirements. This paper suggests that maintaining the capitalization of the banking sector reduces systemic risk not only by addressing solvency risk problems of banks in a crisis but also by attenuating the solvency-liquidity nexus that makes banks particularly vulnerable to an aggregate crisis. Higher capital requirements for systemically important institutions serve a dual purpose: they act as a loss-absorbing buffer when banks' asset values deteriorate, and by improving banks' robustness to an aggregate crisis, they ensure the confidence of creditors to continue to provide funding to the banks.

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Appendix 1. Short-Term Debt and Short-Term Assets Composition

Composition of the Short-Term Debt Estimate (SNL Definitions)

- Federal Funds Purchased: The gross dollar amount of funds borrowed in the form of immediately available funds under agreements or contracts that mature in one business day or roll over under a continuing contract, regardless of the nature of the transaction or the collateral involved. Includes securities sold under agreements to repurchase that involve the receipt of immediately available funds and mature in one business day or roll over under a continuing contract.
- Repurchase Agreements: The gross dollar amount of security repurchase agreements that mature in more than one business day, other than securities sold under repurchase agreements to maturity, but including sales of participations in pools of securities that mature in more than one business day.
- Brokered Deposits ($<$ \$100,000, Maturity $\leq$ One Year): Brokered deposits issued in denominations of less than \$100,000 with a remaining maturity of one year or less and that are held in domestic offices of commercial banks or other depository institutions that are subsidiaries of the reporting bank holding company. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a brokered deposit.
- Time Deposits ($\geq$ \$100,000, Maturity $\leq$ One Year): Time deposits issued in denominations of \$100,000 or more with a remaining maturity of one year or less. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a time deposit.
- Foreign Office Time Deposits (Maturity $\leq$ One Year): All time deposits in foreign offices with remaining maturities of one year or less. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a time deposit.
- Commercial Paper: The total amount outstanding of commercial paper issued by the reporting bank holding company or its subsidiaries.

- Other Borrowed Money: The total amount of money borrowed by the consolidated bank holding company with a remaining maturity of one year or less. For purposes of this item, remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a borrowing without regard to the borrowing's repayment schedule, if any. Includes the dollar amount outstanding of all interest-bearing demand notes issued to the U.S. Treasury by the depository institutions that are consolidated subsidiaries of the reporting bank holding company. Also includes mortgage indebtedness and obligations under capitalized leases with a remaining maturity of one year or less. Also includes the total amount of money borrowed with a remaining maturity of one year or less: (i) on its promissory notes; (ii) on notes and bills rediscounted; (iii) on loans sold under repurchase agreements that mature in more than one business day; (iv) by the creation of due bills representing the bank holding company's receipt of payment and similar instruments, whether collateralized or uncollateralized; (v) from Federal Reserve Banks; (vi) by overdrawing "due from" balances with depository institutions, except overdrafts arising in connection with checks or drafts drawn by subsidiary depository institutions of the reporting bank holding company and drawn on, or payable at or through, another depository institution either on a zero-balance account or on an account that is not routinely maintained with sufficient balances to cover checks or drafts drawn in the normal course of business during the period until the amount of the checks or drafts is remitted to the other depository institution; (vii) on purchases of so-called term federal funds; and (viii) on any other obligation for the purpose of borrowing money that has a remaining maturity of one year or less and that is not reported elsewhere.

Composition of the Short-Term Assets Estimate (SNL Definitions)

- Cash and Non-Interest-Bearing Deposits: The total of all non-interest-bearing balances due from depository institutions, currency and coin, cash items in process of collection, and unposted debits. Includes balances due from banks in the United States, banks in foreign countries and foreign central banks, foreign branches of other U.S. banks, Federal Home Loan Banks, and Federal Reserve Banks.

- Total Interest-Bearing Balances: The total of all interest-bearing balances due from depository institutions and foreign central banks that are held in offices of the bank holding company or its consolidated subsidiaries.
- Federal Funds Sold: The gross dollar amount of funds lent in the form of immediately available funds under agreements or contracts that mature in one business day or roll over under a continuing contract. Includes securities purchased under agreements to resell that involve the receipt of immediately available funds and mature in one business day or roll over under a continuing contract.
- Reverse Repurchases Agreements: The gross dollar amount of security resale agreements that mature in more than one business day, other than securities purchased under resale agreements to maturity, and of purchases of participations in pools of securities that mature in more than one business day.
- Debt Securities Maturing or Repriced (Maturity $\leq$ One Year): All securities held by the consolidated bank holding company with a remaining maturity or amount of time remaining until next repricing date of one year or less. Held-to-maturity securities are reported at amortized cost, and available-for-sale securities are reported at fair value. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of the instrument without regard to the instrument's repayment schedule. Next repricing date is the date the interest rate on a floating-rate debt security can next change. (Y9 Line Item: BHCK0383)

Appendix 2. Stationarity of the Balance Sheet

To test for the stationarity of y_{it}, z_{it}, and other balance sheet quantities, I apply the unit-root test of Pesaran (2007) (CIPS) robust to cross-sectional dependence between individuals in the panel data

Table A1. Panel UR Tests: CIPS Statistics

	Intercept Only		Intercept and Trend	
	CIPS	**CIPS^b**	**CIPS**	**CIPS^b**
y_{it}	**−2.064**	**−1.922**	−2.725	−2.660
z_{it}	−2.538	−2.545	−2.798	−2.849
NI_{it}/TA_{it}	−3.541	−3.831	−4.101	−4.381
Y_{it}	**−2.071**	−2.199	**−2.274**	**−2.468**
Z_{it}	**−1.954**	**−2.098**	**−2.449**	**−2.584**
$\log(TA_{it})$	**−1.709**	**−1.932**	**−2.163**	**−2.336**
$SRISK_{it}/TA_{it}$	−2.579	−2.434	−2.951	−2.989

Notes: CADF 5 percent critical values: −2.11 (intercept only), −2.60 (intercept and trend). CIPS^b is the CIPS statistic based on a balanced panel data set. $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAsssets_{it})$, $Y_{it} = \ln(LTDebt_{it})$, $Z_{it} = \ln(LTAssets_{it})$, NI_{it}: net income, TA_{it}: total assets. In bold: UR hypothesis is not rejected.

set. The null hypothesis is $H_0 : \alpha_{21} = \alpha_{22} = \cdots = \alpha_{2N} = 0$, $i = 1, 2, \ldots, N$ (unit root), and the alternative $H_a : \alpha_{21} < 0, \ldots, \alpha_{2N_0} < 0$, $N_0 \leq N$ (a significant fraction of the panel is stationary). The regression for the CIPS unit-root test is

$$dy_{it} = \alpha_{0i} + \alpha_{1i} dy_{it-1} + \alpha_{2i} y_{it-1} + a_i d\bar{y}_t + b_i \bar{y}_{t-1} + c_i d\bar{y}_{t-1} + \theta_i t + \varepsilon_{it}, \quad (1)$$

where $d\bar{y}_t = N^{-1} \sum_{i=1}^{N} dy_{it}$, $\bar{y}_t = N^{-1} \sum_{i=1}^{N} y_{it}$. The CIPS test statistics are reported in table A1, for cases both with and without trend (i.e., $\theta_i = 0$, $\forall i$). Based on the CIPS statistics and given the critical values of the CADF distribution, y_{it} is stationary only when the regression includes a trend. The hypothesis of the absence of a trend is rejected based on a Wald test; therefore, y_{it} is considered trend stationary in the rest of the paper.

On the other bank sheet aggregates, the UR hypothesis is not rejected for the size (logarithm of total assets) and the long-term balance sheet (logarithm of long-term assets Z_{it} and long-term debt Y_{it}). Finally, the short-term assets, *SRISK,* and the net income divided by total assets are stationary with this test.

Appendix 3. Reverse Causality Test

Table A2. Reverse Causality Test

Dependent Variable:	$\boldsymbol{y}_{it}$	$\boldsymbol{z}_{it}$	$\boldsymbol{(SRISK/TA)}_{it}$
$(SRISK/TA)_{it-1}$	-1.120^{**}	0.074	
	(0.244)	(0.114)	
z_{it-1}	-0.040		**–0.001**
	(0.023)		**(0.002)**
y_{it-1}		-0.003	**0.009****
		(0.022)	**(0.002)**
R^2 (%)	20.811	22.157	**15.151**
Adj. R^2 (%)	15.430	16.868	**9.429**

Notes: Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. The reverse causality test is in the last column (in bold). Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. Robust standard errors are in parentheses. * denotes significant parameter at 5 percent, ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks.

Appendix 4. Robustness Checks

Robustness to Common Factors

The sensitivity of the short-term balance sheet (and its covariates) to the common factors is tested in

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \beta' f_{t-1} + \varepsilon_{it}, \tag{2}$$

where f_t is a vector of common factors.

Interest rates are expected to play an important role on the short-term balance sheet. Three factors related to interest rates are considered: the level of interest rates is captured by the federal funds rate, the difference between long-term and short-term rates is measured by the slope factor of the Treasury yield curve, and the TED spread reflects the perceived counterparty risk of interbank loans compared with Treasury loans. The TED spread is usually referred to as an aggregate funding liquidity risk factor (Cornett et al. 2011; Fontaine and Garcia 2012). In the sample considered, the TED spread is not significant to explain the short-term balance sheet directly but has a negative impact on the profitability of banks and a positive impact on their solvency risk (measured by *SRISK*).

The Treasury slope factor measures the difference between long-term and short-term interest rates. A steeper term structure indicates higher profitability of investing short-term funding in long-term assets (Fontaine and Garcia 2012). This factor also reflects business cycles and could be interpreted as a demand factor for liquidity. It is therefore not surprising to find that short-term debt increases with a steeper slope of the Treasury yield curve.

The positive and significant coefficient of the federal funds rate on short-term debt is more surprising and possibly reflects an endogenous response of the Federal Reserve to funding conditions during the financial crisis. Furthermore, Diamond and Rajan (2005) explain that higher interest rates do not always lead to lower excess demand for liquidity because of the effect of bank failures. Higher interest rates cause more banks to become insolvent and run (because of decreasing assets value). The excess demand will increase with interest rates if, by failing, banks absorb more liquidity than when solvent. Through these two channels (federal interventions and firms' failures), there is an endogenous feedback of aggregate liquidity and solvency risks on the level of interest rates.

Mortgage growth (MTG) increases the demand for short-term debt. MTG is referred to in Fontaine and Garcia (2012) as a factor exclusively affecting the demand for liquidity by increasing the pool of illiquid assets in the economy. Other considered factors include flight-to-quality variables related to money-market mutual funds (MMMF). The growth in MMMF assets (MMG) increases the supply of funding to banks via the shadow banking sector (Adrian and Shin 2009; Fontaine and Garcia 2012), but short-term funding supply decreases when MMMF assets are allocated to safer assets like time deposits (MMA1) or government-sponsored securities (MMA2).

The coefficient associated with MMA1 is negative and significant at the 1 percent level. This result could, however, simply reflect the increase of the FDIC deposit insurance limit in 2008:Q4. Acharya and Mora (2015) document the shift from time deposits and debt issued by banks (and MMA1) to government-sponsored securities (and MMA2), and the "liquidity reversal" in 2008:Q4 where MMA1 started to increase again. When the FDIC deposit insurance limit increased from $100,000 to $250,000 in the fourth quarter of 2008, uninsured deposits included in the short-term debt shifted to the long-term part of the balance sheet. Therefore, the negative impact

Table A3. Testing Common Factors

Dependent Variable:	y_{it}	z_{it}	$(NI/TA)_{it}$	$(SRISK/TA)_{it}$
Fedfund rate$_{t-1}$	0.045**	0.001	−0.031	−0.005
	(0.011)	(0.014)	(0.019)	(0.003)
Treasury slope$_{t-1}$	0.077**	0.013	−0.055	0.006**
	(0.023)	(0.026)	(0.029)	(0.001)
TED$_{t-1}$	0.003	0.043	−0.172**	0.009*
	(0.015)	(0.024)	(0.048)	(0.004)
VIX$_{t-1}$	0.003**	0.0004	−0.002	−0.00005
	(0.001)	(0.001)	(0.001)	(0.0002)
M2G$_{t-1}$	−4.308**	−0.366	0.255	0.154
	(1.351)	(1.035)	(1.078)	(0.171)
MTG$_{t-1}$	3.760**	−1.281	0.946	−0.748*
	(1.120)	(1.455)	(1.236)	(0.368)
MMG$_{t-1}$	0.463**	−0.308	−0.197	0.008
	(0.172)	(0.223)	(0.336)	(0.034)
MMA1$_{t-1}$	−1.994**	1.058	−0.592	−0.300**
	(0.455)	(0.601)	(0.628)	(0.073)
MMA2$_{t-1}$	0.265	−0.291	−1.510**	−0.181*
	(0.222)	(0.383)	(0.509)	(0.086)
R^2 (%)	21.996	23.816	44.559	19.217
Adj. R^2 (%)	16.399	18.350	40.609	13.461

Notes: Estimates from pooled OLS regression with bank dummies, time trends, heterogeneous AR parameters, and common factors. Robust standard errors are in parentheses. * denotes significant parameter at 5 percent, ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks. Treasury slope is the slope factor of the Treasury yield curve. M2G: money supply growth (M2). MTG: mortgage assets growth. MMG: MMMF assets growth. MMA1: proportion of MMMF assets allocated to time deposits. MMA2: proportion of MMMF assets allocated to Treasury, agency, or municipal bonds. Data sources: Federal Reserve Board Selected Interest Rates—H.15 (federal funds rate); FRB Money Stock Measures—H.6 (M2 money supply growth); FRB Financial Accounts of the United States—Z.1 (MMMF flows, mortgage growth); Department of the Treasury (Treasury yield curves); Bloomberg (VIX).

of MMA1 on banks' short-term debt is partly explained by the reallocation in 2008:Q4 of some previously uninsured time deposits (part of the short-term debt) to the long-term debt within banks' balance sheets.

We also note the positive coefficient of the VIX, as banks' exposure to short-term debt was the highest when the VIX peaked during the financial crisis. Finally, short-term assets are not sensitive to any of the considered factors. While the level of short-term assets adjusts to shocks in other parts of the balance sheet, it is not directly affected by financial and macroeconomic conditions.

Table A4. Robustness of the Solvency-Liquidity Nexus to Common Factors

	No Common Factor		Common Factors		Common Correlated Effects	
Dep. Variable:	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}
$(SRISK/TA)_{it-1}$	−0.935**	−0.120	−0.847**	−0.178	−0.900**	−0.137
	(0.261)	(0.101)	(0.318)	(0.096)	(0.280)	(0.106)
$(SRISK/TA)_{it-1} * s_{it-1}$	−0.408	1.757*	−0.687	1.291	−1.413	2.384*
	(0.751)	(0.767)	(0.853)	(0.861)	(0.974)	(1.009)
$(NI/TA)_{it-1}$	9.704**	−7.944*	8.111*	−7.564*	8.512*	−7.964*
	(3.290)	(3.716)	(3.677)	(3.575)	(3.542)	(3.905)
$(NI/TA)_{it-1} * s_{it-1}$	−9.902*	6.315	−8.087	4.817	−7.181	7.926
	(4.396)	(5.183)	(4.788)	(4.920)	(4.655)	(5.512)
z_{it-1}	−0.033		−0.008		0.0004	
	(0.022)		(0.024)		(0.024)	
$z_{it-1} * s_{it-1}$	−0.021*		−0.018*		−0.013	
	(0.008)		(0.008)		(0.008)	
y_{it-1}		−0.002		0.002		0.004
		(0.022)		(0.002)		(0.020)
$y_{it-1} * s_{it-1}$		−0.007*		−0.010		−0.013
		(0.010)		(0.009)		(0.010)
s_{it-1}	0.347*	0.066	0.327*	0.098	0.253	0.148
	(0.144)	(0.159)	(0.140)	(0.154)	(0.140)	(0.158)
R^2 (%)	21.278	22.562	25.079	24.247	26.730	27.265
Adj. R^2 (%)	15.715	17.089	19.416	18.521	21.192	21.767

Notes: Estimates from pooled OLS regression with bank dummies, time trends, heterogeneous AR parameters, and state variable $s_{it} = 1_{\{SRISK_{it}>0\}}$. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$. $(NI/TA)_{it} = NetIncome_{it}/TotalAssets_{it}$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. No Common Factor: regression without common factors. Common Factors: regression with all (lagged) common factors of table A3. Common Correlated Effects: regression with common correlated effects. Robust standard errors are in parentheses. * denotes significant parameter at 5 percent, ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks.

Short-Term Debt Components

Table A5. Testing the Solvency-Liquidity Nexus: Short-Term Debt Mix

Dep. Variable:	y_{it}	FFRepo	BR Dep	Time Dep	For Dep	ComPaper	OtherBor
$(SRISK/TA)_{it-1}$	−1.063**	−1.217**	0.147	−0.363*	−1.155*	−2.330**	−0.281
	(0.245)	(0.403)	(0.518)	(0.175)	(0.531)	(0.364)	(0.377)
$(NI/TA)_{it-1}$	2.354	0.152	−11.694	−1.660	10.880	17.540	3.249
	(2.278)	(2.437)	(8.376)	(4.733)	(6.282)	(10.392)	(9.375)
z_{it-1}	−0.038	0.015	−0.028	−0.046*	−0.191*	−0.091	−0.233**
	(0.023)	(0.051)	(0.096)	(0.019)	(0.093)	(0.083)	(0.079)
No. Observations	2107	1979	950	2096	1337	966	2035
No. Banks	44	44	40	44	34	27	44
R^2 (%)	20.870	19.723	23.649	34.947	38.600	25.330	22.656
Adj. R^2 (%)	15.450	13.843	12.279	30.459	33.355	18.187	17.152

Notes: Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. Dependent variables: log of the different components of the short-term debt (see definitions in appendix 1): federal funds and repos (FFRepo), brokered deposits (BR Dep), uninsured time deposits (Time Dep), foreign deposits (For Dep), commercial papers (ComPaper), and other borrowed money (OtherBor). Robust standard errors are in parentheses. * denotes significant parameter at 5 percent, ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks.

Long-Term Balance Sheet

Table A6. Testing the Solvency-Liquidity Nexus: Short-Term vs. Long-Term Balance

Dep. Variable:	$\boldsymbol{dY}_{it}$	$\boldsymbol{dZ}_{it}$	$\boldsymbol{y}_{it}$	$\boldsymbol{z}_{it}$
$(SRISK/TA)_{it-1}$	−0.013	−0.039	-1.059^{**}	−0.038
	(0.024)	(0.038)	(0.235)	(0.118)
$(NI/TA)_{it-1}$	−0.870	0.290	2.313	−4.185
	(0.592)	(0.508)	(2.232)	(2.348)
z_{it-1}	-0.035^{**}	−0.006	−0.034	
	(0.005)	(0.006)	(0.024)	
y_{it-1}	−0.0004	-0.018^{**}		−0.002
	(0.006)	(0.006)		(0.022)
dZ_{it-1}	0.101^{*}		0.004	−0.110
	(0.046)		(0.109)	(0.116)
dY_{it-1}		-0.104^{*}	−0.137	0.157
		(0.052)	(0.199)	(0.096)
R^2 (%)	11.319	12.008	21.047	22.411
Adj. R^2 (%)	5.197	5.934	15.554	17.013

Notes: Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. Dependent variables: $dY_{it} = \ln(LTDebt_{it}/LTDebt_{it-1})$, $dZ_{it} = \ln(LTAssets_{it}/LTAssets_{it-1})$, $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$. $(NI/TA)_{it} = NetIncome_{it}/TotalAssets_{it}$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. Robust standard errors are in parentheses. * denotes significant parameter at 5 percent, ** at 1 percent. Sample: 2,107 panel observations over 2000:Q1–2013:Q1 (unbalanced), forty-four banks.

Appendix 5. Sample of Banks

Table A7. Sample: Market Capitalization in $Millions (Dec. 30, 2007)

Name	Ticker	SNL ID	RSSD ID	Industry	Market Cap
American Express Co.	AXP	102700	1275216	Specialty Lender	60,834
Bank of America Corp.	BAC	100369	1073757	Bank	183,125
The Bank of New York Mellon Corp.	BK	100144	3587146	Bank	55,522
BB&T Corp.	BBT	100438	1074156	Bank	16,852
Capital One Financial Corp.	COF	103239	2277860	Bank	18,215
Citigroup, Inc.	C	4041896	1951350	Bank	146,644
Fifth Third Bancorp	FITB	100260	1070345	Bank	13,386
The Goldman Sachs Group, Inc.	GS	4039450	2380443	Broker Dealer	85,520
JPMorgan Chase & Co.	JPM	100201	1039502	Bank	146,622
KeyCorp	KEY	100334	1068025	Bank	9,117
MetLife, Inc.	MET	4051708	2945824	Insurance	45,636
Morgan Stanley	MS	103042	2162966	Broker Dealer	56,362
The PNC Financial Services Group, Inc.	PNC	100406	1069778	Bank	22,355
Regions Financial Corp.	RF	100233	3242838	Bank	16,439
State Street Corp.	STT	100447	1111435	Bank	31,360
SunTrust Banks, Inc.	STI	100449	1131787	Bank	21,756
U.S. Bancorp	USB	4047176	1119794	Bank	54,804

(continued)

Table A7. (Continued)

Name	Ticker	SNL ID	RSSD ID	Industry	Market Cap
Wells Fargo & Co.	WFC	100382	1120754	Bank	101,269
Franklin Resources Inc.	BEN	102719	1246216	Asset Manager	28,037
Commerce Bancshares, Inc.	CBSH	100184	2815235	Bank	3,229
CIT Group Inc.	CIT	102820	1036967	Specialty Lender	NA
Comerica Inc.	CMA	100206	1029259	Bank	6,574
Huntington Bancshares Inc.	HBAN	100307	1068191	Bank	5,401
Marshall & Ilsley	MI	100364	3594612	Bank	7,086
M&T Bank Corp.	MTB	100253	1037003	Bank	8,708
National City Corp.	NCC	100378	1069125	Bank	10,433
Northern Trust Corp.	NTRS	100386	1199611	Bank	16,843
New York Community Bancorp, Inc.	NYCB	1024119	2132932	Savings/Thrift/Mutual	5,689
The Charles Schwab Corp.	SCHW	102775	1026632	Broker Dealer	29,547
Synovus Financial Corp.	SNV	100440	1078846	Bank	7,943
UnionBanCal Corp.	UB	1022285	1378434	Bank	6,776
Wachovia Bank	WB	100293	1073551	Bank	75,122
Zions Bancorp	ZION	100501	1027004	Bank	4,995
Associated Banc-Corp	ASBC	100135	1199563	Bank	3,442
Bank of Hawaii Corp.	BOH	100161	1025309	Bank	2,506
BOK Financial Corp.	BOKF	100003	1883693	Bank	3,471
Popular, Inc.	BPOP	100165	2138466	Bank	2,971
Cullen/Frost Bankers, Inc.	CFR	100196	1102367	Bank	2,963

(continued)

Table A7. (Continued)

Name	Ticker	SNL ID	RSSD ID	Industry	Market Cap
City National Corp.	CYN	100225	1131004	Bank	2,866
Discover Financial Services	DFS	4096334	3846375	Specialty Lender	NA
East West Bancorp, Inc.	EWBC	4040606	2734233	Bank	1,527
First Citizens BancShares, Inc.	FCNCA	100247	1105470	Bank	1,619
First Horizon National Corp.	FHN	100292	1094640	Bank	2,294
Fulton Financial Corp.	FULT	100294	1117129	Bank	1,946
Hancock Holding Co.	HBHC	100308	1086533	Bank	1,207
Prosperity Bancshares, Inc.	PB	1018962	1109599	Bank	1,297
SVB Financial Group	SIVB	100433	1031449	Bank	1,673
TCF Financial Corporation	TCB	102002	2389941	Bank	2,272
Webster Financial Corp.	WBS	102030	1145476	Bank	1,710

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Discussion of "Systemic Risk and the Solvency-Liquidity Nexus of Banks"*

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1. Introduction

The financial crisis of 2007–9 demonstrated the strong interactions between the solvency of institutions and liquidity problems in the financial system (see Paulson 2010, Bernanke 2013, and Geithner 2014 for the U.S. perspective). While the Federal Reserve began providing emergency liquidity to U.S. institutions in mid-2007, it took recapitalizations, via the stress tests in the spring of 2009, to decisively turn the crisis around.

Whereas the acquisition of Bear Stearns, the failure of Lehman Brothers, and the government's takeover of AIG were triggered by liquidity shortages, each of those institutions was ultimately in distress due to deeply rooted solvency problems, which were addressed by a combination of private- and public-sector actions.

Examining the shadow banking sector, Covitz, Liang, and Suarez (2013) document that the magnitude of runs on asset-backed commercial paper (ABCP) conduits was at least partially linked to the degree of credit distress of the asset collateral. Perhaps surprisingly, even banks with access to the discount window and deposit insurance experienced run-like dynamics (Brunnermeier 2009, Huang and Ratnovski 2011, and Iyer, Puri, and Ryan 2012).

Against this backdrop, Pierret's (this issue) study of the solvency-liquidity nexus of banks is very welcome. While an extensive theoretical literature has investigated the relative importance of

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liquidity and solvency for the determination of bank runs (Allen and Gale 1998, Rochet and Vives 2004, Diamond and Rajan 2005, and Morris and Shin 2008), surprisingly few empirical studies address the topic (for an exception, see Cornett et al. 2011).

Pierret's contributions are threefold. First, Pierret documents Granger causality between solvency and liquidity. Liquidity is measured by the difference between short-term debt and total assets, while solvency is measured by Acharya, Engle, and Richardson's (2012) *SRISK*. Hence, the measure of liquidity is a contemporaneous balance sheet measure, while *SRISK* is at least in part a forward-looking market-based measure. Higher *SRISK* measures a greater capital shortfall. The definition of *SRISK* is

$$SRISK_{it} = MV_{it}\{k(Lvg_{it} - 1) - (1 - k)(1 - LRMES_{it})\},$$

where MV is the market value of equity, Lvg is market leverage $(MV + \text{Debt})/MV$, and $LRMES$ is long-run marginal expected shortfall, a measure of firms' exposures to an aggregate shock.

Pierret shows that a shock to *SRISK*, increasing solvency risk, is followed by lower short-term debt: The interpretation is that the market limits the amount of short-term funding that a firm can receive when it becomes riskier (Pierret, this issue, table 1). Conversely, higher short-term debt Granger-causes higher *SRISK* (Pierret, this issue, appendix 3, available online). A firm with higher short-term debt is therefore more vulnerable to solvency, as measured by *SRISK*.

This first set of results is consistent with the notion that the liquidity management of firms and the market assessment of solvency are intertwined, hence the title of the paper, "Systemic Risk and the Solvency-Liquidity Nexus of Banks." There is an important asymmetry in the response of solvency to liquidity versus liquidity to solvency: While higher short-term debt Granger-causes more *SRISK*, more *SRISK* Granger-causes less short-term debt. The interpretation is that short-term debt makes firms fragile, while more fragility causes depositors to withdraw funding.

Pierret's second result concerns the impact of a capital shortfall on the solvency-liquidity nexus (Pierret, this issue, table 1, column 3). Firms with a capital shortfall experience a stronger reaction of *SRISK* to shocks in short-term debt. And, in the other direction, firms with a capital shortfall experience a larger decline of short-term debt when *SRISK* unexpectedly increases. Both of the Granger-causality results are consistent with the notion that firms with a capital shortfall (high *SRISK*) are financially constrained.

SRISK is a composite indicator consisting of the market value of equity, market leverage, and long-run marginal expected short-fall. Pierret investigates which of the components of *SRISK* is most important for predicting the level of short-term debt (Pierret, this issue, table 3). Pierret shows that improvement in in-sample fit comes from the ratio of market capitalization to total assets (MV/TA), rather than from the long-run marginal expected short-fall ($LRMES$) or the quasi-market leverage (Lvg).

In addition to the three main results highlighted here, Pierret also shows that alternative measures of bank risk, including Adrian and Brunnermeier's (2010) systemic risk measure, CoVaR, as well as regulatory capital ratios, such as the tier 1 capital ratio, do not Granger-cause short-term debt (table 3). Furthermore, Pierret reports out-of-sample forecasting results (table 4).

The remainder of my discussion is structured as follows. First, I will address identification of shocks in Pierret's vector autoregressions. Next, I will discuss the policy relevance of the findings. Finally, I will make some comments regarding theory. The discussion ends with a conclusion in section 5.

2. Identification

Pierret uses Granger causality based on vector autoregressions to identify the solvency-liquidity nexus. Unfortunately, Granger causality is not true causality. It is a measure of temporal correlations. It can answer this question: When series x moves, does series y tend to follow? What it cannot answer is whether other factors might be moving both x and y. While vector autoregressions are powerful and useful tools, and Granger causality is a useful notion, these results must be interpreted with care.

In Pierret's application, the particular concern is that (co)movement of the solvency and liquidity measures over the sample period was due to shocks that are not truly exogenous to either solvency or liquidity. In particular, after the financial crisis, both solvency and liquidity were heavily impacted by policy changes.

Liquidity was particularly influenced by the Federal Reserve's asset purchase program, which resulted in a sharp increase in central bank reserves in the banking system and a corresponding increase in the deposits-to-assets ratio.

Solvency, on the other hand, was crucially influenced by the tightening of regulations, primarily through the supervisory stress tests. Hence the post-crisis trends in capital and liquidity were impacted importantly by changes in monetary and regulatory policies, and it is likely that the Granger-causality tests are picking up such changes in policy, as well as reactions to truly exogenous shocks.

Measurement of causality in the run-up to and eruption of the crisis is similarly subject to identification issues. For example, both solvency and liquidity had first-order exposures to banks' involvement in shadow banking activities. Banks that were involved in shadow banking increased their leverage covertly by moving risk onto the balance sheets of special-purpose vehicles that were ultimately backstopped by credit lines from the banks. Once the crisis erupted, many banks moved such shadow bank assets back onto their balance sheets, creating funding shortages since these assets were typically funded in unsecured interbank markets.

Due to the riskiness of the assets, solvency concerns were triggered around the same time as funding liquidity problems emerged. Hence a valuation shock to the assets in off-balance-sheet shadow bank vehicles caused both solvency and liquidity shocks, and the vector autoregression does not have enough information to disentangle the effects of these shocks from one another.

Of course, researchers in banking and corporate finance—and in applied microeconomics, more generally—have recognized such identification concerns. In recent years, the literature has shifted toward emphasizing plausibly exogenous variation in the empirical identification of causality.

In banking, Peek and Rosengren (2000) have used bank exposure to the Japanese real estate shock to causally identify the impact of loan supply shocks on economic activity. Ashcraft (2005) has used FDIC-induced closures of healthy bank branches due to the distress of the parent as exogenous variation to identify the impact of banking on regional real activity. Mian and Sufi (2009) have used cross-sectional information to identify the impact of lending in the run-up to the housing crisis on the severity of the downturn, exploiting a differences-in-differences type of identification strategy. Agarwal et al. (2014) measure the impact of supervision on bank performance using exogenous variation in the supervisory schedule across agencies. Angrist and Pischke (2014) provide an overview of techniques in that field.

Ideally, Pierret would present an identification strategy that would allow her to identify exogenous shocks to solvency and liquidity, which would then have allowed her to trace out the nexus between solvency and liquidity in a causal manner. Of course, Pierret is not the only one to struggle with these issues and, to my knowledge, no paper since the crisis has come up with an instrument for the separate identification of liquidity and solvency shocks that could be readily used in the study. Exogenous shocks would have to be unanticipated by the banks, the shareholders of the banks, and the depositors of the banks.

But most shocks impact both solvency and liquidity directly, and there is very little variation in the data that isn't anticipated by somebody. Mian and Sufi's (2009) identification strategy, exploiting cross-sectional heterogeneity before and after the crisis, might suggest a way for Pierret to identify more plausibly causal relationships, compared with the current vector autoregression setup.

3. Policy Implications

The nexus between solvency and liquidity is of primary importance for monetary and regulatory policy. In fact, Pierret starts her paper by citing Federal Reserve Governor Daniel Tarullo's (2013) speech on financial stability, which explicitly discusses the interaction between solvency and liquidity.

Recently, the Federal Reserve proposed a rule that would include a capital charge proportional to the amount of short-term wholesale funding in the macroprudential GSIB surcharge (GSIB stands for global systemically important banking organizations).[1] If implemented, this framework would provide incentives for the largest U.S. banking organizations to hold substantially increased levels of

[1]See the Federal Reserve's announcement at http://www.federalreserve.gov/newsevents/press/bcreg/20141209a.htm and the Federal Register notice at http://www.gpo.gov/fdsys/pkg/FR-2014-12-18/pdf/2014-29330.pdf.

high-quality capital as a percentage of their risk-weighted assets, which would, in turn, encourage such firms to reduce their systemic footprint and lessen the threat that their failure would pose to overall financial stability.[2] This rule is currently only at the proposal stage and is not expected to be phased in until early 2019.

Pierret's work could potentially inform policymakers about the magnitudes of the interactions between solvency and liquidity fragility. In principle, the types of calculations that Pierret is undertaking could help determine the appropriate level of a capital surcharge for short-term wholesale funding. However, even if the identification issues discussed above could be resolved, additional aspects of the solvency-liquidity nexus would have to be taken into account.

First, the interrelation between solvency and liquidity fragility would be expected to vary as a function of the level of capital and liquidity regulation. What I really would like to have seen is a calculation that would answer the following: To what extent would a marginal increase in the capital requirement allow the relaxation of a liquidity requirement (or a liquidity backstop), keeping the overall level of fragility constant? Or, in reverse, to what extent would a government guarantee for runnable deposits allow a relaxation of capital requirements, keeping overall fragility constant? While the theoretical literature cited above might pin down a precise answer to such questions, the theoretical models are too abstract to be translated into policy. Hence a precise estimate of the substitutability of capital and liquidity would be very welcome. To date, we have no such concrete policy guidance.

Second, Pierret's investigations do not uncover the underlying economic frictions that give rise to the interrelatedness of solvency and liquidity problems. The theoretical literature proposes a number of possible channels, including coordination problems, fire-sale externalities, and network effects, among others. The cross-sectional information contained in Pierret's bank-level data could be helpful in pinning down different drivers of the solvency-liquidity nexus. For example, interaction terms with the fraction of wholesale funding

[2]U.S. banking organizations currently subject to the GSIB surcharge include Bank of America, Bank of New York Mellon, Citigroup, Goldman Sachs, JPMorgan Chase, Morgan Stanley, State Street, and Wells Fargo.

over total deposits, the degree of intrafinancial exposure, or the potential for fire-sale vulnerability[3] could be helpful in linking the interrelatedness of solvency and liquidity to specific economic mechanisms. In fact, the data suggest a very wide variety of asset allocations and funding profiles across banking organizations. For example, the banks that own large dealer subsidiaries have very different funding profiles compared with banks that engage mainly in traditional lending activities.

Third, Pierret's framework does not provide a link to aggregate vulnerability, or aggregate lending activity of banks. In the language of Adrian and Boyarchenko (2012), regulators face a systemic risk-return trade-off: Tighter regulation tends to reduce aggregate vulnerability, but credit intermediation becomes more expensive. Regulators have to weigh the overall level of risk in the financial system against the cost of reduced credit intermediation.

To the extent that capital and liquidity requirements might be substitutable, they will have a differential impact on the optimal amount of capital and liquidity, and precise calibration might thus improve welfare. However, while Pierret shows that solvency and liquidity are interrelated at the firm level, she does not make the connection to aggregate solvency or liquidity risk. Relatedly, the *SRISK* measure that is used to gauge solvency risk takes the overall amount of stress in the system as given and asks how big the capital shortfall of an individual institution might be. In contrast, Adrian and Brunnermeier's (2010) CoVaR measure asks to what extent the distress of an individual institution might impact the overall level of systemic risk.

Fourth, the nexus of solvency and liquidity matters for ex post crisis intervention. During the unfolding of the 2007–9 financial crisis, the primary policy tools consisted of liquidity injections by the Federal Reserve. Subsequently, it became clear that liquidity alone could not resolve the crisis, as capital shortages in the banking system were exacerbating existing adverse economic shocks. As a result, the banking regulators, together with the U.S. Treasury, started to focus on ways to recapitalize the banking system. Ultimately, Troubled Asset Relief Program (TARP) funds were used to this end, and

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[3]Duarte and Eisenbach (2014) present a measure of fire-sale risk for U.S. banks.

the first supervisory stress test in 2009 was explicitly targeted at recapitalization of the banking system.

More extensive knowledge of the interrelation between capital and liquidity shortages would certainly have helped calibrate lender-of-last-resort policies, as well as recapitalizations. In fact, the Federal Reserve's Comprehensive Liquidity Assessment and Review (CLAR) complements its Comprehensive Capital Analysis and Review (CCAR) and helps regulators gauge capital and liquidity adequacy under assumed stress scenarios from an ex ante perspective.[4] The Federal Reserve introduced CLAR and CCAR after the crisis, recognizing the importance of forward-looking measurement of both solvency and liquidity fragilities.

4. Theory

My final comment on Pierret's paper concerns the theoretical foundations of the capital-liquidity nexus. While banking regulation is traditionally analyzed with partial equilibrium models that feature coordination failures as the key rationale for regulation (see relevant citations in Pierret's paper), more recently a literature on financial intermediation within macroeconomic equilibrium has emerged (see He and Krishnamurthy 2013 and Brunnermeier and Sannikov 2014). This literature analyzes banking regulations from a new vantage point, providing new and potentially useful insights. The paper that is particularly relevant for Pierret (this issue) is by Adrian and Boyarchenko (2013), who study capital and liquidity requirements jointly.

Adrian and Boyarchenko (2012) develop a macro-finance model with a financial sector that features an endogenous leverage cycle. Capital requirements are risk based, implying a tighter constraint on intermediary risk taking when volatility is high. Volatility and the price of risk are determined jointly, along with the amount of lending and overall macroeconomic activity. Adrian and Boyarchenko (2013) add a liquidity requirement similar to the Basel Committee's proposed liquidity coverage ratio.[5]

[4] See Tarullo (2014).

[5] See http://www.bis.org/publ/bcbs238.pdf.

Both the liquidity requirement and the risk-based capital requirement aim at containing risk taking in the financial sector. However, the impacts of the liquidity and the capital requirements on systemic risk, and aggregate growth, differ. While Adrian and Boyarchenko (2013) show that both types of prudential regulation can help reduce systemic risk, capital requirements typically have a stronger adverse impact on growth, via increased credit intermediation costs. Banking regulators thus face different risk-return trade-offs, depending on the types of regulations used.

Future research on the solvency-liquidity nexus could use the structure of Adrian and Boyarchenko's (2013) model to achieve identification. Of course, the linear vector autoregression approach of Pierret (this issue) would have to be adapted to incorporate the nonlinearities in Adrian and Boyarchenko's (2012, 2013) models, which are essential in models of systemic risk.[6] The advantage of incorporating more economic structure would be that causality, within the model, could be directly estimated, and explicit links to policy instruments could be made. Importantly, these models explicitly allow for welfare analysis, which can connect the solvency-liquidity nexus to welfare-improving capital and liquidity policies.

5. Conclusion

The nexus between solvency and liquidity is an important topic of research. Pierret is to be applauded for taking an important first step in analyzing empirically the joint dynamics of solvency and liquidity constraints over time. While the study is a welcome first step, I believe that further progress in understanding the topic could be made by extending the study in three directions.

First, identification of shocks could be improved by exploiting cross-sectional variation, or by uncovering an instrument that would help overcome the endogeneity problems typical of vector autoregressions. Ideally, an instrumental-variable approach would identify plausibly exogenous liquidity and solvency shocks. In the absence of an instrumental-variable strategy, cross-sectional variation in capital

[6]Dewachter and Wouters (2014) have proposed methodology estimation of the DSGE model by He and Krishnamurthy (2013).

and liquidity could be exploited more forcefully to achieve identification, perhaps along the lines of Mian and Sufi (2009).

Second, policy conclusions are difficult to draw from the paper, as the magnitude and possibly even direction of Granger causality might be endogenous to liquidity injection policies by the central bank, as well as the evolution of regulatory capital and liquidity standards over time. While the paper documents temporal correlations between solvency and liquidity, the quantitative results of the study cannot serve as a basis for setting regulatory policy.

Finally, the use of a structural model of the macroeconomy with a financial sector that faces capital and liquidity shortages, as presented by Adrian and Boyarchenko (2013), might further improve the analysis. The advantage of a structural approach is that it allows the identification of causal relationships, even in the absence of instruments or quasi-experiments. Furthermore, such a model lends itself to welfare analysis and facilitates the quantification of changes in capital or liquidity requirements, which is useful for analyzing the effects on the level of systemic risk, the pricing of credit, and the average growth rate of the economy. Future research in this vein will surely benefit from the empirical insights on the nexus between solvency and liquidity as presented in Pierret (this issue).

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CEO Compensation, Regulation, and Risk in Banks: Theory and Evidence from the Financial Crisis*

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This paper studies the relation between CEOs' monetary incentives, financial regulation, and risk in banks. We develop a model where banks lend to opaque entrepreneurial projects that need to be monitored by bank managers. Bank managers are remunerated according to a pay-for-performance scheme and their effort is not observable to depositors and bank shareholders. Within a prudential regulatory framework that imposes a minimum capital ratio and a deposit insurance scheme, we study the effect of increasing the variable component of managerial compensation on bank risk in equilibrium. We test the model's predictions on a sample of large banks around the world, gauging how the monetary incentives for CEOs in 2006 affected their banks' stock price and volatility

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during the 2007–8 financial crisis. Our international sample allows us to study the interaction between monetary incentives and financial regulation. We find that greater sensitivity of CEOs' equity portfolios to stock prices and volatility is associated with poorer performance and greater risk at the banks where shareholder control is weaker and in countries with explicit deposit insurance.

JEL Codes: G21, G38.

1. Introduction

The recent global recession has demonstrated that capital market failures may be responsible for economic downturns. In the wake of the financial crisis, a consensus appears to have emerged among researchers and practitioners that financial institutions took too much risk in the run-up to the crisis, notwithstanding risk-management arrangements and solvency regulations (Diamond and Rajan 2009). The monetary incentives given to executives have been cited as one of the culprits in the failure of banking governance.[1] Executive compensation tied to firm performance in its various forms—such as bonuses related to firm value, stock options, and equity plans—has become a standard instrument of managerial remuneration in all sectors, and especially in banking.[2] Given the growing importance of CEOs' variable compensation, we need to understand its impact on risk in banks.

We focus on the agency conflicts inside and outside the bank—shareholders vs. bank managers and insiders vs. depositors—to study the determinants of bank risk and its interaction with financial regulation. We develop a model in which bank managers have a variable compensation scheme, and use the resulting insights for empirical exploration of the relationship between CEOs' monetary incentives and bank performance.

[1] See Becht, Bolton, and Röell (2011) and Mehran, Morrison, and Shapiro (2011) for excellent reviews of the literature on the conflicts among the various stakeholders in banks and, in particular, on how executive remuneration can affect risk taking.

[2] Giannetti and Metzger (2013) find that the increase in equity-based compensation and the consequent increase in total compensation is bound up with heightened competition for talent, which creates a retention motive and exacerbates agency problems.

Our theoretical contribution serves to provide guidance in examining the empirical evidence. In our model, banks lend to opaque entrepreneurial projects that need to be monitored by a bank manager.[3] The bank manager might reduce loan losses by monitoring the loan portfolio, but this effort is not observable to outsiders. To induce monitoring, shareholders reward the manager with a bonus tied to the bank's performance.[4] Depositors are insured and minimum capital requirements are in place. Shareholders may directly inspect the bank manager and in some cases may decide to replace him with a new manager. In this setting, the risk choice is endogenous; it is the equilibrium outcome of the strategic interaction between bank managers and shareholders. Comparative statics exercises illuminate the way in which equilibrium risk at a bank reacts to changes in the CEO's variable compensation, and how its sign and measure are affected by regulation and by the efficacy of control by shareholders.

In particular, we suggest a possible perverse effect of larger managerial bonuses on bank risk. On the one hand, the larger the bonus, the greater the monitoring effort of the bank manager, so that bank risk is reduced; on the other hand, a larger bonus discourages shareholders' control by lowering their stake in the overall return of the loan portfolio, and so leads to greater risk. We also show that for a given capital structure and regulatory environment, the sign of the relation between bonus and risk is decreasing in the efficacy of shareholders' control. In other words, the perverse effect of the bonus is greater where shareholder control is weaker. Finally, within this framework, we find that a deposit insurance scheme, by incorporating the expectations of an increase in risk from larger bonuses, may under certain conditions weaken shareholders' control. In this case, the perverse correlation between executive bonus and risk is exacerbated.

[3]The model builds on Cerasi and Daltung (2007) in its version for banks, developed in Cerasi and Rochet (2014).

[4]The presence of a variable component in the compensation of executives may represent a choice for shareholders. Here, however, we take this specific form of the managerial compensation as exogenously set, taking as a stylized fact the observation that performance-based pay schemes are now standard for bank executives. As a matter of fact, the empirical analysis closely follows this approach, measuring how changes in the variable compensation of bank executives affect bank performance.

The empirical analysis is based on novel information on a panel of large banks in various countries for which executive compensation is observed. We exploit the cross-sectional heterogeneity in managerial compensation practices and financial regulation to study the impact on risk.[5] We find support for the main predictions of the theoretical model by analyzing the relation between monetary incentives provided to CEOs in 2006 and banks' return and risk during the financial crisis. We test whether the monetary incentives for executives fixed before the financial crisis explain banks' poor performance and greater incurred risk during the financial crisis of 2007–8. There are two reasons for using the crisis for an experiment. First, the design of executive compensation schemes is pointed to, in public discussion, as one of the main culprits in the increased risk taking that public opinion blames for the crisis. This issue has been analyzed in detail for the United States, notably by Fahlenbrach and Stulz (2011), but except for Suntheim (2010), less work has been done about other countries. Second, it is reasonable to assume that when shareholders designed their CEOs' contracts in the years preceding the financial crisis, they did not anticipate the collapse of the financial system; the monetary incentives we find in 2006 were presumably designed before that date. To summarize, the financial crisis cannot be classified as an anticipated shock; on the contrary, it is likely that both financial market operators and bank managers were unaware of the impending crisis. This thesis is supported by two facts: (i) average stock returns of banks were extremely high before the crisis;[6] (ii) if they had anticipated the financial crisis, they should have sold their stock, but we find no statistically significant change in the proportion of inside ownership of CEOs in our sample between the second quarter of 2005 or 2006 and the second quarter of 2007.[7]

[5]We combine four sources of data: Capital IQ – People Intelligence by Standard and Poor's, Bankscope, Datastream, and the third wave of the World Bank's Bank Regulation and Supervision Survey; see section 4 for a detailed description of the data-collection process.

[6]Furthermore, our regression analysis shows a negative correlation between stock returns in 2006 and performance during the crisis; this suggests that the better-performing banks in 2006 performed worse during the crisis.

[7]Insider holding is measured by the ratio of the number of restricted and unrestricted shares held by CEOs at the end of the second quarter of each year

In the empirical analysis, pay-for-performance sensitivity of CEOs' compensation is measured using information on cash bonuses and equity portfolios (the sum of the CEO's shares and stock options). We distinguish between two measures of pay-for-performance sensitivity of equity portfolios: (i) the sensitivity of CEOs' stock-option portfolios to share prices (option delta) plus the direct ownership of shares (ownership from shares and options); and (ii) the sensitivity of the stock-option portfolio to stock volatility (option vega). Finally, we measure bank performance as the buy-and-hold return and the standard deviation of stock returns over the period 2007:Q3–2008:Q4.

For the entire sample, we find that greater pay-for-performance sensitivity at the end of 2006 does not appear to be related to either the drop in stock returns or higher stock-price volatility during the financial crisis. This lack of evidence of a relation between variable compensation and bank risk extends the empirical evidence on U.S. banks by Fahlenbrach and Stulz (2011) to banks outside the United States as well. This result is also consistent with the insights of our model, namely that an increase in the managerial bonus has ambiguous effects on equilibrium risk; given that banks differ in governance and in the regulatory framework, the negative and positive effects of variable compensation may be partially offsetting for the sample as a whole. However, starting from this negative result and following the insights of our model, we exploit bank heterogeneity and cross-country differences to split our sample along several lines, capturing features of bank governance and regulation, to detect patterns in the correlation between the way executives are remunerated and bank risk.

In particular, we find that CEOs' equity incentives (ownership from shares and options and option vega) were associated with worse performance during the crisis by the banks where the shareholders'

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to the total number of shares outstanding at the end of the year. The average insider holdings were 1.41 percent, 1.76 percent, and 1.38 percent at the end of the second quarter of 2005, 2006, and 2007, respectively. There is no statistically significant change even excluding restricted shares. For the case of U.S. banks, similar evidence has been found by Fahlenbrach and Stulz (2011), while Cziraki (2014) found that only the executives of the banks most exposed to the housing market might possibly have foreseen the collapse starting in mid-2006.

control of delegated managerial activities was relatively ineffective compared with the whole sample. By using different proxies for efficacy of control at both the bank and country level, we support the theoretical prediction that weaker internal control combined with greater pay-for-performance sensitivity in executive compensation might explain increased risk taking.

Furthermore, we study the interaction between CEOs' variable compensation and measures of prudential regulation at the country level, such as the presence of an explicit deposit insurance scheme[8] and the difference between the actual capital at the bank level and the minimum capital requirement defined by each country authority in 2006.

The empirical evidence suggests that explicit deposit insurance, combined with our measures of variable compensation, may well have increased the risk appetite of insiders and resulted in worse performance (either lower buy-and-hold returns or greater stock-return volatility) during the financial crisis. We do not find evidence of interaction between CEOs' variable compensation and capital requirements during the crisis.

The rest of the paper is organized as follows: the next section relates this paper to the literature; section 3 presents our model; section 4 describes how we collected our data and provides some descriptive statistics on the sample of banks and their CEOs' compensation; section 5 analyzes the correlation between bank performance and CEO compensation in the whole sample; section 6 studies the interaction between executive incentives and bank performance in different sub-samples, in order to capture different aspects of financial regulation and bank governance; and section 7 concludes.

[8]Following Demirguc-Kunt, Karacaovali, and Laeven (2005), explicit deposit insurance differs from implicit deposit insurance by the presence of a formal definition of the scheme in national banking laws; explicit deposit insurance varies among countries in terms of the types of financial institution covered and the amount of coverage. In this paper we divide the countries into two groups, depending on whether or not an explicit law applies to commercial banks; we further assume that the insurance is funded by a fair premium paid by the commercial bank. Although restrictive, this assumption appears to fit the application of the law in most countries.

2. Related Literature

In the wake of the recent financial crisis, there is a growing literature on the relation between different aspects of corporate governance, executive compensation, and risk in banking and their interaction with financial regulation. Let us define our paper relative to the various contributions of that literature.

Banking mainly involves liquidity provision and maturity transformation. Thanks to the existence of deposit insurance, deposits are a cheap source of funding for banks, which explains why commercial banks represent a special case of highly leveraged firms, as discussed in Dewatripont and Tirole (1999) and in the excellent reviews of bank corporate governance by Becht, Bolton, and Röell (2011) and Mehran, Morrison, and Shapiro (2011). The corporate finance literature acknowledges the effect of leverage in altering the preferences for risk shifting and the conflict between shareholders and debtholders (Jensen and Meckling 1976). However, depositors, as they are insured, are quite passive claimholders and do not oppose shareholders' initiatives, as is shown extensively in Mehran, Morrison, and Shapiro (2011). This explains why bank shareholders are successful in aligning CEOs with their interests also in their taste for excessive risk taking; see the good discussion in Bolton, Mehran, and Shapiro (2010). In our model the bank is leveraged, deposit insurance is in place and the bank manager is remunerated according to a pay-for-performance scheme, and active shareholders may decide to inspect and possibly fire the top executive. In this context, increasing the variable component of compensation might discourage shareholders' initiative and so heighten bank risk.

Seminal contributions by John and John (1993) and Berkovitz, Israel, and Spiegel (2000) focused on the relation between CEOs' variable compensation and bank leverage, while John, Saunders, and Senbet (2000) focused on CEOs' compensation and regulation. Several more recent theoretical papers have studied how the design of compensation may affect risk taking in banks, with a view to suggesting how to redesign executive compensation so as to protect all the stakeholders in banking; see, for instance, Benmelech, Kandel, and Veronesi (2010), Bolton, Mehran, and Shapiro (2010), John, Mehran, and Quian (2010), and Kolm, Laux, and Loranth (2014). Unlike these contributions, our own exercise is intended to determine how greater pay-for-performance sensitivity impacts risk taking in different corporate governance and regulatory settings. We do not seek to understand how close the actual remuneration is to the optimal remuneration but simply to gauge how a change in the level of remuneration might affect risk taking.

Empirically, we contribute to the literature on the role of bank CEO compensation in shaping risk taking and how corporate governance and financial regulation interact with it.

We build upon Laeven and Levine (2009) and Gropp and Kohler (2010), who empirically analyze the interaction between corporate governance and regulation and its effect on bank risk. In relation to the recent financial crisis, Beltratti and Stulz (2012) show that shareholder-friendly boards have effectively aligned bank managers with their interests at the expense of depositors. We complement those studies by exploring a specific tool of corporate governance, namely executive compensation.

Our paper is also close in spirit to Fahlenbrach and Stulz (2011) and Guo, Jalal, and Khaksari (2014), who have empirically explored the relation between CEOs' incentives and bank performance and risk in the 2007–8 financial crisis for a cross-section of U.S. banks. They find that banks where CEOs' monetary incentives were more closely aligned with shareholders' interests did not perform better. While confirming this result as regards our entire sample, we also find a negative correlation between variable compensation and ex post performance at banks with weaker governance and at banks in countries with explicit deposit insurance. In interpreting this evidence, we relate our findings to our model, where risk is endogenous and is shaped jointly by shareholders' oversight and managerial monetary incentives.

From a different perspective, Cheng, Hong, and Scheinkman (2010) assume that risk is an exogenous characteristic of the bank, together with productivity, and that risk-averse CEOs must be compensated with greater total remuneration when they are hired by a riskier bank. They find strong evidence of an effect of banks' fundamentals (risk and productivity) on total executive compensation, and weaker evidence of an effect on variable compensation. Their analysis challenges the interpretation of our empirical results, as the relation between ex post risk and ex ante CEO variable compensation may be affected by a confounding factor such as ex ante risk or productivity; we address this concern in the empirical setting by accounting for differences in fundamental productivity and risk across banks.

Finally, Ellul and Yeramilli (2013) provide a first attempt to get inside the black box of the banks' internal organization, studying the effect of the risk-management function on risk in a sample of U.S. banks. Their analysis prompted us to examine the effect of executive compensation schemes and the potential conflict with other stakeholders.

3. The Model

Consider a bank holding a portfolio of size L_0 of risky loans with perfectly correlated returns. Each loan returns $R > 1$, although loan losses ℓ occur with probability p. Thus, the portfolio returns $(R-\ell)L_0$ with probability p, and RL_0 otherwise; the returns are fully observable by third parties. The bank collects funds from wealthy dispersed investors whose alternative return on their capital is 1. We assume that all agents are risk neutral.

At date 0, bank shareholders, who own capital E_0, collect deposits D_0 and extend loans L_0. Depositors are fully insured; hence, each unit of deposit bears zero risk premium.[9] Given the presence of the deposit insurance, the income of the loans portfolio is divided as follows: when the portfolio is successful, it returns RL_0, and what is left, once depositors are repaid the promised amount D_0, goes to bank shareholders; when loan losses are realized and the portfolio returns $(R - \ell)L_0 < D_0$, all the income goes to the deposit insurance fund that repays depositors D_0, which leaves bank shareholders without any income. We will assume that the deposit insurance premium is fully funded through taxpayers' money and that bank shareholders do not internalize it.[10] The amount of insured deposits

[9] A more realistic case is when the bank is funded by a mix of insured deposits and unsecured debt. In appendix 2 we discuss this case and show that when the great majority of debtholders are uninsured in equilibrium, the risk is identical to that of a bank with a risk-sensitive deposit insurance premium charged to the bank.

[10] In the last sub-section we will discuss the case of a risk-sensitive deposit insurance with a fair premium charged on the balance sheet of the bank at date 0.

that the bank will be able to collect is given by the bank's balance sheet at time 0, i.e.,

$$L_0 = E_0 + D_0. \tag{1}$$

We will assume in what follows that there is a capital ratio k imposed by the regulator requiring a minimum of capital for each unit of loans, namely $L_0 \leq E_0/k$.

Loans can be directly monitored by exerting an effort $m \in [0, 1]$ at a private cost $\frac{M}{2}m^2$ with $M \geq 0$ to reduce the probability of losses from p_H to p_L. Assume that

$$R - p_L\ell - \frac{M}{2} > 1 > R - p_H\ell,$$

which implies that only monitored loans are worth financing. When loans are monitored, they have a positive net present value; hence, the size of the bank is limited by its minimum capital ratio.

We assume that shareholders delegate the task of monitoring loans to a bank manager. Because monitoring cannot be observed but has a (private) cost, the bank manager might shirk this duty. To avoid this, shareholders can inspect the bank manager at random and also reward him with monetary incentives. We postpone the analysis of monetary incentives to the next sub-section and focus now on the inspection technology. The shareholders can inspect the activity of the bank manager with intensity $s \in [0, 1]$ at a (private) cost $\frac{C}{2}s^2$ with $C > 0$. As a result of this inspection, shareholders might decide to fire the manager and replace him with an external one (we explore this aspect later on).

The two efforts, the "internal" supervision by shareholders and the activity of monitoring the portfolio of loans, cannot be observed by outsiders of the bank but are privately costly for the party in charge of it, causing a double moral hazard problem. However, the combined impact of monitoring the loans and the internal supervision affects the probability of losses p. The specific value of this probability must be derived from the equilibrium choices of effort of the bank manager and shareholders, as will subsequently become clear.

We may summarize the timing of events on three dates $t = (0, 1, 2)$ as follows:

- At $t = 0$, bank shareholders with capital E_0 collect insured deposits D_0 and lend L_0 (limited by a capital ratio $L_0 \leq E_0/k$); they hire a manager to monitor loans.
- At $t = 1$, the bank manager might exert a monitoring effort with intensity m to reduce expected loan losses; the bank shareholders inspect the manager with probability s; and in some cases, they decide to replace the incumbent manager with an external one.
- At $t = 2$, the loans return a revenue, and the income is shared among the parties.

At the beginning of date 0, the managerial compensation is disclosed to all third parties. Effort choices are not observable, while returns from projects are observable to outsiders. This timing of events implies that outsiders can observe the managerial compensation but cannot infer the true effort choices of insiders. The model is solved backwards: equilibrium efforts and returns are computed for a given managerial compensation.

3.1 Bank Managerial Compensation

The bank manager, whose choice of effort responds to monetary incentives, is offered a monetary compensation, the sum of a fixed salary and a cash bonus on each loan. The fixed salary is set equal to zero for the sake of simplicity. In addition, the bank manager is paid a cash bonus $b \in [0, R)$ whenever the loan portfolio succeeds without losses and whenever shareholders—as a result of inspection—decide not to fire him.[11] The bonus represents the variable part of the managerial compensation and, given that it is tied to the good performance of the portfolio of loans, can be interpreted as a "pay-for-performance" scheme. Only conditional on the result of their inspection, shareholders might decide to fire the incumbent bank manager. Whenever the incumbent bank manager is fired, a new manager is hired and, as a result, the probability of loan losses switches from p to an average value $\phi \in (p_L, p_H)$. Because the new bank manager

[11] The decision to fire the bank manager is at the complete discretion of shareholders. This is in line with the empirical fact that managerial contracts are riskier than workers' labor contracts. In particular, in the managerial contract, there is no need for a "good cause" to fire the employee.

is offered the same managerial compensation, shareholders benefit from firing the incumbent bank manager only when—as a result of inspection—they observe an effort level below that of an average external manager.[12] Therefore, to reduce loan losses, it is strictly preferable to retain the incumbent manager. In conclusion, shareholders will not fire the incumbent manager unless they observe an effort level below that of an average external manager.

The insiders of the bank, shareholders and the bank manager, choose their efforts non-cooperatively and simultaneously. The equilibrium concept applied here is Nash equilibrium in monitoring and inspection choices. To derive the equilibrium bank risk, we have to solve for the efforts as a fixed point of the best reply functions.

Figure 1 describes the actions of the insiders together with the variables affecting their gross revenues for each different choice. From figure 1 we can derive the probability of loan losses, taking into account all the possible actions:

$$\begin{aligned} p(m,s) &= mp_L + (1-m)\left[s\phi + (1-s)p_H\right] \\ &= p_L + (1-m)\left[\Delta - s\Delta_\phi\right], \end{aligned} \tag{2}$$

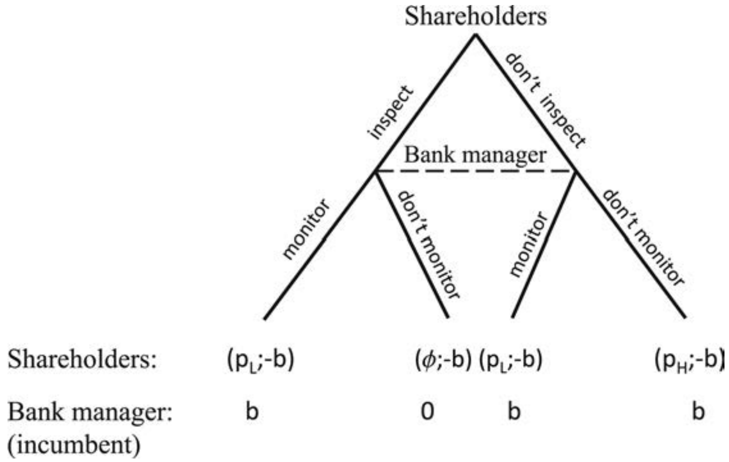
where $\Delta \equiv p_H - p_L$ and $\Delta_\phi \equiv p_H - \phi$. The probability of losses is p_L when the bank manager exerts effort regardless of the shareholder effort. Notice that inspection by shareholders is effective in reducing loan losses only if the external bank manager is more capable than the slacking incumbent manager, i.e., $\phi > p_L$.

The probability of loan losses p captures either a measure of loans' performance or a measure of the variance of the loan portfolio returns.[13]

[12]This assumption guarantees that shareholders do not always fire the incumbent bank manager, disregarding the outcome of the inspection, given that the managerial effort is not observable from outsiders. After firing the incumbent manager and hiring an external one, they reward the new manager with exactly the same compensation scheme: thus, firing the old manager does not allow saving on the bonus payment.

[13]In the model when the bank manager or the shareholders exert a greater effort in monitoring the loan portfolio risk, p decreases. This corresponds to either an increase in the mean value of the portfolio, $R(1-p)$, or a reduction of the variance, $Rp(1-p)$, when p is smaller than 0.5, which seems a sensible restriction to adopt when loan losses are rare. However, our ex ante measure of risk p cannot be observed and we must capture it with observable measures. In the empirical

Figure 1. Decision Tree for Shareholders and Bank Manager



Notes: The decision tree represents all the possible actions for shareholders and the incumbent bank manager. Each branch represents the decision about the action of monitoring and inspecting. At the bottom of the tree we report the specific values of the variables affecting the payoff of each player. For instance, in the left branch, shareholders and bank manager decide to exert their respective efforts, hence the probability of loan losses is p_L and, conditional on zero loan losses, the bank manager is rewarded the bonus b.

3.2 Equilibrium Bank Risk

Given bank shareholders' limited liability, in the event the loan portfolio falls shorter due to losses, the deposit insurance repays insured depositors the entire face value D_0. Hence, the expected profit of bank shareholders can be expressed as

$$U^B(m,s) = [1 - p(m,s)]\,[(R-b)\,L_0 - D_0] - \frac{C}{2}s^2 L_0,$$

where the probability $p(m,s)$ is defined in (2), the first term represents the expected total return of the bank portfolio net of

analysis our ex ante measure of risk p is approximated either by a measure of performance—that is, the buy-and-hold return of bank stock—or by a measure of ex post volatility, the standard deviation of bank stock returns.

managerial bonus and repayment to depositors, and the second term is the shareholders' inspection cost.

The best reply function of shareholders in terms of inspection intensity s is the solution to

$$\frac{\partial U^B}{\partial s} = (1-m)\Delta_\phi \left[(R-b) - \frac{D_0}{L_0}\right] - Cs = 0 \qquad (3)$$

for each level of bank manager's monitoring m, where the amount of deposits D_0, the size of the loan portfolio L_0, and the managerial bonus b are all taken as given.

Equation (3) indicates that, for a given bonus and amount of deposits, the benefit of inspecting depends negatively upon the managerial effort: a greater managerial effort improves the probability of success of the project without costs for shareholders, while inspection entails a positive private cost. The shareholders prefer the bank manager to be the one to exert the effort to save their private cost of inspection. Hence, because of this free-riding problem, there is substitutability between the two efforts.

For given managerial compensation, the expected utility of the incumbent bank manager is

$$U^M(m,s) = [1-q(m,s)]\, bL_0 - \frac{M}{2}m^2 L_0,$$

where $1-q(m,s) \equiv 1-p(m,s)-s(1-m)(1-\phi)$ is the probability that the bank manager will cash the bonus. The bank manager earns the bonus with probability $[1-p(s,m)]$ unless he is fired with probability $s(1-m)$. Notice that the probability of observing loan losses is smaller than the probability of losing the bonus for the incumbent manager, that is, $p(m,s) - q(m,s) = -s(1-m)(1-\phi) < 0$. The portfolio of loans could be successful, and in this case, the incumbent bank manager does not pocket the bonus (because he is fired), and the bonus is paid to the new manager who has exerted the monitoring.

The best reply function of the bank manager in terms of monitoring m is the solution to

$$\frac{\partial U^M}{\partial m} = [\Delta + s(1-p_H)]\, b - Mm = 0 \qquad (4)$$

for each intensity of inspection by shareholders s, where the managerial bonus b is given. Equation (4) indicates that, for a given bonus, the monitoring effort of the bank manager increases with the inspection of shareholders: a larger probability of inspection increases the threat of being fired and thus induces a greater managerial effort.

Shareholders and bank manager choose simultaneously and non-cooperatively their efforts at date 1. We characterize the mixed-strategy Nash equilibrium of the game in the following proposition:

PROPOSITION 1. *When the lending size is limited by the capital ratio* k *such that* $L_0 \leq E_0/k$ *and there is a deposit insurance funded with public money, the monitoring intensity* $\widehat{m}$ *of the bank manager, the inspection of shareholders* $\widehat{s}$*, and the probability of loan losses* $\widehat{p}$ *are the solution to the following system of equations:*

$$(1-\widehat{m})A - C\widehat{s} = 0 \tag{5}$$

$$\left[\Delta + \widehat{s}(1-p_H)\right] b - \widehat{m}M = 0 \tag{6}$$

$$\widehat{p} - p_L - (1-\widehat{m})(\Delta - \widehat{s}\Delta_\phi) = 0, \tag{7}$$

with $A \equiv \Delta_\phi \left[R - b - (1-k)\right]$.

Proof. See appendix 1.

We might capture bank risk with the ex ante probability of loan losses $\widehat{p}$; therefore, we can perform some meaningful comparative static exercises around the equilibrium values $(\widehat{p}, \widehat{s}, \widehat{m})$. For instance, we can study the impact of a larger capital ratio k, as well as measures of ex post profitability such as R and cost of shareholders' control C, on equilibrium bank risk. In particular, it is possible to demonstrate the following result:

PROPOSITION 2. *The probability of loan losses* $\widehat{p}$ *decreases with a larger capital ratio* k *and with a smaller inspection cost by shareholders* C*.*

Proof. See appendix 1.

The model predicts that a larger capital ratio reduces the ex ante risk of the bank. The intuition is the following: a larger capital ratio, a larger k, reduces the need for external funds from depositors for a given size of the bank L_0. This increases the marginal revenue of shareholders and improves their incentives to inspect the bank manager. This has a positive effect on managerial monitoring and on the overall expected return of the portfolio of loans. With the same logic, a smaller inspection cost by shareholders, a lower C, causes the opposite effect by decreasing the marginal cost of internal supervision. In the empirical analysis, we measure both effects, exploiting the cross-country variation of our sample. On the one hand, we measure the effect of different capital ratios, and on the other hand, we compare regulatory systems with different intensities of external supervision that affect the cost of internal control.

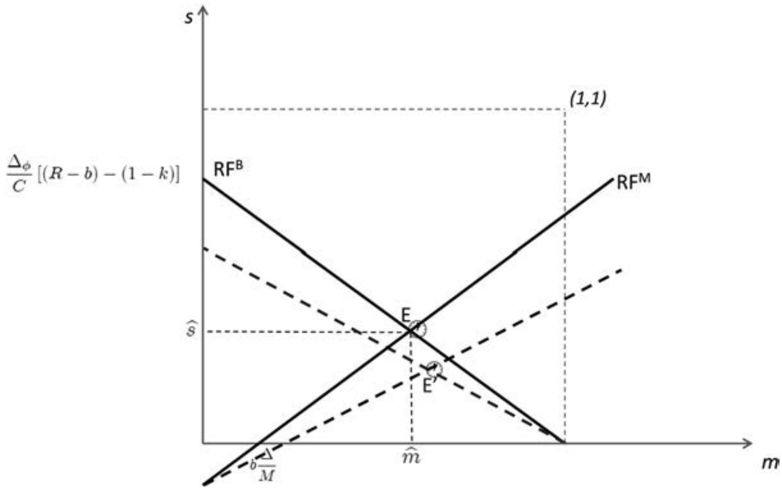
Finally, within our model we can study the effect of a larger managerial bonus on the risk of the bank.

PROPOSITION 3. *A larger managerial bonus b has a negative effect on the intensity of inspection $\widehat{s}$ of shareholders, while it might improve the monitoring effort $\widehat{m}$ of the bank manager. Overall, a larger bonus has an uncertain effect on the probability of loan losses $\widehat{p}$.*

Proof. See appendix 1.

The ambiguity of the impact of the managerial bonus on bank risk derives from the complex interaction of monetary incentives set to reward the bank manager with shareholders' incentives. As a matter of fact, the efforts of the two insiders, shareholders and the bank manager, are substitutes. Shareholders' incentives might deteriorate as a consequence of paying a larger bonus. The stake retained by shareholders when paying a larger bonus is smaller (effect through b) and their inspection is less effective if the manager behaves (effect through $(1 - m)$); thus, ceteris paribus, in equation (3) the marginal benefit of inspection is smaller. However, a larger bonus has a positive impact on the monitoring effort of the bank manager. The overall effect on the equilibrium probability of loan losses $\widehat{p}$ is the result of these two opposite forces: an increased managerial effort due to the larger monetary incentive of the bonus and a reduced internal control by shareholders. This explains the uncertainty of the sign of the effect on risk when increasing the managerial bonus.

Figure 2. Increase in the Managerial Bonus *b*



Notes: The diagram represents the reaction functions of the shareholders, RF_B (negative slope), and the bank manager, RF_M (positive slope). The mixed-strategy equilibrium is at the intersection E of the two linear functions. An increase in the bonus b shifts both reaction functions (dashed grey lines). While the level of inspection by shareholders decreases, the effect on the monitoring effort is uncertain. The reason is that a larger bonus has a direct effect on the managerial effort due to the larger reward, but it also reduces the inspection intensity by shareholders.

In figure 2, we represent the equilibrium efforts as the intersection E between the two best reply functions; we can perform graphically the comparative static exercise that results from a change in b in proposition 3 by shifting the two best reply functions.

Proposition 3 shows that the equilibrium outcome, represented in the new intersection E', has an ambiguous effect on p due to the uncertain impact on bank managerial effort. While, on the one hand, the bonus increases the monetary reward for the bank manager who behaves, on the other hand, it decreases the inspection effort by shareholders, inducing greater shirking by the bank manager. The net effect on the managerial effort is therefore uncertain.

The ambiguity of this last result calls for an empirical exploration of the impact of a larger bonus on bank risk.

It is interesting to evaluate the effect of a larger bonus according to different levels of capitalization of the bank.

PROPOSITION 4. *In a bank with a larger capital ratio k, a larger bonus b is more effective in reducing the probability of loan losses $\widehat{p}$.*

Proof. See appendix 1.

In appendix 3 we provide some numerical simulations to illustrate the results in propositions 3 and 4.

3.3 Risk-Sensitive Deposit Insurance

We now relax the assumption of a deposit insurance funded with taxpayers' money. When the deposit insurance premium is charged to the bank at date 0, there is an additional countervailing effect due to the expected impact of a larger managerial bonus on the risk through the deposit insurance premium.[14]

Assume that the bank shareholders pay a fair premium at date 0 to the deposit insurance to refund depositors for the expected shortfalls on the face value of their deposits, that is,

$$\pi_0 = p(m, s)\left[D_0 - (R - \ell)L_0\right]. \tag{8}$$

Now the bank's balance sheet at date 0 is given by

$$E_0 + D_0 = \pi_0 + L_0. \tag{9}$$

All the rest of the model is unchanged. Now the equilibrium is the following:

PROPOSITION 5. *When the lending size is limited by the capital ratio k such that $L_0 \leq E_0/k$ and the deposit insurance premium charged on the bank is fair, the monitoring intensity $\widetilde{m}$ of the bank manager, the inspecting effort of shareholders $\widetilde{s}$, and the probability of loan losses $\widetilde{p}$ are the solution to the following system of equations:*

$$(1 - k) - (R - \widetilde{p}\ell) + (1 - \widetilde{p})\left[b + \widetilde{\Omega}\right] = 0 \tag{10}$$

[14] In appendix 2, we indicate that this case is perfectly equivalent to that of a bank funded mainly with unsecured debt. Our model can therefore be exploited to discuss the effect of a greater managerial bonus with different degrees of market discipline.

$$[\Delta + \widetilde{s}(1 - p_H)]\, b - \widetilde{m}M = 0 \tag{11}$$

$$\widetilde{p} - p_L - (1 - \widetilde{m})\,(\Delta - \widetilde{s}\Delta_\phi) = 0, \tag{12}$$

with $\widetilde{\Omega} \equiv \frac{C\widetilde{s}}{(1-\widetilde{m})\Delta_\phi}$.

Proof. Assume that conditions (3) and (4) are binding; after substituting the fair premium (8) into (9), we derive the equations (10) and (11). Adding the definition of probability (12), we derive the system of equations (10)–(12), which determines the equilibrium values $(\widetilde{p}, \widetilde{s}, \widetilde{m})$. Notice that this system is non-linear and therefore cannot be solved explicitly.

The effect of a change in the level of the bonus on the probability of loan losses $\widetilde{p}$ is based on the result in proposition 6 in appendix 1. When the overall effect of a larger bonus is positive, a risk-sensitive deposit insurance premium changes, reflecting a lower riskiness; therefore, the stake of revenues from loans retained by shareholders increases, improving their marginal benefit of inspection. This initiates a virtuous circle by which the negative effect on the inspection of shareholders is reduced. Hence, an increase in managerial bonus can be even more beneficial. However, when a larger bonus increases bank risk, a risk-sensitive deposit insurance premium might exacerbate the negative effect: a risk-sensitive premium reacts to the increase in risk by reducing the stake of revenues from loans retained by shareholders, and this creates a further disincentive to their inspecting effort. The overall negative effect on risk might be even larger with a risk-sensitive deposit insurance. This is why, in the empirical analysis, we measure the effect of a larger managerial compensation by taking into account the cross-country heterogeneity derived from the different institutional arrangements concerning deposit insurance.

4. Data Sources

In this paper, we contribute to the empirical literature with a new database by matching four different sources of data. The final objective is to build a panel of large banks from several countries where each single observation is a CEO and his bank. In particular, we combine information at the bank level (such as accounting records information) with information on CEO compensation, for different years and for different countries. To link these data, absent direct linkages between accounting records and CEO compensation data, we merged observations from two different sources: Bankscope[15] and Capital IQ – People Intelligence.[16] From Capital IQ, we initially selected all commercial banks, savings institutions (SIC codes 6020, 6021, 6029, and 6036), and bank holding companies (BHCs, with SIC code 6719) for which the compensation of CEOs was available for at least one year within the period 2005–9; from BHCs we excluded banks for which the primary specialization is brokerage and financial services (SIC codes 6162, 6199, 6200, and 6211). We then matched these selected banks with the top ten largest publicly listed banks for each country; the largest banks have been ranked in terms of total assets and have been selected each year from 2005 to 2009. Following this repeated selection process (every year starting from 2005 to 2009), we discarded a bank if it was observed in the pre-crisis years but disappeared during the crisis because of mergers and acquisitions or insolvency. Then, we extracted information from Datastream about stock returns and equity prices at daily and weekly frequency in the years from 2005 to 2009. Finally, we added the indicators on financial regulation at the country level following Caprio, Laeven, and Levine (2007), who derived the information from the third wave of the World Bank's Bank Regulation and Supervision Survey.[17] In conclusion, we obtain a sample of the 116 largest banks from twenty-six countries.[18] Not surprisingly, the majority of observations belong to countries where the disclosure of managerial compensation is mandatory (as, for example, in the United States).

[15]Bankscope is a directory and financial reporting service on 30,000 banks worldwide provided by Bureau van Dijk. It provides standardized reports, ratings, and ownership data as well as financial analysis functions.

[16]Capital IQ – People Intelligence is a database provided by Standard and Poor's on the profiles of public and private firms worldwide, including financials, officers and directors, ownership, advisory relationships, transactions, securities, key developments, estimates, key documents, credit ratings, and filings.

[17]We present a list and a detailed description of our variables of interest in appendix 4.

[18]We present the final list of banks and countries in table 10 in appendix 5.

4.1 Descriptive Statistics

In the next two sub-sections, we provide summary statistics for our sample of banks and the way their CEOs are remunerated. In particular, in the following sub-section, we examine banks' accounting statements at the end of 2006 and their performance in the later period October 2007–December 2008; in the subsequent sub-section we examine summary statistics of CEO compensation and equity ownership measured at the end of 2006.

4.1.1 Banks

Table 1 provides the descriptive statistics for our sample of 116 large banks (all variables are in U.S. dollars). The value of total assets is in fact significantly larger compared to related papers that focus on U.S. banks—as, for instance, Fahlenbrach and Stulz (2011). Our sample is comparable to the sample in Beltratti and Stulz (2012), although we have fewer observations because compensation variables are not available for all banks due to the lack of mandatory disclosure rules. While sample size may represent a limit for the external validity of the empirical analysis, focusing on the largest banks has the advantage of enhancing their comparability. As argued by Laeven and Levine (2009), the largest groups tend to better comply with international accounting standards.

The average and median equity book-to-market ratio are smaller than 1; this indicates that banks were potentially growing in 2006. This evidence, combined with a positive average market stock return from stock prices between 2005 and 2006 of about 27 percent, suggests that the huge drop in stock returns from mid-2007 was, at least to some extent, unexpected even at the end of 2006. Tier 1 and total regulatory capital ratios are not observed for all banks in our sample. The mean value of the total regulatory capital ratio suggests that banks in 2006 had capital, on average, above the required minimum of Basel I. We will include tier 1 capital ratio as a control variable in our regression analysis, given its importance for the evaluation of bank stability for supervisory authorities—although we lack the information on its value for more than 10 percent of the banks in our sample. The average buy-and-hold return in the period 2007:Q3–2008:Q4 was approximately −48 percent; this underlines

Table 1. Summary Statistics for the Sample of Banks

	Mean	St. Dev.	Median	Number
A. Descriptive Statistics in 2006				
Total Assets	287171.4	558105.1	61590.9	116
Total Liabilities	270839.8	528171.2	56701.26	116
Market Capitalization	49713.84	236197.1	7491.345	116
Equity Book-to-Market Ratio	.9652698	1.339303	.6215296	116
Market Return from Stock Prices 2005–6	.2759742	.26403	.2703018	116
ROA	1.469828	1.547135	1.105	116
Equity over Total Assets (Book Value)	.0768866	.0153843	.0654814	116
Deposit Ratio	.8125634	.1464496	.8572832	113
Tier 1 Capital Ratio	9.5378	3.009371	8.61	100
Total Regulatory Capital Ratio	13.02724	5.323436	11.8	105
B. Performance Variables in the Financial Crisis				
Buy-and-Hold Return 2007–8	−.4833044	.2581407	−.4886037	116
Standard Deviation 2007–8	.0664146	.0198295	.0640443	116

Notes: The table provides summary statistics for our sample of banks. The definitions of the variables and the list of banks are in appendix 4 and 5, respectively. All variables in panel A are measured in millions of U.S. dollars at the end of fiscal year 2006. Original variables used to obtain performance indicators in panel B have been downloaded from Datastream in U.S. dollars.

how deep the financial crisis has been for the banking sector worldwide.

4.1.2 CEO Compensation

Table 2 provides descriptive statistics on the compensation packages and the value of equity portfolios for the CEOs employed in 2006 in our sample of banks. Panel A summarizes the various elements of total compensation. While average annual compensation is approximately \$3 million, the median value is approximately \$1 million; this suggests that even within our sample of large banks, there is

Table 2. Summary Statistics for CEO Compensation

	Mean	St. Dev.	Median	Number
A. Annual Compensation				
Total Compensation	3576.3	6029.7	1353.7	116
Salary	798.5	573.1	758.1	116
Cash Bonus	1410.1	2468.2	429.3	116
Equity Bonus	1367.7	3889.8	0	116
Cash Bonus over Salary	1.5	2.4	0.6	116
Equity Bonus over Salary	1.38	3.89	0	116
Total Bonus over Salary	2.88	5.75	.97	116
Cash Bonus over Total Bonus	0.5	0.4	0.6	116
B. Equity Portfolio				
Value of Shares	16385.6	41417.1	725.4	116
Value of Stock Options	19002.6	67158.2	0	116
Value of Total Equity Portfolio	35388.2	90413.2	1068.7	116
Value of Total Equity Portfolio/Total Compensation	21.4	93.9	1.1	116
Value of Total Equity Portfolio/Salary	48.46	125.44	1.93	116
C. Equity Portfolio Incentives				
Ownership from Shares (% over Total)	1.4	6.5	.02	116
Ownership from Shares and Options (% over Total)	1.5	6.5	.02	116
Percentage Equity Risk (Vega of Options)	0.7	2.4	0	116

Notes: The table provides summary statistics on the compensation and the portfolio of equity of CEOs appointed in the selected banks in 2006. The definitions of the variables are in appendix 4. All variables in panel A and panel B are measured in thousands of U.S. dollars at the end of fiscal year 2006.

a significant variability in total compensation across CEOs. Cash bonus is, on average, 1.5 times the salary. Moreover, cash bonuses are more widespread than bonuses paid in equity (shares and/or stock options); the median value of equity bonus is in fact zero, which implies that more than 50 percent of the banks in our sample did not award any stock and/or option in 2006 to their CEOs. Panel B summarizes the statistics on the equity portfolio of CEOs. Equity portfolio is the sum of shares (restricted and unrestricted) and stock options held by each CEO at the end of 2006. The average value of the equity portfolio was $35 million. The median value of shares (restricted and unrestricted) was approximately $725,000 at the end of 2006. Panel C summarizes some of the variables that will be used in the empirical analysis; they measure the sensitivity of the value of equity portfolio to changes in returns and risk of banks' share prices. As for the stock options, following Core and Guay's (2002) approximation, we distinguish between the sensitivity of CEO stock-option portfolios to share prices (option delta) and the sensitivity to volatility of stocks (option vega). The reason is that while Guay (1999) finds that firm equity risk is positively related to the convexity of the monetary incentives provided to their CEOs, Coles, Naveen, and Naveen (2006) find that the stock-return volatility of risky investments is positively affected by the deltas and vegas calculated on managers' options. We finally define the ownership from shares and stock options as the sum of option delta and direct insider ownership from shares.[19]

The figures on the average value of ownership from shares and stock options in our data indicate that a CEO would gain an additional 1.4 percent in the value of his equity portfolio for a 1 percent increase in stock prices, while the value of percentage equity risk (the vega weighted for all options) means that a CEO would see an increase of 0.7 percent in his stock-options wealth for a 1 percent increase in volatility of stock prices.

5. Financial Crisis and CEO Compensation

In this section, we analyze how the variables related to CEO monetary incentives in the pre-crisis year affected the performance of banks during the financial crisis. Following the structure and the predictions of the model, in the empirical analysis, we assume that shareholders were not expecting the evolution of their bank performance in the financial crisis at the time when they set the

[19]See appendix 4 for a detailed definition of the variables used in the empirical analysis.

compensation schemes before the collapse. Consequently, we run the following OLS regression:

$$Y_{i,07-08} = \alpha + \beta VC_{i,2006} + \gamma Controls_{i,2006} + \epsilon_{i,07-08}, \qquad (13)$$

where the dependent variable $Y_{i,07-08}$ is either buy-and-hold return (BHR, hereafter) of each bank stock price or standard deviation (SD, hereafter) of stock returns in the period 2007:Q3–2008:Q4. We decided to exclude the first two quarters of 2009 when computing these variables because bank returns in this last part of the recession may have been affected by national recovery policies.[20] On the right-hand side of equation (13), we measure CEO monetary incentives by using different measures of variable compensation in 2006, $VC_{i,2006}$. Following related literature on the effect of variable compensation on risk (Benmelech, Kandel, and Veronesi 2010), we consider separately measures of shorter-term incentives given by annual cash compensation and measures of longer-term incentives given by the equity portfolio of CEOs. Short-term incentives are measured by cash bonus over salary in 2006. Equity incentives are measured by the ownership from shares and options and by the percentage equity risk evaluated in 2006. In the theoretical section of the paper, we have demonstrated that the risk of the bank arises endogenously from the strategic interaction between managers, whose effort depends on variable compensation, and the shareholders, whose effort depends on the capital structure of the bank; consequently, to isolate the effect of variable compensation on risk, it is important that our empirical results adequately control for bank characteristics that shape shareholder incentives. In our regression analysis, we will add variables at the bank level to control for size (the log of market capitalization), for leverage (measured by equity to total asset), and for capital adequacy and liquidity (tier 1 capital ratio). When analyzing the determinants of risk taking of a bank, it is also important to control for measures of productivity because the literature acknowledges that risk and productivity are endogenously determined (Hughes

[20]As a consequence, we do not conform to National Bureau of Economic Research dates of the Great Recession, namely 2007:Q3–2009:Q2. However, as a robustness check, we repeated the analysis by including the first and the second quarter of 2009 in the measure of BHR and SD. The results, not included in the current version, are substantially unchanged.

and Mester 2013, for instance). Furthermore, Cheng, Hong, and Scheinkman (2010) argue that risk and productivity represent a predetermined characteristic of the bank that is exogenous with respect to executives' compensation. To rule out the possibility that the relation between $Y_{i,07-08}$ and $VC_{i,06}$ can be confounded by some predetermined characteristics of the bank, such as productivity, we add controls such as the market return from stock prices between 2005 and 2006, the equity book-to-market ratio, and the ROA (return on assets) measured in 2006. The first two variables capture the expectations of financial markets about the future performance of the bank, while the latter is a standard measure of productivity.[21] Finally, although in the model we assume that all depositors are insured, in reality, a non-negligible fraction of bank external funding may be unsecured; in this case, uninsured creditors may exert market discipline in addition to the control of shareholders. For this reason, we incorporate the fraction of deposits from customers over total deposits (which include money-market and short-term funding from other institutions) as an additional control in the regression analysis.[22]

5.1 Stock Return

In this section, we consider the BHR in the period 2007:Q3–2008:Q4 as the dependent variable. Table 3 summarizes the results.

[21] As an additional robustness check, we also employ the asset turnover in 2006 as a measure of productivity; moreover, we repeat all the subsequent empirical analyses by controlling for the average ROA and the average asset turnover in the period 2005–7. Averages may represent a better measure of the fundamental productivity of banks because they might smooth down abnormal yearly changes. However, the inclusion of such averages comes at the cost of losing some observations: this is why we have left the ROA observed in 2006 in the current empirical exercise. Finally, we repeated all the analyses by considering as a further control the average of the standard deviation in the period 2005–7. All these robustness checks, available upon request, substantially confirm our main results.

[22] As an alternative measure for the intensity of the control by other stakeholders in addition to shareholders, we employ an index of monitoring by the private sector at the country level from the third wave of the Bank Regulation and Supervision Survey; our results, available upon request, are substantially confirmed.

Table 3. Regression Analysis: Buy-and-Hold Returns 2007:Q3–2008:Q4

Dependent Variable:	**BHR**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Cash Bonus over Salary	−0.00752	−0.00261	−0.00439	−0.00699	−0.000348
	(0.0105)	(0.0112)	(0.0122)	(0.0115)	(0.0118)
Ownership from Shares and Options	0.333	0.242	−0.183	−0.313	−0.440
	(0.386)	(0.403)	(0.296)	(0.295)	(0.329)
Percentage Equity Risk	−1.324	−1.120	−1.723*	−1.726	−1.643
	(0.963)	(0.963)	(0.951)	(1.061)	(1.092)
Log of Market Capitalization		−0.0110	−0.0146	−0.000000413	0.00905
		(0.0110)	(0.0152)	(0.0189)	(0.0170)
Equity Book-to-Market Ratio			−0.431**	−0.0433**	−0.0344**
			(0.0203)	(0.0196)	(0.0164)
Market Return (2005–6)			−0.343***	−0.337***	−0.318***
			(0.0942)	(0.0857)	(0.0913)
ROA			0.00758	0.00335	0.0270
			(0.0194)	(0.0278)	(0.0460)
Equity over Total Assets (Book Value)				0.676	−0.327
				(0.808)	(1.088)
Deposit Ratio				0.459*	0.663***
				(0.272)	(0.208)
Tier 1 Capital Ratio					0.0185*
					(0.0107)
Constant	−0.468***	−0.382***	−0.214	−0.741**	−1.147***
	(0.0308)	(0.0964)	(0.161)	(0.360)	(0.300)
N	116	116	116	113	100
Adj. R^2	0.006	0.005	0.117	0.211	0.316

Notes: Robust standard errors are in parentheses. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively. All covariates are measured in U.S. dollars at the end of fiscal year 2006.

In column 1, we study the relation between the BHR of banks during the financial crisis and three different components of the variable compensation of CEO remuneration. We use separate measures of CEO monetary incentives to distinguish between short-run incentives (cash bonus over salary) and long-run incentives (the equity portfolio); within this second type, we distinguish between the ownership from shares and options and the percentage equity risk. At first glance, we find no direct relation between each single component of the variable compensation and ex post performance. In columns 2–5, we analyze the effects of our measures of variable compensation, also controlling for variables at the bank level. In column 2, we control for size; in column 3, we add measures of ex ante performance and productivity; in column 4, we add a measure of leverage and the deposit ratio as additional controls; in column 5, we add the tier 1 capital ratio.[23] The results reveal that, while variable compensation had no direct impact on BHR for the whole sample, banks with higher stock returns and book-to-market ratios in 2006 performed significantly worse than other banks during the financial crisis; moreover, banks with higher tier 1 and banks that relied relatively more on customer deposits performed better. These results are in line with the findings of Fahlenbrach and Stulz (2011), although they focus on a sample of U.S. banks. In the next section, we will show how this conclusion might be challenged by introducing variables aimed at capturing the quality of bank governance and financial regulation.

5.2 Risk Return

Now we simply replicate the previous analysis using the standard deviation of stock returns as the dependent variable. The reason is that the convexity of monetary incentives given to CEOs may affect not only the average return of stocks of banks but also its risk (Coles, Naveen, and Naveen 2006). Results are in table 4.

The results in columns 1–4 indicate a statistically significant effect of monetary incentives given by stock options on realized

[23]While we acknowledge the importance of this variable for the performance of banks, we separately add it in the regression analysis, as it is not observed for approximately 10 percent of banks in our sample.

Table 4. Regression Analysis: Standard Deviation 2007:Q3–2008:Q4

Dependent Variable:	**SD**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Cash Bonus over Salary	0.000602	−0.0001000	0.000767	0.000795	0.000602
	(0.000707)	(0.000753)	(0.000868)	(0.000779)	(0.000790)
Ownership from Shares and Options	−0.0481***	−0.0350***	−0.0346***	−0.0237**	−0.0129
	(0.0100)	(0.0109)	(0.0125)	(0.0109)	(0.0126)
Percentage Equity Risk	0.174*	0.144	0.190**	0.154*	0.163**
	(0.0972)	(0.0963)	(0.0957)	(0.0797)	(0.0772)
Log of Market Capitalization		0.00158*	−0.00108	−0.00173	−0.00105
		(0.000857)	(0.00129)	(0.00120)	(0.00102)
Equity Book-to-Market Ratio			−0.00437***	−0.00380***	−0.00316***
			(0.00136)	(0.00103)	(0.000975)
Market Return (2005–6)			0.0154***	0.0153***	0.0212***
			(0.00581)	(0.00465)	(0.00457)
ROA			−0.00231**	−0.00339	−0.00586**
			(0.00115)	(0.00258)	(0.00279)
Equity over Total Assets (Book Value)				0.0453	0.0535
				(0.0608)	(0.0871)
Deposit Ratio				−0.0404***	−0.0356**
				(0.0132)	(0.0147)
Tier 1 Capital Ratio					−0.00000409
					(0.000702)
Constant	0.0651***	0.0527***	0.0770***	0.112***	0.101***
	(0.00214)	(0.00724)	(0.0136)	(0.0203)	(0.0190)
N	116	116	116	113	100
Adj. R^2	0.060	0.077	0.163	0.242	0.279

Notes: Robust standard errors are in parentheses. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively. All covariates are measured in U.S. dollars at the end of fiscal year 2006.

volatility of bank stock returns during the financial crisis. In particular, ownership from shares and options and the percentage equity risk affected the volatility of stock returns in two opposite directions. While the first is associated with a smaller volatility, the second is associated with a higher one. However, the effect of these variables becomes weaker in terms of statistical significance in column 5 when we add the tier 1 as an additional control. This last result calls for a further exploration of the relation between capital requirements and variable compensation.

6. The Effect of Financial Regulation

The evidence provided in the previous section is coherent with proposition 3 of our model: variable compensation may have an ambiguous effect on risk taking depending upon the incentives of bank managers and shareholders, which ultimately depend upon the regulatory environment and the relative efficiency of monitoring over inspecting activities; coherently, in our whole sample, we do not find any direct effects of variable compensation on performance. Our interpretation is that the potential positive effects of a larger variable compensation have been, to some extent, counterbalanced by their negative effects; as a result, we do not find a direct effect of the variable compensation of CEOs on return and risk. However, this result does not prevent the possibility that variable compensation may have significantly impacted the performance of banks only under certain regulatory/institutional conditions. The scope of the next analysis is precisely to explore the interaction between regulation and variable compensation on ex post performance, under the guidance of the insights from the theoretical section. In particular, we present additional empirical analysis to address three main theoretical predictions: (i) weaker control by shareholders, combined with variable compensation, might increase the risk-taking attitude of bank managers; (ii) when variable compensation has a negative effect on the risk of banks, a risk-sensitive deposit insurance premium might exacerbate its negative effect; for this reason, we will exploit differences in the institutional arrangements with regard to deposit insurance at the country level; and (iii) higher capital requirements may reduce risk-taking incentives by insiders.

6.1 The Effect of Shareholders' Control

Let us study the effects of CEO monetary incentives in contexts in which the efficiency and consequently the intensity of control by shareholders over bank managers is relatively stronger compared with the rest of the sample. For this purpose, we identify proxies for the efficiency of control both at the bank and country level, introducing measures of financial regulation. Following seminal contributions in the corporate governance literature (Jensen and Meckling 1976; Shleifer and Vishny 1986), we proxy the efficiency of control by ownership concentration in the bank. The main hypothesis is that in banks with lower ownership concentration, dispersed shareholders have less power and fewer incentives to control managerial behavior due to the greater marginal cost compared with the benefit. We measure ownership concentration as the sum of the shares of the largest three shareholders (C3 index) in 2006, and we examine how ownership concentration interacts with variable compensation in shaping the risk of individual banks. We split the sample into two sub-samples, according to whether the value of the C3 index is below (greater cost of inspection by shareholders, due to share dispersion) or above the median and explore if there is a significant difference in the average compensation schemes adopted in the two groups of banks. Evidence from table 5 indicates that banks with lower ownership concentration were significantly bigger (total assets measured at the end of 2006) and awarded significantly larger bonuses (both in form of cash and equity) to their CEOs in 2006.

To study if this difference in compensation structure has impacted performance of banks during the financial crisis, we run a regression analysis similar to that in section 5 by splitting the original sample into two sub-samples. Results are in table 6.

Columns 1 and 2 replicate the regression analysis of the full specification in column 5 of tables 3 and 4 for the sub-sample of banks with lower ownership concentration. Notice that we have fewer observations in this analysis compared with table 5, as the inclusion of tier 1 as a regressor reduces the sample size. The analysis reveals that, in banks with a lower ownership concentration, the larger the equity bonus (measured as either shares and stock-options holdings or percentage equity risk), the worse the bank performance both in terms of stock returns and volatility. Columns 3 and 4 follow a

Table 5. Ownership Concentration: Banks, Variable Compensation, Performance

	C3 Below Median	C3 Above Median	Difference
A. Bank-Level Descriptive Statistics			
Total Assets	413958.2	160384.6	253573.6*
	(690077.5)	(345696.9)	
Market Capitalization	86977.7	12449.9	74527.8
	(330701.1)	(19175.7)	
Equity over Total Assets (Book Value)	0.0714	0.0824	−0.0109
	(0.0340)	(0.0641)	
Market Return from Stock Prices 2005–6	0.267	0.285	−0.0109
	(0.254)	(0.276)	
Tier 1 Capital Ratio	9.276	9.810	−0.534
	(3.096)	(2.923)	
B. Compensation Variables			
Cash Bonus over Salary	2.144	0.853	1.291**
	(3.079)	(1.123)	
Equity Bonus over Salary	2.223	0.553	1.670*
	(5.231)	(1.338)	
Total Bonus over Salary	4.367	1.406	2.961**
	(7.663)	(1.913)	
Value of Total Equity Portfolio/Total Compensation	27.86	14.90	12.96
	(119.4)	(58.98)	
C. Performance in the Financial Crisis			
Buy-and-Hold Return 2007–8	−0.499	−0.468	−0.0312
	(0.272)	(0.245)	
Standard Deviation 2007–8	0.0691	0.0638	0.00531
	(0.0229)	(0.0159)	
N	58	58	

similar empirical strategy for the sub-group of banks with greater concentration. In this sub-group of banks, we do not find any effect of ownership from shares and option, while we find a positive effect of percentage equity risk on performance during the financial crisis;

Table 6. Ownership Concentration, Variable Compensation, and Performance in the Financial Crisis

Dependent Variable:	Low Concentration		High Concentration	
	BHR	SD	BHR	SD
	(1)	(2)	(3)	(4)
Cash Bonus over Salary	0.00316	0.000597	0.00358	0.000686
	(0.0138)	(0.000967)	(0.0271)	(0.00183)
Ownership from Shares and Options	−6.976***	0.276*	−0.173	−0.0105
	(2.344)	(0.155)	(0.397)	(0.0172)
Percentage Equity Risk	−2.524***	0.212***	3.172***	−0.161***
	(0.825)	(0.0666)	(0.678)	(0.0546)
Log of Market Capitalization	−0.0167	−0.000391	0.0280	−0.00136
	(0.0272)	(0.00224)	(0.0205)	(0.00130)
Equity Book-to-Market Ratio	−0.104***	−0.00246	−0.00442	−0.00307***
	(0.0323)	(0.00243)	(0.0124)	(0.00103)
Market Return (2005–6)	−0.364**	0.0267***	−0.317**	0.0177***
	(0.166)	(0.00900)	(0.131)	(0.00648)
ROA	−0.0114	−0.00404	0.0750	−0.00911
	(0.0665)	(0.00415)	(0.0759)	(0.00565)
Equity over Total Assets (Book Value)	0.135	−0.0480	−0.642	0.196
	(1.620)	(0.148)	(1.715)	(0.144)
Deposit Ratio	0.752**	−0.0327	0.761***	−0.0458**
	(0.324)	(0.0259)	(0.232)	(0.0194)
Tier 1 Capital Ratio	0.0448**	−0.000280	0.00443	−0.000646
	(0.0168)	(0.00122)	(0.0158)	(0.00115)
Constant	−1.079**	0.0969**	−1.344***	0.114***
	(0.487)	(0.0420)	(0.326)	(0.0214)
N	51	51	49	49
Adj. R^2	0.418	0.242	0.298	0.272

Notes: Robust standard errors are in parentheses. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively. All covariates are measured in U.S. dollars at the end of fiscal year 2006.

this is in fact associated with higher returns and lower volatility.[24] These results support the prediction of the model. Greater variable compensation, in the form of equity bonuses, has led to worse performance (lower returns and higher volatility) in banks with weaker internal control by shareholders. This evidence is coherent with the findings in Gropp and Kohler (2010) indicating that more widely held banks faced greater loan losses in the financial crisis. To check the robustness of this result, we replace C3 with other proxies for the efficiency of supervision by exploiting some of the variables contained in the third wave of the World Bank's Bank Regulation and Supervision Survey. In particular, we use two proxies at the country level: (i) an index of restrictions on bank activities; (ii) an index of supervisory power of bank supervisory authorities. Our hypothesis is that, on the one hand, restrictions on bank activities by the financial authority reduce managerial slack and thus lead to higher efficiency; on the other hand, greater power of bank supervisory authorities makes the ex ante cost of bank manager misbehavior larger from the shareholder point of view, thus inducing greater internal control. We split the sample of banks into two sub-samples according to whether the values of those indices are above or below the median. Results (not reported in the current version, but available upon request) indicate that, in the group of countries where the restrictions on bank activities were below the median, a greater variable compensation (in particular, equity portfolio incentives) is related to worse performance (measured by using either stock return or standard deviation). In the other sub-group we don't find any effect of variable compensation. A similar result is obtained for banks in countries where the supervisory authority is less powerful. All these empirical findings seem to indicate that weaker supervision (due to higher internal shareholder costs), combined with higher pay-for-performance sensitivity in CEO compensation schemes, might explain the higher risk in banks.

6.2 Deposit Insurance

Theoretical insights from the version of our model that incorporates a risk-sensitive deposit insurance mechanism imply that, when

[24]These results are robust to the inclusion of an alternative measure of bank size, such as total assets, that replaces market capitalization.

the variable compensation reduces risk, the existence of an explicit insurance premium is beneficial. The opposite is true, however, when higher variable compensation implies higher risk incentives for insiders. Again, these results call for an empirical test of the predictions of the model. In this sub-section, we analyze the interaction between deposit insurance and variable compensation on risk in banks. To this purpose, we divide our initial sample of banks into two groups: those banks based in countries where an explicit deposit insurance arrangement was in place in 2006 and those in countries without it (which we label as countries with implicit deposit insurance systems). As a first step, we check if there is a significant difference in the average compensation schemes adopted in the two groups of banks. Evidence in table 7 reveals that the group of banks with explicit deposit insurance has rewarded more equity bonus to their CEOs; however, the small sample size of the other group does not make the statistical comparison reliable.

Keeping this sample limitation in mind, we test if the interaction of explicit deposit insurance with the compensation structure has an impact on the performance of banks during the financial crisis. While displaying the results also for the other sub-sample for the sake of completeness, we are aware that the small sample size reduces our confidence in the statistical significance of the results. We employ a regression analysis similar in spirit to the previous section. Results are in table 8.

Columns 3 and 4 replicate the regression analysis of the full specification in column 5 of tables 3 and 4 for the sub-sample of banks based in countries with explicit deposit insurance. Results in column 3 suggest that banks that provided higher equity incentives to their CEOs (both ownership from shares and options and percentage equity risk) are associated with worse performance in terms of stock returns during the financial crisis. Results in column 4 suggest, instead, that only percentage equity risk can be associated with higher volatility. Taken together, the theoretical insights and empirical results suggest that explicit deposit insurance, combined with variable compensation schemes, increased the risk attitude of shareholders and bank managers and resulted in worse performance during the financial crisis.

Table 7. Deposit Insurance: Banks, Variable Compensation, Performance

	Implicit Dep. Ins.	Explicit Dep. Ins.	Difference
A. Bank-Level Descriptive Statistics			
Total Assets	78758.6	449614.9	−370856.3**
	(95508.8)	(675523.4)	
Market Capitalization	78643.9	−67599.7	11044.2
	(14500.5)	(303572.6)	
Equity over Total Assets (Book Value)	0.0921	0.0632	0.0289*
	(0.0856)	(0.0277)	
Market Return from Stock Prices 2005–6	0.259	0.272	−0.0129
	(0.197)	(0.174)	
Tier 1 Capital Ratio	9.140	8.875	0.265
	(2.130)	(1.998)	
B. Compensation Variables			
Cash Bonus over Salary	1.269	1.935	−0.666
	(1.215)	(2.907)	
Equity Bonus over Salary	0.437	2.160	−1.723
	(0.651)	(4.893)	
Total Bonus over Salary	1.706	4.096	−2.389
	(1.480)	(7.150)	
Value of Total Equity Portfolio/Total Compensation	6.350	9.865	−3.514
	(12.35)	(24.79)	
C. Performance in the Financial Crisis			
Buy-and-Hold Return 2007–8	−0.418	−0.543	0.125*
	(0.181)	(0.241)	
Standard Deviation 2007–8	0.0635	0.0684	−0.00484
	(0.0125)	(0.0228)	
N	27	69	

6.3 Capital Requirements

In this last sub-section, we study the empirical relation between capital requirements, variable compensation, and risk taking. Theoretical insights from the model suggest that higher capital ratio (and,

Table 8. Deposit Insurance, Variable Compensation, and Performance in the Financial Crisis

Dependent Variable:	Implicit Deposit		Explicit Deposit	
	BHR	SD	BHR	SD
	(1)	(2)	(3)	(4)
Cash Bonus over Salary	−0.0421	0.00232	0.00549	0.000719
	(0.0273)	(0.00181)	(0.0118)	(0.000950)
Ownership from Shares and Options	−17.79**	−0.128	−1.751***	0.0351
	(6.877)	(0.596)	(0.381)	(0.0382)
Percentage Equity Risk	2.958**	−0.163	−2.181***	0.232***
	(1.069)	(0.103)	(0.532)	(0.0672)
Log of Market Capitalization	−0.0964*	−0.00652	−0.0118	−0.00177
	(0.0559)	(0.00499)	(0.0230)	(0.00178)
Equity Book-to-Market Ratio	−0.430***	−0.0197	−0.0484**	−0.00216
	(0.128)	(0.0123)	(0.0239)	(0.00168)
Market Return (2005–6)	0.720***	0.0411***	−0.0447	0.0193
	(0.143)	(0.0130)	(0.224)	(0.0192)
ROA	0.571***	0.00653	0.0724	−0.00640
	(0.199)	(0.0185)	(0.0744)	(0.00520)
Equity over Total Assets (Book Value)	−10.07**	−0.434	0.682	0.0302
	(3.614)	(0.286)	(1.456)	(0.142)
Deposit Ratio	0.428	−0.0610	0.478*	−0.0428
	(0.596)	(0.0490)	(0.257)	(0.0266)
Tier 1 Capital Ratio	−0.00477	0.00117	0.0462***	−0.00214
	(0.0279)	(0.00197)	(0.0154)	(0.00158)
Constant	0.246	0.182**	−1.241***	0.133***
	(0.830)	(0.0695)	(0.381)	(0.0333)
N	22	22	62	62
Adj. R^2	0.483	0.025	0.325	0.274

Notes: Robust standard errors are in parentheses. *, **, and *** denote $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively. All covariates are measured in U.S. dollars at the end of fiscal year 2006.

consequently, lower leverage) might lead to lower risk taking from the shareholder perspective because a larger capital ratio increases the marginal revenue of his effort. As a proxy for the level of capital, we consider the difference between the actual capital (total regulatory capital ratio measured at the bank level) and the minimum

Table 9. Distance between Actual and Required Capital Requirements: Banks, Variable Compensation, Performance

	Distance Below Median	Distance Above Median	Difference
A. Bank-Level Descriptive Statistics			
Total Assets	293935.2	332067.0	−38131.8
	(467886.3)	(677072.6)	
Market Capitalization	75052.6	34329.9	40722.7
	(346980.8)	(62990.7)	
Equity over Total Assets (Book Value)	0.0620	0.0887	−0.0267**
	(0.0262)	(0.0631)	
Market Return from Stock Prices	0.291	0.266	0.0250
	(0.233)	(0.261)	
Tier 1 Capital Ratio	8.068	11.13	−3.061***
	(1.598)	(3.366)	
B. Compensation Variables			
Cash Bonus over Salary	1.473	1.678	−0.205
	(2.553)	(2.434)	
Equity Bonus over Salary	0.744	1.952	−1.208
	(2.383)	(4.616)	
Total Bonus over Salary	2.217	3.630	−1.414
	(4.532)	(6.711)	
Value of Total Equity Portfolio/Total Compensation	14.44	31.21	−16.77
	(60.15)	(125.5)	
C. Performance in the Financial Crisis			
Buy-and-Hold Return 2007–8	−0.543	−0.426	−0.117**
	(0.223)	(0.229)	
Standard Deviation 2007–8	0.0675	0.0618	0.00572
	(0.0169)	(0.0166)	
N	52	53	

capital requirement (defined by each country authority).[25] We divide our sample of banks into two groups according to the value of this difference, one below and the another above the median. Evidence from the descriptive analysis in table 9 shows that there is not a

[25] The minimum required capital ratio has been collected directly from the third wave of the Bank Regulation and Supervision Survey (as described in appendix 4). Notice that about 80 percent of banks in our sample operate in countries where the required ratio is less than or equal to 8 percent.

significant difference in the balance sheet or CEO compensation variables between the banks in the two groups; instead, we find that more-capitalized banks performed relatively better during the financial crisis than poorly capitalized banks, confirming the baseline results in section 5. Turning to the regression analysis, we do not find consistent evidence that variable compensation affected return and risk in the two sub-groups of banks; this result, which is perfectly coherent with evidence found by Chesney, Stromberg, and Wagner (2010), Beltratti and Stulz (2012), and Demirguc-Kunt, Detragiache, and Merrouche (2013), suggests that shareholders in poorly capitalized banks may have perfectly aligned their incentives with those of their CEOs to take more risk.

7. Conclusions

This paper contributes to the recent literature on the determinants of risk in banks. In particular, we analyze the impact of CEOs' variable compensation as well as that of corporate governance and financial regulation. We set out a theoretical framework that can illuminate the determinants of risk in banks when the agency conflicts between managers, shareholders, and depositors are important; and we test the model's predictions with an analysis of banks' performance during the financial crisis, using a novel database on banks in different countries. We can summarize the results as follows:

- There is no evidence of an association between variable compensation and bank performance (measured as stock returns and standard deviation of stock returns) for the entire sample.
- There is evidence of a correlation between variable compensation and risk when we interact it with banks' corporate governance arrangements and the financial regulatory framework in the country where the bank is located.
- CEOs' monetary incentives are associated with lower stock returns and higher volatility in banks where shareholders'

control is weak—i.e., when ownership concentration is low—and where restrictions on banks' activities and the power of supervisory authorities are relatively weaker.

- For banks in countries with explicit deposit insurance, an increase in CEOs' variable compensation is associated with worse performance and greater risk.
- Highly capitalized banks were more resilient during the financial crisis; their stock returns dropped less and their standard deviation was smaller.

This evidence offers substantial support for the indications of our model. To our knowledge, the paper is one of the first model-assisted empirical studies of the interrelations between CEOs' monetary incentives, financial regulation, and risk taking at banks in different countries. The understanding of these interactions may have important policy implications in the current debate about prudential regulation.

Appendix 1. Computations and Proofs

Proof of Proposition 1

Assume that conditions (4) and (3) are binding; after substituting the balance sheet (1) into (3), we derive equations (5) and (6). We can solve this linear system of equations and derive the equilibrium values of $\widehat{s}$ and $(1-\widehat{m})$ as follows:

$$(1-\widehat{m}) = \frac{(M-\Delta.b)}{M+\frac{A}{C}(1-p_H)b}$$

and

$$\widehat{s} = \frac{A}{C}(1-\widehat{m}) = \frac{A}{C}.\left[\frac{(M-\Delta.b)}{M+\frac{A}{C}(1-p_H)b}\right].$$

We need to assume $M \geq \Delta.b$ in order to guarantee that the two efforts, and thus the two probabilities, are positive. To derive the risk in equilibrium, i.e., equation (7), we simply substitute the two values $\widehat{s}$ and $(1-\widehat{m})$ into (2).

Proof of Proposition 2

To sign the impact of changes on the equilibrium values of efforts, we can study the derivative of $\widehat{s}$ and $(1-\widehat{m})$ with regard to each of the variables of interest at the time and then derive the overall effect on (7).

Effect of a Change in k

The derivatives of k on the equilibrium value of the two efforts $\widehat{s}$ and $(1-\widehat{m})$ are given by

$$\frac{d\widehat{s}}{dk} = \frac{M.\frac{\Delta_\phi}{C}(M-\Delta.b)}{\left[M+\frac{A}{C}(1-p_H)b\right]^2} \geq 0$$

and

$$\frac{d(1-\widehat{m})}{dk} = -\frac{(M-\Delta.b)\frac{\Delta_\phi}{C}(1-p_H)b}{\left[M+\frac{A}{C}(1-p_H)b\right]^2} \leq 0.$$

Both effects can be signed without uncertainty. The overall effect of k on the equilibrium risk $\widehat{p}$ is given by the total derivative of (7) with regard to k, that is,

$$\frac{d\widehat{p}}{dk} = \frac{d(1-\widehat{m})}{dk}(\Delta - \widehat{s}\Delta_\phi) - (1-\widehat{m})\Delta_\phi \frac{d\widehat{s}}{dk}.$$

The overall effect on the probability of loan losses is negative, and therefore a stronger capital requirement reduces bank risk.

Effect of a Change in C

Similarly to the previous exercise, we can study the effect of a change in C on the equilibrium efforts. The derivatives of a change in C on the two equilibrium values $\widehat{s}$ and $(1-\widehat{m})$ are given by

$$\frac{d\widehat{s}}{dC} = -\frac{\frac{A}{C^2}(M-\Delta.b)}{\left[M+\frac{A}{C}(1-p_H)b\right]^2} \leq 0$$

and

$$\frac{d(1-\widehat{m})}{dC}=\frac{(M-\Delta.b)\frac{A}{C^2}(1-p_H)b}{\left[M+\frac{A}{C}(1-p_H)b\right]^2}\geq 0.$$

Both effects can be signed without uncertainty. The overall effect of C on the riskiness $\widehat{p}$ is given by the total derivative of (7) with regard to C, that is,

$$\frac{d\widehat{p}}{dC}=\frac{d(1-\widehat{m})}{dC}(\Delta-\widehat{s}\Delta_\phi)-(1-\widehat{m})\Delta_\phi\frac{d\widehat{s}}{dC}.$$

It is easy to see that the overall effect on the probability of loan losses is positive, and therefore a smaller inspection cost by shareholders reduces bank risk.

Proof of Proposition 3

The sign of the impact of changes on the equilibrium value of efforts can be studied by taking the derivatives of $\widehat{s}$ and $(1-\widehat{m})$ with regard to b and then studying the effect on (7). The derivatives of the two equilibrium values $\widehat{s}$ and $(1-\widehat{m})$ are given by

$$\frac{d\widehat{s}}{db}=-\frac{M.\left\{\frac{\Delta_\phi}{C}(M-\Delta.b)+\left[\Delta+\frac{A}{C}(1-p_H)\right]\right\}}{\left[M+\frac{A}{C}(1-p_H)b\right]^2}\leq 0$$

and

$$\frac{d(1-\widehat{m})}{db}=\frac{-M.\left[\Delta+\frac{A}{C}(1-p_H)\right]+\frac{\Delta_\phi}{C}(1-p_H)b(M-\Delta.b)}{\left[M+\frac{A}{C}(1-p_H)b\right]^2}\lesseqgtr 0,$$

which has an uncertain effect depending on which effect prevails. The first effect is the "direct" effect of the bonus on the managerial effort, while the second effect is the "indirect" substitution effect through the lower inspection intensity of shareholders. The overall effect on the riskiness depends upon the sign of the effect of the bonus on the managerial effort. The sign of the effect of b on the probability $\widehat{p}$ is given by the derivative of (7) with regard to b, that is,

$$\frac{d\widehat{p}}{db}=\frac{d(1-\widehat{m})}{db}(\Delta-\widehat{s}\Delta_\phi)-(1-\widehat{m})\Delta_\phi\frac{d\widehat{s}}{db}.$$

Given that the inspection effort diminishes as a consequence of a larger bonus, the probability of loan losses is reduced only when the increase in managerial effort compensates for the smaller effort by shareholders. Hence for riskiness to become smaller, the direct effect of the bonus must be stronger than the indirect effect. The larger is M, the more likely it is.

Proof of Proposition 4

Assume we increase simultaneously the capital ratio k and the bonus b in order to maintain the overall value of A unchanged, that is, $db = dk$. In this special case, it is easy to see that the equilibrium values of $(1-\widehat{m})$ and $\widehat{s} = \frac{A}{C}(1-\widehat{m})$ are smaller. The overall effect of the derivative of b on $\widehat{p}$ is more likely to be negative: the reason is that, on the one hand, the derivative $\frac{d(1-\widehat{m})}{db}$ is negative while its weight $(\Delta - \widehat{s}\Delta_\phi)$ is larger; on the other hand, the second term (with a negative sign) is the derivative $\frac{d\widehat{s}}{db}$, which is negative, but its weight $(1-\widehat{m})\Delta_\phi$ is smaller. Overall, it is more likely that the term with a negative sign will prevail.

Proposition 6 and Its Proof

PROPOSITION 6. *A larger bonus b has a negative effect on the intensity of inspection $\widetilde{s}$ of shareholders, while it might improve the monitoring effort $\widetilde{m}$ of the bank manager. Overall, a larger bonus has an uncertain effect on the probability of loan losses $\widetilde{p}$.*

Proof. The sign of the impact of a change in the bonus b on the equilibrium values $(\widetilde{p}, \widetilde{s}, \widetilde{m})$ can be derived, following Chiang (1984), through the application of the Cramer rule to the system of linear equations (10)–(12) around the equilibrium values of $(\widetilde{p}, \widetilde{s}, \widetilde{m})$. Taking the total differential of the system of equations with regard to b, we have

$$G \times \begin{bmatrix} \frac{d\widetilde{p}}{db} \\ \frac{d\widetilde{s}}{db} \\ \frac{d\widetilde{m}}{db} \end{bmatrix} = \begin{bmatrix} -(1-\widetilde{p}) \\ -\left[\Delta + \widetilde{s}\,(1-p_H)\right] \\ 0 \end{bmatrix},$$

where G is defined as

$$G = \begin{bmatrix} -\left[(b-\ell)+\widetilde{\Omega}\right] & \widetilde{\Omega}\frac{(1-\widetilde{p})}{\widetilde{s}} & \widetilde{\Omega}\frac{(1-\widetilde{p})}{(1-\widetilde{m})} \\ 0 & (1-p_H)\,b & -M \\ 1 & (1-\widetilde{m})\Delta_\phi & (\Delta-\widetilde{s}\Delta_\phi) \end{bmatrix}.$$

The sign of the effect of b on the probability $\widetilde{p}$ is the ratio between two determinants, i.e., $\frac{d\widetilde{p}}{db} = \frac{|G_1|}{|G|}$. Matrix G_1 is the 3x3 matrix given by G in which the first column is replaced by the vector on the right-hand side of the system of linear equations. The determinant $|G_1|$ is

$$(1-\widetilde{p})\left\{-\left[(1-p_H)\,b(\Delta-\widetilde{s}\Delta_\phi)+M(1-\widetilde{m})\Delta_\phi\right] + \frac{\widetilde{\Omega}}{\widetilde{s}}\left[\Delta+\widetilde{s}\,(1-p_H)\right]\left[\Delta-2\widetilde{s}\Delta_\phi\right]\right\}.$$

The sign of the effect is uncertain. Given that the determinant $|G|$,

$$-\left[(b-\ell)+\widetilde{\Omega}\right]\left[(1-p_H)\,b(\Delta-\widetilde{s}\Delta_\phi)+M(1-\widetilde{m})\Delta_\phi\right] - \frac{\widetilde{\Omega}(1-\widetilde{p})}{\widetilde{s}(1-\widetilde{m})}\left[M(1-\widetilde{m})+(1-p_H)\,b\widetilde{s}\right],$$

is negative, the overall sign of the effect depends upon $|G_1|$. The overall effect is negative whenever $|G_1|$ is positive, and vice versa. The sign of the effect of b on the inspection $\widetilde{s}$ is the ratio between two determinants, i.e., $\frac{d\widetilde{s}}{db} = \frac{|G_2|}{|G|}$. Matrix G_2 is the 3x3 matrix given by G in which the second column is replaced by the vector on the right-hand side of the system of linear equations. Its determinant $|G_2|$,

$$\left[(b-\ell)+\widetilde{\Omega}\right]\left[\Delta+\widetilde{s}\,(1-p_H)\right](\Delta-\widetilde{s}\Delta_\phi) + (1-\widetilde{p})\left\{M+\frac{\widetilde{\Omega}}{(1-\widetilde{m})}\left[\Delta+\widetilde{s}\,(1-p_H)\right]\right\},$$

is positive. Given that $|G| < 0$ and $|G_2| > 0$, the overall sign of the effect is negative, that is, $\frac{d\widetilde{s}}{db} < 0$. Finally, the sign of the effect of b on the monitoring intensity $\widetilde{m}$ is the ratio between two determinants, i.e., $\frac{d\widetilde{m}}{db} = \frac{|G_3|}{|G|}$. Matrix G_3 is the 3x3 matrix given by G in which the third column is replaced by the vector on the right-hand side of the system of linear equations. Its determinant $|G_3|$ is

$$-\left[\Delta + \widetilde{s}\,(1 - p_H)\right]\left\{\left[(b-\ell) + \widetilde{\Omega}\right](1-\widetilde{m})\Delta_\phi + (1-\widetilde{p})\frac{\widetilde{\Omega}}{\widetilde{s}}\right\}$$
$$+ (1-\widetilde{p})\,(1-p_H)\,b.$$

When the last term is not too large (small b), then $|G_3| < 0$, and given that $|G| < 0$ the overall sign of the effect is positive, that is, $\frac{d\widetilde{m}}{db} > 0$.

Appendix 2. Case with Unsecured Debt

Assume the bank is funded at date 0 with $\alpha\%$ unsecured debt (uninsured depositors) and $(1-\alpha)\%$ insured deposits with $\alpha \in [0,1]$. We also let the deposit insurance premium be charged on the bank for a proportion $\beta \in [0,1]$, where $\beta = 0$ captures the case of a premium funded with taxpayers' money and $\beta = 1$ captures the risk-sensitive premium charged directly to the bank. The balance sheet in this case is

$$E_0 + \alpha D_0 + (1-\alpha)D_0 = \beta\pi_0 + L_0.$$

The returns of the portfolio of loans at date 2 must be divided among the different stakeholders of the bank in all possible states of the world. If the portfolio of loans returns RL_0, then each insured depositor is repaid D_0, while unsecured debtholders receive D_2 and the bank manager is rewarded the bonus b. If the portfolio of loans returns $(R-\ell)\,L_0$, then the deposit insurance repays $(1-\alpha)D_0$ to insured depositors, while unsecured debtholders receive $\max\{0;(R-\ell)L_0 - (1-\alpha)D_0\}$ and the bank manager does not cash the bonus. The fair deposit insurance premium is therefore defined as

$$\pi_0 = p\max\left\{(1-\alpha)D_0 - (R-\ell)\,L_0; 0\right\}.$$

The participation constraint for unsecured debtholders requires that their future revenue compensates their date 0 investment, i.e.,

$$(1-p)D_2 + p\max\left\{(R-\ell)\,L_0 - (1-\alpha)D_0; 0\right\} = \alpha D_0. \qquad (14)$$

The best reply function of bank shareholders is

$$\frac{\partial U^B}{\partial s} = (1-m)\Delta_\phi \left[(R-b) - (1-\alpha)\frac{D_0}{L_0} - \frac{D_2}{L_0}\right] - Cs = 0. \quad (15)$$

We have to distinguish between two cases.

CASE 1. $(R-\ell)\, L_0 \leq (1-\alpha)D_0$.

In this case, the portfolio revenue is not sufficient to repay unsecured debtholders, since insured depositors are the majority; therefore, condition (14) becomes

$$\frac{D_2}{L_0} = \frac{\alpha}{1-p}\frac{D_0}{L_0},$$

while the fair deposit insurance premium is

$$\frac{\pi_0}{L_0} = p\left\{(1-\alpha)\frac{D_0}{L_0} - (R-\ell)\right\}.$$

After substituting those two expressions into the date 0 balance sheet, the best reply function (15) becomes

$$\frac{\partial U^B}{\partial s} = (1-m)\Delta_\phi \left[(R-b) - \frac{[1-p(1-\alpha)]}{1-p}\frac{[1-k-\beta p\,(R-\ell)]}{1-\beta p(1-\alpha)}\right] - Cs = 0.$$

When $\alpha \to 0$ (100 percent insured deposits), it is immediate to derive the two special sub-cases developed in the paper, that of a deposit insurance paid with taxpayers' money ($\beta = 0$) and that of a risk-sensitive deposit insurance premium charged directly to the bank ($\beta = 1$).

CASE 2. $(R-\ell)\, L_0 \geq (1-\alpha)D_0$.

In this case, the portfolio revenue is high enough to repay something to unsecured debtholders, since there are few insured depositors; condition (14) becomes

$$\frac{D_2}{L_0} = \alpha\frac{D_0}{L_0} + \frac{p}{1-p}\left[\frac{D_0}{L_0} - (R-\ell)\right];$$

and the fair deposit insurance premium is null. After substituting these two values into the date 0 balance sheet, the best reply function (15) becomes

$$\frac{\partial U^B}{\partial s} = (1-m)\Delta_\phi \left[(R-b) - \frac{[1-k-p\,(R-\ell)]}{1-p} \right] - Cs = 0.$$

For any value of α, provided that it is large enough to fit case 2—as, for instance, $\alpha \to 1$ (100 percent unsecured debt)—this is equivalent to the case of a risk-sensitive deposit insurance charged at date 0 directly on the bank balance sheet (i.e., $\beta = 1$).

Appendix 3. A Numerical Example

Here we provide some numerical simulations to gain insights on theoretical propositions 3 and 4. We first fix the values of the parameters of the model as follows:

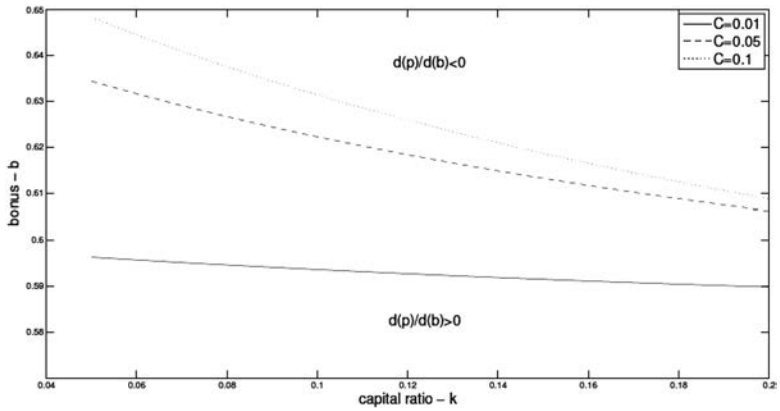
Parameter	Value
R	2.5
M	0.7
p_H	0.4
p_L	0.0
ϕ	0.1

We select a grid of reasonable values for the other two parameters of interests, k and C. Finally, we plot the combinations of b and k for which the derivative is zero, i.e.,

$$\frac{d\widehat{p}}{db} = \frac{d(1-\widehat{m})}{db}(\Delta - \widehat{s}\Delta_\phi) - (1-\widehat{m})\Delta_\phi \frac{d\widehat{s}}{db} = 0.$$

Then we repeat the exercise for different values of C. Figure 3 shows the different combinations of bonus and capital ratio such that the derivative of the probability with regard to the bonus is zero. These numerical results illustrate the result in proposition 2, namely that the overall effect of a larger bonus on the probability of loan losses depends upon a combination of k and C, since they affect both the incentive of shareholders and of the bank manager. Notice that,

Figure 3. The Effect of a Larger Bonus *b* on Risk



Notes: The diagram represents the combinations of bonus b and capital ratio k such that the impact of a change in the bonus on the probability of loan losses p is zero. Above the curves the derivative is negative (hence a larger managerial bonus reduces bank risk), while the opposite occurs below the curve. The curves are drawn for different values of C. The smaller is C (greater efficiency in control by shareholders), the more likely it is that the bonus reduces bank risk.

conditionally on these parameter values, the area where the derivative is positive is increasing in C. This implies that, for a given capital ratio k, an increase in the bonus reduces the probability of loan losses when the efficiency of inspection is high (C is low—solid line); however, the same jump in the bonus may instead increase the probability of loan losses if the efficiency of inspection is low (C is high—dotted line). Intuitively, an increase in the bonus leads to a reduction in the inspection by shareholders; the higher the inspection cost, the greater the reduction. This indirect effect on the managerial effort, through a reduction in inspection, might overcome the direct effect of an increase in the bonus, causing an increase in risk. The figure also highlights that the magnitude of the effect of the increase in C is decreasing in the capital ratio k; in fact, the higher the capital ratio, the smaller the distance between the curves. This finding intuitively validates proposition 4. In strongly capitalized banks, the elasticity of the inspection effort of shareholders with respect to the bonus is smaller. This implies that the area where the derivative of the probability of loan losses with respect to the bonus is positive shrinks for higher values of k; the higher the value of C, the greater the reduction.

Appendix 4. Definition of Key Variables

Balance Sheet (Source: Bankscope)

- Total Assets: Total earning assets plus cash and due from banks plus foreclosed real estate plus fixed assets plus goodwill plus other intangibles plus current tax assets plus deferred tax plus discontinued operations plus other assets in 2006.
- Total Liabilities: Total interest-bearing liabilities plus fair-value portion of debt plus credit impairment reserves plus reserves for pension and other plus tax liabilities plus other deferred liabilities plus discontinued operations plus insurance plus other non-interest-bearing liabilities in 2006.
- Market Capitalization: Total number of shares at the end of 2006 multiplied by the price of shares at the end of 2006.
- Equity Book-to-Market Ratio: Total equity (common equity plus non-controlling interest plus securities revaluation reserves plus foreign exchange revaluation reserves plus other revaluation reserves in 2006) over market capitalization.
- Deposit Ratio: Total customer deposits (current plus savings plus term deposits) over total deposits, money-market, and short-term funding.
- Tier 1 Capital Ratio: A regulatory measure of capital adequacy, that is, the shareholder funds plus perpetual non-cumulative preference shares as a percentage of risk-weighted assets and off-balance-sheet risks measured under the Basel rules.
- Total Regulatory Capital Ratio: Total capital adequacy ratio under the Basel rules. It measures tier 1 plus tier 2 capital, which includes subordinated debt, hybrid capital, loan loss reserves, and the valuation reserves as a percentage of risk-weighted assets and off-balance-sheet risks.
- ROA: Return on average asset (before tax).

- Market Return from Stock Prices 2005–6: Share price at the end of 2006 plus dividend per share in 2006 minus the price at the end of 2005, all over the price of shares at the end of 2005.
- C3: The sum of the shares of the largest three shareholders.

Compensation (Source: Capital IQ – People Intelligence)

- Total Compensation: Salary plus cash bonus plus equity bonus paid in 2006.
- Salary: Amount paid as fixed salary in 2006.
- Cash Bonus: Amount paid in cash as bonus in 2006.
- Equity Bonus: The value of bonus not paid in cash in 2006; it sums up restricted stock awards, stock grant awards, and option awards (the value of options).
- Total Bonus over Salary: Total bonus (cash bonus plus equity bonus) over salary.
- Value of Shares: Number of shares (unrestricted and restricted) held by the CEO multiplied by the price of share at the end of 2006.
- Value of Stock Options: The value of options calculated using the Black and Scholes formula; the exercise price and the share price at the end of the year and the expiration year is provided by Capital IQ. The risk-free interest rate is the ten-year maturity interest rate on U.S. bonds (source: Federal Reserve). The total number of options is given by the sum of exercisable options, unexercisable options, and unearned and unexercised options (that have been excluded from the sum of total options).
- Value of Total Equity Portfolio: Value of shares plus value of stock options.
- Ownership from Shares (% over Total): The ratio between the number of shares held by the CEO (source: Capital IQ) and the total number of shares of the company (source: Datastream) multiplied by 100.
- Ownership from Shares and Options (% over Total): Ownership from shares plus the delta-weighted options (see below) divided by the total number of shares outstanding.

- Delta-Weighted Options: The sum of each option held by the CEO at the end of 2006 multiplied by the delta of the respective option (sensitivity of CEO's option portfolio value to share price calculated using the formula by Core and Guay 2002).
- Percentage Equity Risk (Vega of Options): Sensitivity of the CEO's option portfolio value to stock-return volatility. It is the weighted sum of the vegas of each option held by the CEO at the end of 2006; the weights are determined by the number of each option award divided by the total number of options. It is multiplied by 100.

Stock Returns (Source: Datastream)

- Buy-and-Hold Return 2007–8 (BHR): Buy-and-hold return on stock weekly returns over the period 2007:Q3–2008:Q4.
- Risk Return 2007–8 (SD): Standard deviation of weekly returns over the period 2007:Q3–2008:Q4.

Regulation (Source: Bank Regulation and Supervision Survey, Third Wave)

- Private Monitoring: An index of monitoring on the part of the private sector.
- Official: An index of the power of the commercial bank supervisory agency, including elements such as the rights of the supervisor to meet with and demand information from auditors, to force a bank to change the internal organizational structure, to supersede the rights of shareholders, and to intervene in a bank.
- Deposit Insurance: Dummy variable equal to 1 if the country has an explicit deposit insurance.
- Restrict: An index of regulatory restrictions on the activities of banks, consisting, for example, of limitations on the ability of banks to engage in securities market activities, insurance activities, and real estate activities, and to own non-financial firms.
- Minimum Capital Requirement: This answers the survey question, What is the minimum capital-to-asset ratio requirement?

Appendix 5. List of Banks

Table 10. List of Banks

Country	Name of Bank
Australia	Australia and New Zealand Banking Group Limited
	National Australia Bank Limited
	Bendigo and Adelaide Bank Limited
	Bank of Queensland Ltd.
	Westpac Banking Corporation
	Commonwealth Bank of Australia
Austria	Erste Group Bank AG
Belgium	Dexia SA
Canada	The Toronto-Dominion Bank
	Laurentian Bank of Canada
	Royal Bank of Canada
	The Bank of Nova Scotia
	Home Capital Group Inc.
	Canadian Imperial Bank of Commerce
	National Bank of Canada
	Bank of Montreal
	Canadian Western Bank
China	China Merchants Bank Co. Ltd.
Czech Republic	Komercni Banka AS
Denmark	Danske Bank A/S
France	Credit Agricole S.A.
	BNP Paribas SA
	Societe Generale Group
Germany	Commerzbank AG
	Aareal Bank AG
	Deutsche Postbank AG
	Deutsche Bank AG
Hong Kong	Dah Sing Financial Holdings Limited
	Hang Seng Bank Limited
	The Bank of East Asia, Limited
	Wing Hang Bank Limited
	BOC Hong Kong Holdings Ltd.
	Chong Hing Bank Limited
	Dah Sing Banking Group Limited

(continued)

Table 10. (Continued)

Country	Name of Bank
India	Bank of Baroda
	ICICI Bank Ltd.
	Housing Development Finance Corporation Limited
	Oriental Bank of Commerce
	HDFC Bank Ltd.
Ireland	Allied Irish Banks p.l.c.
	The Governor and Company of the Bank of Ireland
Israel	Israel Discount Bank Limited
	Bank Leumi Le-Israel BM
	First International Bank of Israel Ltd.
	Mizrahi Tefahot Bank, Ltd.
	Union Bank of Israel Ltd.
	Bank Hapoalim B.M.
Italy	Unione di Banche Italiane Scpa
	Banca Popolare di Sondrio
	UniCredit S.p.A.
	Banco Popolare Scarl
	Banca Carige S.p.A.
	Banca popolare dell'Emilia Romagna
Jordan	Arab Bank plc
	Capital Bank of Jordan
	Bank of Jordan
	Cairo Amman Bank
Malaysia	Malayan Banking Berhad
Namibia	FNB Namibia Holdings Limited
Netherlands	Van Lanschot NV
Norway	Dnb Asa
	Helgeland Sparebank
	Sandnes Sparebank
	SpareBank 1 Nord-Norge
	SpareBank 1 SMN
	SpareBank 1 SR-Bank
	SpareBank 1 Buskerud-Vestfold
	Sparebanken M.re
	Sparebanken Pluss

(continued)

Table 10. (Continued)

Country	Name of Bank
Pakistan	NIB Bank Limited
	Faysal Bank Limited
	Habib Metropolitan Bank Limited
	United Bank Ltd.
	Bank Al Habib Limited
	Bank Alfalah Limited
	Allied Bank Limited
	MCB Bank Ltd.
	Askari Bank Limited
Poland	Bank Polska Kasa Opieki
	Bank Millennium Spolka Akcyjna
	BRE Bank SA
	Bank Zachodni WBK SA
	Bank Handlowy W Warszawie SA
South Africa	Absa Group Limited
	Standard Bank Group Limited
	Capitec Bank Holdings Ltd.
	FirstRand Limited
	Sasfin Holdings Limited
	Cadiz Holdings Ltd.
	Nedbank Group Limited
Spain	Banco Popular Espanol S.A.
	Banco Santander, S.A.
	Banco Bilbao Vizcaya Argentaria, S.A.
Sweden	Nordea Bank AB
	Swedbank AB
	Skandinaviska Enskilda Banken AB
	Svenska Handelsbanken AB
United Kingdom	HSBC Holdings plc
	Standard Chartered plc
	Paragon Group of Companies plc
	The Royal Bank of Scotland Group plc
	Arbuthnot Banking Group plc
	Barclays plc
	Lloyds Banking Group plc

(continued)

Table 10. (Continued)

Country	Name of Bank
United States of America	U.S. Bancorp Fifth Third Bancorp SunTrust Banks, Inc. Regions Financial Corporation BBandT Corporation Citigroup, Inc. JPMorgan Chase and Co. Bank of America Corporation The PNC Financial Services Group, Inc. Wells Fargo and Company SLM Corporation The Bank of New York Mellon Corporation

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Discussion of "CEO Compensation, Regulation, and Risk in Banks: Theory and Evidence from the Financial Crisis"

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The Cerasi and Oliviero contribution in this issue explores an important question from the banking regulation perspective: how does bank CEO compensation affect risk taking? It first lays out a model that illustrates how using variable compensation for bank CEOs (an exogenous free parameter in the model) may have an ambiguous effect on the CEO's risk-taking behavior. The key feature of the model is that both the bank's CEO and its shareholders can monitor the project. In the presence of bank leverage constraints and a deposit insurance, more variable compensation may lead to the substitution of shareholder monitoring with monitoring by the CEO. This substitution implies that the direction of the effect of variable compensation on risk taking cannot be signed in general. This is an interesting point because it highlights that theory does not provide clear guidance on whether—and, if so, how—to regulate bank CEO pay to reduce risk taking. Whether capping bank CEO bonus pay curtails bank risk taking and, if so, by how much is a fundamentally empirical question.

The fundamental challenge in addressing this empirical question is one of providing the appropriate counterfactual. Suppose one observed in the data that CEOs with a higher proportion of variable compensation take more risk. Does this imply that capping variable compensation leads to less risk taking? Unfortunately, the answer is no. A correlation between variable compensation and risk taking may arise even if risk taking by the bank is unaffected by compensation. Cheng, Hong, and Scheinkman (2015) make this point in a model where banks with heterogeneous productivity and riskiness set the optimal variable component of the compensation contract. As in the present paper, the resulting correlation between bank risk and variable compensation is ambiguous. On the one hand, for a given fixed wage, high-risk/high-productivity banks will pay higher compensation. On the other, for a given productivity, it will be costlier to provide incentives via variable compensation in high-risk banks.

Distinguishing which of these two models (exogenous compensation/endogenous risk versus exogenous risk/endogenous compensation) explains reality better is important from a policy perspective because the two models may have the opposite design prescriptions for reducing risk taking. In the most likely scenario, both risk taking and compensation are endogenous, in which case a theory that nests optimal choices in along both dimensions is required to provide an appropriate benchmark for empirical analysis.

When many, or all, of the observed analysis variables are decision outcomes—as in the plausible scenario described above—straightforward regression analysis almost never provides the empirical counterpart of a comparative statics theoretical exercise. Consider, for example, the main regression used in the empirical section of the paper: the level and standard deviation of bank stock returns during the 2007–8 crisis are regressed on measures of CEO variable compensation (and controls). If CEO variable compensation is exogenously set at random in a way that is uncorrelated with bank characteristics or the regulatory environment, then this regression provides a measure of the effect of variable compensation on stock performance. If compensation is an endogenous bank choice, related to the regulatory environment and the bank's business model, then the coefficient on compensation in this regression only has a statistical interpretation (it provides the best linear approximation of the conditional expectation function of bank returns on compensation). Thus, the empirical analysis does not provide the means to accepting or refuting the model. Instead, the empirical analysis can be linked to the theoretical model *only if* we are willing to assume that the assumptions of the model are true.

The assumptions underlying the interpretation of regression coefficients are even more stringent when they rely on comparisons across partitions of the data along choice variables. Consider, for example, subsection 5.1 (The Effect of Shareholder Supervision), which compares the coefficient from the regression described in the previous paragraph across banks with high and low shareholder dispersion. The analysis interprets this variable as the cost of shareholder supervision, which in the model is also an exogenous free parameter, and interprets the difference of the coefficient across the two samples as a difference in the effect of compensation on stock returns in high-supervision-cost and low-supervision-cost environments. This interpretation is appropriate only if both variable compensation and shareholder dispersion are assigned to banks independently of bank and institutional environment characteristics, and independently of each other.

If shareholder dispersion is not a technological cost parameter but a choice variable—for example, because it is a means for shareholders to exercise supervision and control—then this last assumption (that variable compensation and shareholder dispersion are independent) cannot hold if the assumptions of the model are true. In the model, shareholders' incentive to monitor the CEO is a function of compensation, which implies that shareholder concentration is also a function of compensation. Partitioning the data along an endogenous variable renders the comparison of coefficients across subsamples impossible to interpret, even if compensation were randomly assigned across banks.

Answering the empirical questions posed by this paper is a very difficult task. This paper represents a very valuable first step towards understanding the theoretical and empirical relationships between bank risk taking, compensation, and regulation.

Reference

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Liquidity Hoarding and Inefficient Abundant Funding*

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This paper studies banks' choice between building liquidity buffers and raising funding ex post to deal with reinvestment shocks. We uncover the possibility of an inefficient liquidity squeeze equilibrium when ex post funding is abundant. In the model, banks typically build larger liquidity buffers when they expect funding to be expensive. However, when banks hold larger liquidity buffers, pledgeable income is larger and they hence can raise more funding, which in the aggregate raises the funding cost. This feedback loop between liquidity hoarding and the cost of ex post funding yields multiple equilibria, one being an inefficient liquidity squeeze equilibrium where banks do not build any liquidity buffer. Comparative statics show that this inefficient equilibrium is more likely when the supply of ex post funding is large. Last, in this equilibrium, a "borrower"-of-last-resort policy can improve social welfare if drying up ex post funding restores bank incentives to hold liquidity ex ante.

JEL Codes: D53, D82, D86.

1. Introduction

Financial crises usually find their roots in boom periods that tend to precede them. The 2008–9 financial crisis is no exception in this

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respect: significant vulnerabilities developed in the run-up to the crisis. For example, liquidity buffers, e.g., cash, claims on the central bank, and claims on the government, which still accounted for around 10 percent of U.S. banks' total assets in the late 1990s, dropped down to around 5 percent in 2007, at the onset of the financial crisis.[1] This undoubtedly made U.S. banks more vulnerable to financial distress, given that holding liquidity buffers is key for funding during adverse conditions.[2] Yet, a key question is, why did banks decide to reduce their liquidity buffers so much? One answer is easy funding conditions: banks were indeed able to raise funding, irrespective of the size and quality of their balance sheet. Yet, when funding became suddenly more expensive and scarce, U.S. banks lacked the relevant assets as financial distress rose.[3]

Notwithstanding the role that unexpected changes in funding conditions can play in triggering financial crises, this paper focuses on an alternative mechanism which highlights the externalities at play in liquidity buffer holdings and how they relate to funding conditions. More specifically, we provide an analytical model to show that agents rationally do not hold enough liquidity buffers compared with the social optimum when the funding supply is sufficiently large. In this model, the economy paradoxically runs short of liquidity because funding is abundant, not because it suddenly becomes very scarce.

We build on the seminal paper by Holmström and Tirole (1998), where banks build liquidity buffers to self-insure against shocks affecting illiquid projects. Illiquid projects typically display a higher yield but are subject to shocks and then require reinvestment.[4]

---

[1]Source: International Monetary Fund's International Financial Statistics. Liquid assets are the sum of reserves at the central bank (line 2:20), other claims on monetary authorities (line 2:20:N), claims on the central government (line 2:22:A), and claims on state and local governments (line 2:22:B). Total assets are the sum of liquid assets (defined as above), foreign assets (line 2:21), claims on the private sector (line 2:22:D), and claims on other financial corporations (line 2:22:G).

[2]For example, claims on the government can be sold against cash when need be, a reason why they are also called "safe-haven" assets.

[3]Financial institutions' inability to evaluate current funding conditions at that time as abnormal was due to an inherent myopia of banks and/or to the perception that public authorities would support banks if such conditions were to evaporate.

[4]Reinvestment risk works here as a rollover risk, since getting the final payoff once a reinvestment shock has happened requires raising fresh funds.

To carry out reinvestment, banks can either use liquidity buffers or they can raise funds ex post. Yet, raising funds faces limits because future income streams are not fully pledgeable. Hence, besides providing self-insurance, liquidity buffers also help banks raise more funds. To this framework we add an exogenous supply of funding and ask how it affects the banks' decision to build liquidity buffers.

The main result of the model is that there can be multiple equilibria. The economy can coordinate on a "liquidity squeeze" equilibrium where banks do not build liquidity buffers and are unable to meet reinvestment needs when a shock occurs. Multiple equilibria result from a positive externality of aggregate liquidity buffers on the funding cost. Let us detail the mechanism. First, banks typically choose to hold large liquidity buffers if they expect funding to be costly. Second, when future income streams are not fully pledgeable, banks holding large liquidity buffers can raise a large amount of funding. Large liquidity buffers in the aggregate hence lead to a high demand for funding, which drives up the equilibrium funding cost. And with a higher funding cost, banks are willing to build large liquidity buffers. Larger *aggregate* liquidity buffers therefore raise *individual* incentives to hold liquidity buffers through the positive effect on funding cost. This externality yields two possible equilibria, one where banks build large liquidity buffers and another one where banks do not build any liquidity buffer. Importantly, the first equilibrium, where banks prefer to build liquidity buffers, always dominates. This is because illiquid projects deliver a high return even if they face a shock owing to large reinvestment, while liquidity buffers provide a high return owing to the high funding cost.[5]

Next, we show that the positive feedback loop between liquidity buffer holdings and the funding cost is more likely when the exogenous funding supply is large. Indeed, when banks hold large liquidity buffers, those banks that need to reinvest can raise a large amount of funding—because holding liquidity raises pledgeable income and relaxes the borrowing constraint—but those that face no reinvestment need can also supply a large amount of funding. When the exogenous funding supply is large, changes in banks' liquidity holdings have a second-order effect on the *total* funding supply,

[5]This mechanism illustrates the view that abundant and easy funding can lead to over-investment in illiquid projects, i.e., inefficient risk taking.

given that the latter is dominated by the large exogenous supply. As a result, the relative increase in the demand for funding dominates and the equilibrium funding cost needs to go up to balance the market.[6] The positive feedback loop is therefore more likely when the exogenous supply of funding is large.

Last, we focus on policy options to improve social welfare. The inefficiency in the equilibrium where banks do not hold liquidity is due to the cost of funding being too cheap. Hence a lender-of-last-resort policy which contributes to further cutting the cost of ex post funding cannot bring any solution. On the contrary, a borrower-of-last-resort policy looks more natural to combat this inefficiency, as such a policy would consist in making funding more expensive.[7] To do so, the central bank can, for example, issue bonds. This would raise the demand for funding, and to the extent that the excess supply of funding disappears, the increase in the funding cost would preclude the equilibrium without liquidity holdings.

This paper contributes to our understanding of the mechanics of liquidity crises. As noted above, we build on the Holmström and Tirole (1998) approach in which banks use liquidity buffers to meet refinancing needs stemming from shocks affecting illiquid projects. We also closely follow Caballero and Krishnamurthy (2001, 2004), who look extensively at the problem of underinsurance against refinancing shocks in an open-economy context. A key difference with their approaches is that we do not get into the problem of refinancing non-tradable assets with limited tradable resources. Moreover, in our framework, inefficiencies stem from the abundance and not from an abrupt shortage of interim refinancing. This model also speaks to the recent literature on the macroeconomic effects of large capital flows that have been directed towards advanced economies (Bernanke 2005, 2009). While the recent theoretical and empirical literature has stressed some positive implications of these large flows (see Caballero, Farhi, and Gourinchas 2008 and Mendoza, Quadrini,

[6]On the contrary, when the exogenous funding supply is low, then the funding supply increases more than the funding demand when banks hold larger liquidity buffers. The funding cost then needs to go down to balance the market.

[7]In the second best, the amount of liquidity buffer is not contractible. The simple policy consisting in imposing a minimal liquidity ratio is therefore not possible, as that would boil down to assuming that the policymaker can contract on the amount of liquidity buffers.

and Ríos-Rull 2009 or Warnock and Warnock 2009), our model raises more skepticism, underscoring a possible detrimental implication of such flows.

We also build on Diamond and Dybvig (1983), Diamond and Rajan (2001), and Allen and Gale (2004) in which banks provide liquidity to depositors while investing in long-term assets, thereby facing a risk of bank run.[8] Bhattacharya and Gale (1987) extends the original Diamond-Dybvig framework and looks at how liquidity provided by the interbank market affects banks' willingness to hold liquidity. Bolton, Santos, and Scheinkman (2011) provides a model where agents' reliance on inside liquidity as opposed to outside liquidity—in our framework, liquidity buffer holdings vs. ex post funding—can affect the timing of trades on the market for liquidity. This model also features a multiple equilibria mechanism. An important difference, however, is that outside liquidity is efficient in their framework. On the contrary, our model highlights abundant funding as a potential source of inefficiency. It should also be clear that many different and important aspects relating to the notion of liquidity—see, for instance, Gorton and Pennacchi (1990) for an information-based approach to liquidity—are simply not covered in this paper. Finally Acharya, Shin, and Yorulmazer (2011) is also related: this paper looks at how foreign bank entry reduces domestic banks' incentives to hold liquid assets. The focus there, however, relates to fire sales.

The paper is organized as follows. The following section lays down the main assumptions of the model. Section 3 describes the decentralized equilibrium and its main properties. Section 4 investigates possible policy options to improve welfare. Conclusions are drawn in section 5.

2. Timing and Technology

We consider a single good economy populated with a unit mass continuum of banks and a unit mass continuum of investors.

[8]Note, however, that in the standard Diamond-Dybvig framework (1983), multiple equilibria relate to depositors' behavior for a given allocation between illiquid investments and liquidity buffers. In our framework, it is this allocation which can be subject to multiple equilibria.

The economy lasts for three dates: $0, 1$, and 2. All agents are risk neutral and derive utility from profits at date 2. They can freely store capital at any date t with a unit return at date $t + 1$. A bank storing capital will be said to hold liquidity buffers, and L will denote a bank's liquidity buffer holdings.

2.1 Banks

Each bank starts with a unit endowment at date 0 and can invest an amount $I \geq \kappa$ in an illiquid project, κ being the minimum size requirement for illiquid projects $(0 < \kappa < 1)$. At date 1, banks experience an idiosyncratic shock with a probability α. In the absence of a shock—banks are then said to be *intact*—the project returns ρI at date 2. But if the shock hits—banks are then said to be *distressed*—the project yields no return at date 2. Yet, *distressed* banks have a reinvestment opportunity: reinvesting an amount J of fresh resources at date 1 in the project returns $\rho_1 J$ at date 2, with $\rho_1 > (1 - \alpha)\rho > 1$. Last, banks can only pledge a fraction ϕ of illiquid projects' output and $\phi\rho_1 < 1$. Banks facing a reinvestment shock therefore have a reinvestment opportunity whose output is relatively difficult to pledge. This imperfect pledgeability will introduce a positive relationship between liquidity buffer holdings L at date 0 and reinvestment J at date 1.[9,10]

2.2 Investors

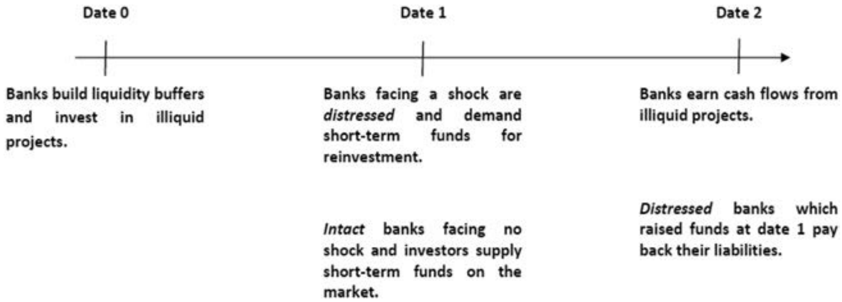
Investors are willing to provide liquidity to banks or raise liquidity from banks at date 1. Their net liquidity supply is denoted λ, which can be either positive or negative.[11]

[9] We refer to agents investing in illiquid projects as banks because they are those in the model who face a liquidity mismatch.

[10] The pledgeability constraint for banks facing a shock is hence binding since their pledgeable return $\phi\rho_1$ is lower than the opportunity cost of capital (equal to 1 here).

[11] The assumption that investors take actions only at date 1 is a matter of simplification. If investors had on top of that an endowment at date 0, there would be two further issues that would either reinforce or complement the mechanism described here. First, banks could issue claims at date 0. This possibility—introducing leverage for banks at date 0—would actually reinforce the multiple equilibria property described later. Second, investors could decide strategically

Figure 1. Timing of the Model



2.3 Frictions

Banks face two frictions. First, idiosyncratic shocks are *not contractible* and therefore cannot be diversified. Banks hence need to self-insure through liquidity buffer holdings. Second, banks' allocation at date 0 between liquidity buffers and illiquid investment is *observable* but *not verifiable.* With this assumption, investors cannot charge to a bank an interest rate which would depend on the bank's individual allocation. The funding cost at date 1 will actually depend on the aggregate amount of liquidity banks hold, which will be the source of the pecuniary externality.

2.4 Timing

Figure 1 summarizes the timing of the model. At date 0, banks choose how much to invest in illiquid projects and how much liquidity to hold. At date 1, a fraction α of banks are *distressed.* These banks can then use their liquidity buffers and raise funds to carry out reinvestment. Investors and *intact* banks can then lend to *distressed* banks. They may also prefer to store their liquidity holdings if this is more profitable than lending. Finally, at date 2, banks pay back their liabilities, if any, and consume.

---

to provide their funds at date 0 or at date 1, depending on the return attached to each of these options. Under some conditions, this possibility to choose strategically the timing of the funding supply can itself be a source of multiple equilibria, independently of the mechanism highlighted here.

At the heart of the model is a trade-off for banks which have to compromise between the initial investment I on the one hand and the reinvestment J in the event of a shock on the other hand. Maximizing initial investment I requires minimizing liquidity buffer holdings L and thereby pledgeable income. This in turn cuts reinvestment J in the event of a shock. Conversely, maximizing liquidity holdings L to mitigate shocks requires sacrificing initial investment I.

3. Liquidity, Funding Cost, and the Decentralized Equilibrium

The decentralized equilibrium is based on two building blocks. The first is banks' choice at date 0 between liquidity holdings and illiquid investment. This allocation decision depends primarily on the funding cost at date 1. The second is the equilibrium of the market at date 1 where *distressed* banks raise funding from investors and *intact* banks. The equilibrium cost of funding then depends on banks' allocation decision at date 0 and, specifically, on how much in aggregate liquidity buffers they hold. We start by setting up the banks' allocation problem and the equilibrium of the market for funding. Then, we derive the different equilibria.

3.1 Banks' Optimal Liquidity Buffer

Consider a bank which holds an amount L of liquidity and invests $I = 1 - L \geq \kappa$ in an illiquid project at date 0. Then if the bank is *intact*, the project returns $(1 - L)\rho$ at date 2. In addition, the bank has an amount L of available funds at date 1 which can either be stored with a unit return or lent to *distressed* banks with a return denoted r. For simplicity and without loss of generality, we will restrict to cases where the funding cost, denoted r, satisfies $1 < r < \rho_1$ so that lending is always preferred to storing. An *intact* bank therefore reaps Lr at date 2. The *intact* bank's final profit π_g writes as

$$\pi_g(L) = (1 - L)\rho + Lr. \tag{1}$$

When $r < \rho$, the bank's profit π_g decreases with liquidity buffers L. Building liquidity buffers is therefore costly for a bank which does not face any shock. If now the bank is *distressed*, the project yields no output at date 2. But the bank can reinvest. To do so, it can rely on liquidity buffers L; it can also raise an amount D of funds—from investors and *intact* banks—against the promise to pay back rD at date 2. Reinvestment hence yields a cash flow $(L+D)\rho_1$ so that the *distressed* bank's final profit π_b writes as

$$\pi_b\left(D,L\right)=\left(L+D\right)\rho_1-rD. \tag{2}$$

Moreover, *distressed* banks face a pledgeability constraint: repayments should not exceed pledgeable final output, $rD \leq \phi(L+D)\rho_1$. *Distressed* banks hence choose to raise D^* at date 1 such that

$$D^*\left(r,L\right)=\begin{cases}\frac{\phi\rho_1}{r-\phi\rho_1}L & \text{if } r\leq\rho_1\\ 0 & \text{otherwise,}\end{cases} \tag{3}$$

and *distressed* banks' final profits π_b write as

$$\pi_b\left(L\right)=\rho_1L+\left(\rho_1-r\right)\frac{\phi\rho_1L}{r-\phi\rho_1}. \tag{4}$$

A *distressed* bank with larger liquidity holdings L enjoys larger profits when the pledgeability constraint binds, as it can raise more funds—$D^*(L)$ increases with L. This is the self-insurance aspect of holding liquidity buffers.

Now that we have determined banks' profits when *intact* and when *distressed*, we can turn to the bank's allocation decision at date 0. The probability of distress being α, the problem for a bank consists in choosing liquidity L which maximizes expected profits:

$$\begin{gathered}\max_L \pi=\left(1-\alpha\right)\pi_g\left(L\right)+\alpha\pi_b\left(L\right)\\ \text{s.t. } 0\leq L\leq 1-\kappa.\end{gathered} \tag{5}$$

Banks face a simple trade-off: holding liquidity implies forgoing profits when *intact* but contributes to higher profits when *distressed*. The funding cost r at date 1 affects this trade-off in two ways. First, a larger funding cost reduces profits for *distressed* banks and hence incentives to hold liquidity. Second, a larger funding cost raises the return on liquidity buffers for *intact* banks; it hence provides incentives to build larger liquidity buffers. When this second effect dominates, banks choose to hold more liquidity at date 0 if they expect a larger funding cost r at date 1. We will indeed focus on this case in what follows: When the funding cost is $r = \rho_1$, banks prefer to hoard liquidity, i.e., $\partial\pi/\partial L|_{r=\rho_1} > 0$, and this holds if $\rho_1 > (1-\alpha)\rho$, which we assumed is always true. Conversely, when the funding cost is $r = 1$, banks prefer illiquid investments, i.e., $\partial\pi/\partial L|_{r=1} < 0$, and this holds when ϕ is sufficiently low.[12] Let us now denote $\widehat{r}$ the funding cost such that banks are indifferent between liquidity buffers and illiquid investments, i.e., $\partial\pi/\partial L|_{r=\widehat{r}} = 0$. Then, under the assumption that ϕ is sufficiently low, there is a unique funding cost $\widehat{r}$ which satisfies $1 < \widehat{r} < \rho_1$, and it writes as

$$\widehat{r} = \frac{\rho + \psi\rho_1}{2} + \sqrt{\left(\frac{\rho + \psi\rho_1}{2}\right)^2 - \rho\phi\rho_1}, \tag{6}$$

where $\psi = \frac{\phi-\alpha}{1-\alpha}$. As is shown in figure 2, when the funding cost r is below $\widehat{r}$, banks do not build any liquidity buffer, $L = 0$, but when the funding cost r is above $\widehat{r}$, they are better off holding liquidity and choose $L = 1 - \kappa$.[13]

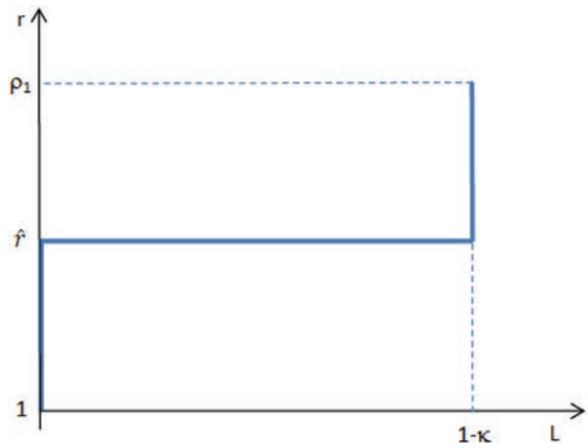
3.2 The Equilibrium Funding Cost

Let us now turn to the market for reinvestment which opens at date 1. On this market, *distressed* banks can raise funding from investors and *intact* banks to finance reinvestment. A fraction α of banks face distress, and the individual demand for funding from each *distressed* bank is $D^*(r, L)$. The aggregate demand for funding is therefore $\alpha D^*(r, L)$. Conversely, a fraction $1 - \alpha$ of banks end up *intact* and each bank holds an amount L of liquidity buffers. Aggregate funding supply from banks is $(1 - \alpha)L$ and investors' net funding supply

[12]Specifically, the condition $\partial\pi/\partial L|_{r=1} < 0$ simplifies as $\phi\rho_1 < \frac{\beta-\rho_1}{\beta-1}$ with $\beta = \frac{1-\alpha}{\alpha}(\rho - 1)$.

[13]Under the assumption that $\partial\pi/\partial L|_{r=1} < 0$, i.e., $\phi\rho_1 < \frac{\beta-\rho_1}{\beta-1}$, the negative root of the equation $\partial\pi/\partial L = 0$ always lies below 1 and is hence irrelevant. This is why we focus on the positive root in (6). To put it differently, the assumption $\phi\rho_1 < \frac{\beta-\rho_1}{\beta-1}$ ensures that when $1 < r < \rho_1$, $\partial\pi/\partial L$ is monotonically increasing in the funding cost r, moving from negative to positive numbers, once and only once.

Figure 2. Banks' Optimal Liquidity Buffers



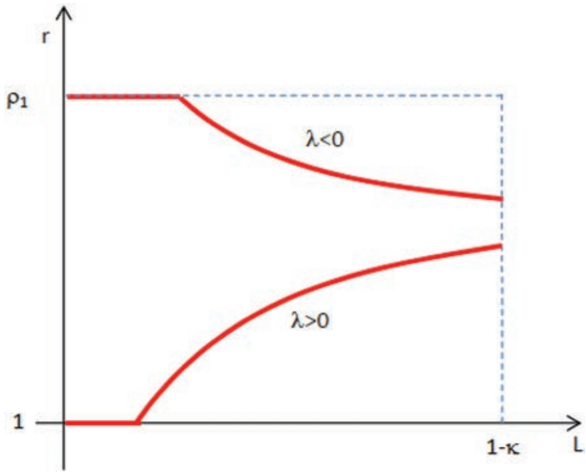
is λ. The equilibrium of the market for funding at date 1 therefore writes as

$$\alpha D^* \left(r, L\right) = \lambda + \left(1 - \alpha\right) L. \qquad (7)$$

Note that this expression is only valid if the funding cost r satisfies $1 \leq r \leq \rho_1$ so that *intact* banks and investors are willing to lend and *distressed* banks are willing to borrow. The equilibrium is indeed trivial if either $\lambda \geq \alpha \frac{\phi \rho_1}{1-\phi \rho_1}(1-\kappa)$ or $\lambda \leq -(1-\alpha)(1-\kappa)$. In the first case, the supply of funding $\lambda + (1-\alpha)L$ is always larger than the demand for funding $\alpha D^*(r, L)$, while in the second case it is the demand for funding $\alpha D^*(r, L)$ which is always larger than the supply of funding $\lambda + (1-\alpha)L$. We therefore exclude these two possibilities in what follows and focus on the case where investors' net funding supply λ satisfies $-(1-\alpha)(1-\kappa) < \lambda < \alpha \frac{\phi \rho_1}{1-\phi \rho_1}(1-\kappa)$.

When banks choose to hold larger liquidity buffers L at date 0, the supply of funding goes up because *intact* banks have more funds available. However, the demand for funding also goes up, as *distressed* banks can also demand more funds. This is because the pledgeability constraint—which limits the amount of funds *distressed* banks can raise—is relaxed. The change in the equilibrium cost of funding is therefore a priori ambiguous. To determine which of these

Figure 3. Equilibrium of the Market for Funds



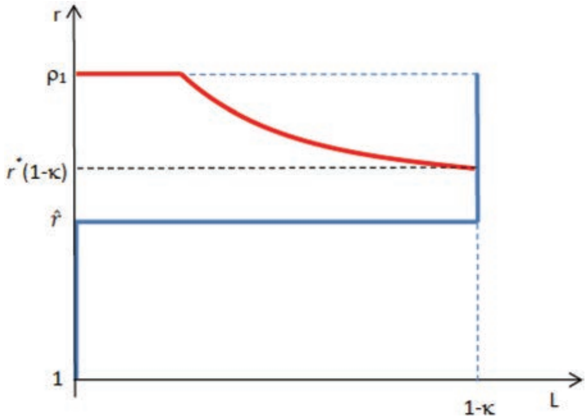
two effects dominates, we can use (7) to write the expression for the equilibrium funding cost as

$$r^* (L) = \phi \rho_1 + \frac{\alpha \phi \rho_1 L}{\lambda + (1 - \alpha) L}. \tag{8}$$

When investors' net funding supply λ is positive, an increase in banks' liquidity holdings L raises the equilibrium funding cost r^* because the aggregate demand for funding increases more than the aggregate supply of funding, $\partial r^* / \partial L|_{\lambda > 0} > 0$. On the contrary, when investors' net funding supply λ is negative, an increase in banks' liquidity holdings L reduces the equilibrium funding cost r^* because the aggregate supply of funding increases more than the aggregate demand for funding, $\partial r^* / \partial L|_{\lambda < 0} < 0$. These two cases are represented in figure 3.

Investors' net funding supply λ affects the equilibrium funding cost in two ways: a level and a slope effect. When investors' net funding supply λ goes up, this reduces the *level* of the equilibrium funding cost but also, importantly, raises the *slope* of the equilibrium funding cost with regard to aggregate liquidity holdings (which can turn from negative to positive as in figure 3).

Figure 4. The Equilibrium with Liquidity Buffers



3.3 The Decentralized Equilibrium

We can now determine the decentralized equilibrium using the two relations described above: the problem (5) determines the optimal liquidity buffer $L^*(r)$ depending on the funding cost r, and the relationship (7) determines the equilibrium funding costs $r^*(L)$ as a function of aggregate liquidity buffers.

PROPOSITION 1. *The decentralized equilibrium is such that*

(i) banks hold maximum liquidity buffers $L^* = 1 - \kappa$ *when* $\lambda \leq 0$ *and* $r^*(L = 1 - \kappa) \geq \widehat{r}$,

(ii) banks are indifferent between holding liquidity buffers and investing in illiquid projects when $\lambda \leq 0$ *and* $r^*(L = 1-\kappa) < \widehat{r}$,

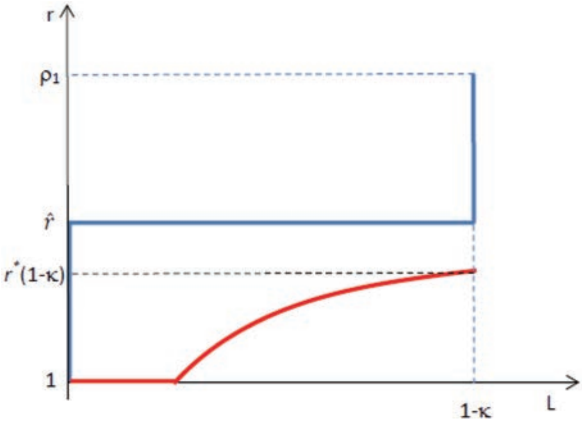
(iii) banks hold no liquidity buffer $L^* = 0$ *when* $\lambda > 0$ *and* $r^*(L = 1 - \kappa) < \widehat{r}$, *and*

(iv) banks face multiple equilibria: they may either hold maximum liquidity buffers $L^* = 1-\kappa$ *or no liquidity buffer* $L^* = 0$ *when* $\lambda > 0$ *and* $r^*(L = 1 - \kappa) \geq \widehat{r}$.

Proof. Cf. the appendix.

Consider first the equilibrium where banks prefer to hold liquidity buffers—represented in figure 4. This equilibrium arises when investors' net funding supply λ is relatively low: Denoting

Figure 5. The Equilibrium without Liquidity Buffers

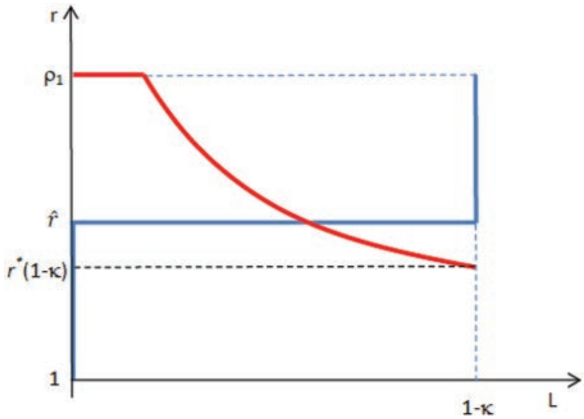


$\mu = \frac{\phi\rho_1 - (1-\alpha)\widehat{r}}{\widehat{r} - \phi\rho_1}(1-\kappa)$, the conditions $\lambda \leq 0$ and $r^*(L = 1-\kappa) \geq \widehat{r}$ can be simplified as $\lambda \leq \min\{0; \mu\}$. The intuition for this equilibrium is pretty simple: Irrespective of how much liquidity banks decide to hold, a relatively low net funding supply λ ensures a large funding cost r. And when the funding cost is large, banks are better off holding liquidity buffers. This equilibrium is also more likely to hold if the probability α of distress is larger. The need for banks to build liquidity buffers naturally increases if distress is more likely.

Turning now to the equilibrium where banks prefer illiquid investments and do not build any liquidity buffers, it arises when $\lambda > 0$ and $r^*(L = 1-\kappa) < \widehat{r}$, i.e., when investors' net funding supply λ satisfies $\lambda > \max\{0; \mu\}$. Figure 5 provides a graphical representation of this equilibrium. The intuition for this equilibrium is very similar to that of the previous equilibrium, where banks prefer to hold liquidity buffers: Irrespective of how much liquidity banks decide to hold, a relatively large net funding supply λ ensures a low funding cost r. And when the funding cost r is low, banks are better off investing in illiquid projects and not holding any liquidity buffer. This equilibrium is also less likely to hold if the probability α of distress is larger. The need for banks to build liquidity buffers naturally decreases if distress is less likely.

Then we are left with two cases to examine. When $\mu < 0$, there is an equilibrium where banks are indifferent between holding

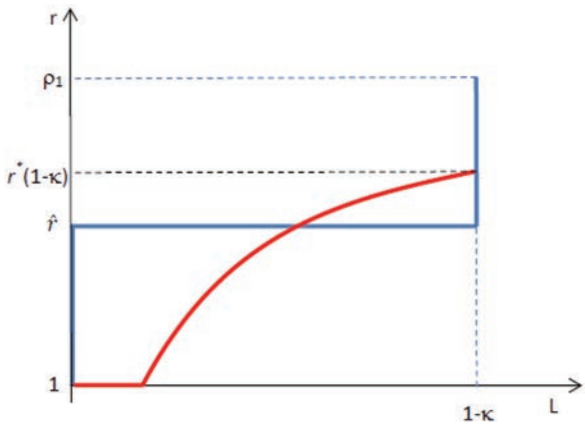
Figure 6. The Mixed-Strategy Equilibrium



liquidity buffers and investing in illiquid projects when $\lambda \leq 0$ and $r^*(L = 1 - \kappa) < \widehat{r}$, which simplifies as $\mu < \lambda \leq 0$. When investors' net funding supply is negative, the relationship between the equilibrium funding cost and the amount of liquidity banks decide to hold is negative. As is shown in figure 6, if banks decide to hold a large amount of liquidity, then the equilibrium cost of funding will be low and banks will not have incentives to hold liquidity. Similarly, if banks decide to invest in illiquid projects and not hold any liquidity, then the equilibrium cost of funding will be high and banks will not have incentives to invest in illiquid projects. As a result, there is no pure-strategy equilibrium. The equilibrium funding cost is then such that banks are indifferent between holding liquidity and investing in illiquid projects and the amount of liquidity banks hold just balances the market for funding.

On the contrary, when $\mu > 0$, the economy faces multiple equilibria when $\lambda > 0$ and $r^*(L = 1-\kappa) \geq \widehat{r}$, which simplifies as $0 < \lambda \leq \mu$. Banks may either hold maximum liquidity buffers $L^* = 1 - \kappa$ or no liquidity buffers $L^* = 0$. When investors' net funding supply is positive, the relationship between the equilibrium funding cost and the amount of liquidity banks decide to hold is positive. Hence if banks decide to hold liquidity $L = 1 - \kappa$, then the equilibrium cost of funding is relatively high, which provides incentives to banks to hold liquidity. Similarly, if banks decide to invest in illiquid projects,

Figure 7. Multiple Equilibria



$L = 0$, then the equilibrium cost of funding is relatively low, which provides incentives to banks to invest in illiquid projects. There are hence multiple equilibria. Figure 7 provides a graphical example.

Three further remarks can be made here. First, the equilibrium where banks do not hold liquidity can be described as a "liquidity squeeze" since *distressed* banks have a profitable reinvestment opportunity which they are unable to exploit, as they lack pledgeable income. Interestingly, this equilibrium is not related to an abrupt or sudden reduction in investors' funding supply λ, as is the case with sudden stops or capital flow reversals. On the contrary, it emerges because investors' large funding supply λ reduces the funding cost r and thereby the profits banks can reap from holding liquidity at date 0. Banks are therefore better off investing in illiquid projects. Second, while the funding cost r is low in the equilibrium where banks do not hold liquidity buffers, the shadow cost of capital is rather large, as *distressed* banks are not able to exploit their reinvestment option. The low funding cost r rather reflects here the scarcity of banks' pledgeable income. Third, multiple equilibria require the condition $\mu > 0$. To understand the intuition for this condition, it is useful to note that when the economy faces multiple equilibria, there is a mixed-strategy equilibrium on top of the two pure-strategy equilibria described above. Yet, the condition $\mu > 0$ ensures that this mixed-strategy equilibrium is unstable, i.e., not robust to small perturbations. To see this, we can note that the condition $\mu > 0$ can be written as $\alpha \frac{\phi \rho_1}{\widehat{r} - \phi \rho_1} > 1 - \alpha$. Then if banks coordinate on the mixed-strategy equilibrium, the funding cost would be $r = \widehat{r}$, and the condition $\alpha \frac{\phi \rho_1}{\widehat{r} - \phi \rho_1} > 1 - \alpha$ then states that if banks decide to hold marginally more liquidity, the marginal change in the demand for funding $\alpha \frac{\phi \rho_1}{\widehat{r} - \phi \rho_1}$ would be larger than the marginal change in the supply of funding $1 - \alpha$. As a result, the funding cost would need to increase to balance the market, and this increase in the funding cost would encourage banks to further increase their liquidity holdings, etc. The economy would eventually end up in the equilibrium where banks are better off holding liquidity. The condition $\mu > 0$ therefore ensures that banks' liquidity holdings have a positive pecuniary externality on the cost of funding. This is why it is required for multiple equilibria. This is also why we can focus on the two pure-strategy equilibria and disregard the mixed-strategy equilibrium. Last, using the expression for $\widehat{r}$, the condition $\mu > 0$ can be simplified as $\rho_1 > (1 - \alpha)\rho$, which holds by assumption.[14]

3.4 Social Welfare

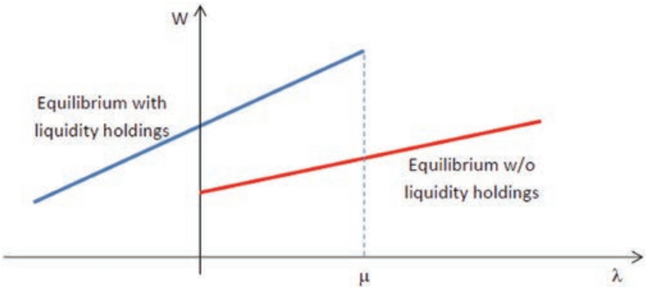
We consider social welfare W as the sum of banks' and investors' profits and investigate which of the equilibria described above is socially optimal.

$$W = (1 - \alpha)\, \pi_g\,(L^*) + \alpha \pi_b\,(L^*) + \lambda r^*\,(L^*) \tag{9}$$

Let us start with the equilibrium where banks prefer to invest in illiquid projects and do not hold any liquidity. This equilibrium holds when investors' funding supply satisfies $\lambda > 0$. Banks then enjoy expected profits $(1 - \alpha)\rho$ while investors reap a unit return on their funding supply λ. Social welfare W therefore writes as $W = W^i(\lambda) = (1-\alpha)\rho + \lambda$. Let us turn now to the equilibrium where banks are better off holding liquidity. This equilibrium holds when investors' funding supply satisfies $\lambda < \mu$. In this equilibrium, each bank holds an amount of liquidity $1 - \kappa$, and banks enjoy expected

[14]The condition $\mu > 0$ is equivalent to $\widehat{r} < \frac{\phi \rho_1}{1-\alpha}$. Then, given that $\partial \pi / \partial L$ is increasing in r and that $\partial \pi / \partial L = 0$ when $r = \widehat{r}$, the condition $\mu > 0$ holds if and only if we have $\partial \pi / \partial L > 0$ when $r = \frac{\phi \rho_1}{1-\alpha}$, which simplifies as $\rho_1 > (1 - \alpha)\rho$.

Figure 8. Social Welfare and Investors' Funding Supply



profits $(1-\alpha)\pi_g(1-\kappa)+\alpha\pi_b(1-\kappa)$ while investors reap a return on $r^*(1-\kappa)$ on their funding supply λ. In this case, after some algebra, social welfare W writes as $W = W^l(\lambda) = (1-\alpha)\kappa\rho + (1-\kappa+\lambda)\rho_1$. The social welfare function can hence be summarized as

$$W = \begin{cases} W^i(\lambda) & \text{if } \lambda > 0 \\ W^l(\lambda) & \text{if } \lambda \leq \mu. \end{cases} \tag{10}$$

PROPOSITION 2. *With multiple equilibria, the equilibrium in which banks hold liquidity ensures higher social welfare.*

Proof. Cf. the appendix.

Figure 8 represents social welfare W as a function of investors' funding supply λ for the two possible equilibria. It shows that social welfare under the equilibrium where banks hold liquidity is higher for any possible value of λ. This result relates to the pecuniary externality of aggregate liquidity buffers on the funding cost. In the equilibrium in which banks prefer to build liquidity buffers, illiquid projects display a high return because *distressed* banks are able to exploit their reinvestment opportunity while *intact* banks enjoy a high return both on illiquid projects and on liquidity buffers. Moreover, investors also enjoy a relatively high return. Hence aggregate output and social welfare are both relatively high. By contrast, in the equilibrium in which banks do not build liquidity buffers, *distressed* illiquid projects are relatively unproductive—their return is actually zero—because there is no reinvestment and investors only reap the minimal return on storage. As a result, aggregate output and social welfare are relatively low. The equilibrium in which banks do not build liquidity buffers hence provides lower welfare.

4. Policy Options to Restore Efficiency

In the previous section, we established that in the presence of multiple equilibria, the equilibrium in which banks do not hold any liquidity buffer is dominated. We now investigate whether there are any welfare-improving policies conditional on a given equilibrium. To do so, we consider a central bank which can act either as a lender of last resort or as a "borrower" of last resort. In the former case, the central bank lends $\lambda_{cb} > 0$ to *distressed* banks, while in the latter case, the central bank issues an amount $-\lambda_{cb}$ of bonds ($\lambda_{cb} < 0$) and sells such bonds to *intact* banks and investors. The central bank, having no endowment, needs to borrow to act as a lender of last resort. We assume it does so at a cost ρ_{cb} which satisfies $1 < \rho_{cb} < \rho_1$. Similarly, the central bank, having no investment opportunity, can only park the funds raised when acting as borrower of last resort at the storage facility for a unit return. Last, we assume perfect commitment: the central bank always delivers on the announced policy λ_{cb}.

4.1 Central Bank Intervention and Social Welfare

In the equilibrium where banks do not hold liquidity, i.e., when the total funding supply satisfies $\lambda + \lambda_{cb} > 0$, *distressed* banks cannot borrow—$D^*(L = 0) = 0$—and the funding cost is $r = 1$, as investors park their funds at the storage facility. A central bank acting as a lender of last resort therefore cannot affect the funding cost, which cannot go below 1. Banks and investors are hence unaffected. Social welfare net of intervention costs W^n therefore writes as $W^n = W^i(\lambda) - (\rho_{cb} - 1)\lambda_{cb}$. Similarly, when the central bank issues bonds at date 1, if the bond issuance does not affect banks' liquidity holdings, then the equilibrium funding cost is still $r = 1$. Banks and investors are hence still unaffected. Social welfare net of intervention costs W^n then writes as $W^n = W^i$ given that the central bank does not bear any cost (it borrows and lends at the same rate $r = 1$).

Let us now turn to the equilibrium where banks hold liquidity, i.e., the total funding supply satisfies $\lambda+\lambda_{cb} \leq \mu$. Now a central bank acting as a lender/borrower of last resort affects the funding cost. A positive funding supply λ_{cb} reduces the funding cost for *distressed* banks and allows for larger borrowing. The central bank then earns the return r^*—the equilibrium funding cost—but borrows the funds lent at a cost ρ_{cb}. It hence undergoes a cost $(\rho_{cb}-r^*)\lambda_{cb}$. After some algebra, social welfare net of central bank intervention costs writes as $W^n = W^l(\lambda)+(\rho_1-\rho_{cb})\lambda_{cb}$.[15] Now when the central bank issues bonds at date 1, it does so at the prevailing funding cost r^* and parks the funds raised at the storage facility. It hence faces a cost $-(r^*-1)\lambda_{cb}$ (remember that $\lambda_{cb} < 0$ in the case of "borrower"-of-last-resort policies). Social welfare net of central bank intervention costs then writes as $W^n = W^l + (\rho_1 - 1)\lambda_{cb}$. Wrapping up these results, social welfare W^n under central bank intervention writes as

$$W^n(\lambda_{cb}) = \begin{cases} W^i(\lambda) - (\rho_{cb}-1)\lambda_{cb}\mathbf{1}_{[\lambda_{cb}>0]} & \text{if } \lambda+\lambda_{cb} > 0 \\ W^l(\lambda) + \left(\rho_1 - \rho_{cb}\mathbf{1}_{[\lambda_{cb}>0]} - \mathbf{1}_{[\lambda_{cb}<0]}\right)\lambda_{cb} & \text{if } \lambda+\lambda_{cb} \leq \mu. \end{cases} \tag{11}$$

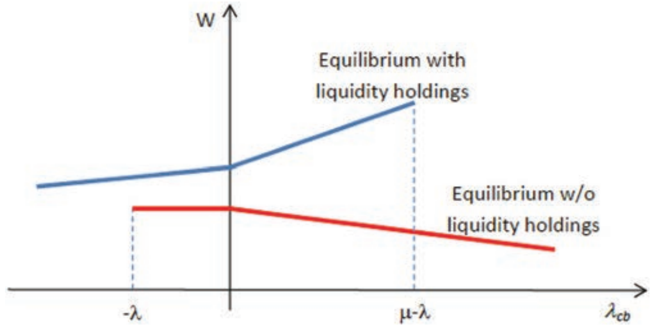
PROPOSITION 3. *The socially optimal policy for the central bank consists in announcing it will act as a lender of last resort, lending an amount* $\lambda^*_{cb} = \mu-\lambda$ *to distressed banks if the economy coordinates on the equilibrium where banks hold liquidity. Conversely, the socially optimal policy for the central bank consists in announcing it will act as a "borrower" of last resort, issuing an amount of bonds* $-\lambda^*_{cb} = \lambda$ *if the economy were to coordinate on the equilibrium where banks do not hold liquidity.*

Proof. Cf. the appendix.

Figure 9 represents social welfare W as a function of the central bank funding supply λ_{cb}. It shows two properties: (i) social welfare is

[15]Note that the expression for W^n is very intuitive. It writes as the sum of two terms: social welfare in the absence of any central bank intervention W^l and the social gain to central bank intervention $(\rho_1-\rho_{cb})\lambda_{cb}$, given that the funds λ_{cb} are borrowed at a cost ρ_{cb} and reinvested with a return ρ_1.

Figure 9. Social Welfare and Central Bank Intervention



always higher under the equilibrium where banks hold liquidity, and (ii) social welfare under the equilibrium where banks hold liquidity is increasing in λ_{cb}, while social welfare under the equilibrium where banks do not hold liquidity is weakly decreasing in λ_{cb}. The intuition for these results is relatively straightforward. In the equilibrium where banks hold liquidity, the cost of funding is relatively high, and reducing funding helps *distressed* banks, raising more funds and thereby increasing reinvestment. This is why social welfare under the equilibrium where banks hold liquidity is increasing in λ_{cb}. Yet the central bank's action faces a limit, as the reduction in the funding cost can affect banks' incentives to hold liquidity ex ante. As a result, the socially optimal policy consists for the central bank in lending an amount $\lambda^*_{cb} = \mu - \lambda$ to *distressed* banks. By contrast, in the equilibrium where banks do not hold liquidity, the opposite holds: the cost of funding is relatively low, and raising it through a borrower-of-last-resort policy can be helpful insofar as this changes banks' incentives to hold liquidity ex ante (remember that social welfare is higher in the equilibrium where banks hold liquidity). Yet such a policy is costly under the equilibrium where banks hold liquidity. However, this cost is always dominated by the welfare gain the economy enjoys when switching equilibriums. This is why drying up liquidity is then optimal, i.e., $\lambda^*_{cb} = -\lambda$.

A lender-of-last-resort policy can be helpful to improve social welfare but only insofar as *distressed* banks have some pledgeable income. In the absence of pledgeable income, a "borrower"-of-last-resort policy is needed to restore incentives to hold liquidity.

5. Conclusion

The model derived in this paper provides a framework to analyze banks' decision to build liquidity buffers ex ante as opposed to raising funding ex post. In particular, the model illustrates that a positive feedback loop can emerge between liquidity buffers and the funding cost when the economy faces a positive funding supply from investors. As a result, the economy can coordinate on an inefficient equilibrium in which banks do not build liquidity buffers and are unable to cope with shocks. Next, the paper investigates how policy can improve on social welfare and highlights that lender-of-last-resort policies, by further reducing funding costs, are no help in raising incentives to hold liquidity. However, a borrower-of-last-resort policy which aims at raising the funding cost and thereby changes incentives for liquidity holding can be helpful. Yet to be successful, it needs to be sufficiently massive to dry up liquidity on the market.

Appendix

Proof of Proposition 1

According to previous results, banks' optimal liquidity buffer $L^*(r)$ satisfies

$$L^*(r) = \begin{cases} 0 & \text{if } 1 \leq r < \widehat{r} \\ 1-\kappa & \text{if } \widehat{r} \leq r \leq \rho_1. \end{cases} \tag{12}$$

Turning now to the market for funding, and denoting $r^*(1-\kappa) = \frac{1-\kappa+\lambda}{(1-\alpha)(1-\kappa)+\lambda}\phi\rho_1$, the equilibrium funding cost $r^*(L)$ satisfies

$$r^*(L) = \begin{cases} \mathbf{1}[\lambda > 0] + \rho_1 \mathbf{1}[\lambda \leq 0] & \text{if } L = 0 \\ r^*(1-\kappa) & \text{if } L = 1-\kappa. \end{cases} \tag{13}$$

When banks do not hold liquidity buffers, i.e., $L^* = 0$, then there is an excess supply of funding if $\lambda > 0$ and an excess demand for funding when $\lambda \leq 0$. Conversely, when banks hold liquidity buffers $L^* = 1-\kappa$, then following (7), the equilibrium funding cost r solves $\alpha\frac{\phi\rho_1}{r-\phi\rho_1}(1-\kappa) = (1-\alpha)(1-\kappa)+\lambda$, which simplifies as $r = r^*(1-\kappa)$.

Using (12) and (13), we can now derive the decentralized equilibrium.

When $\lambda \leq 0$, the equilibrium funding cost is $r^* = \rho_1$ if $L = 0$, while it is $r^* = r^*(1-\kappa)$ if $L = 1-\kappa$. Hence, $L = 0$ cannot be an equilibrium and we are left with two cases: if $r^*(1-\kappa) \geq \widehat{r}$, then $L^* = 1-\kappa$ is the unique equilibrium—banks are better off holding maximum liquidity buffers. But if $r^*(1-\kappa) < \widehat{r}$, then neither $L = 0$ nor $L = 1-\kappa$ can be an equilibrium. There is hence a mixed-strategy equilibrium and banks are indifferent between holding liquidity and investing in illiquid projects.

Now when $\lambda > 0$, the equilibrium funding cost is $r^* = 1$ if $L = 0$, while it is $r^* = r^*(1-\kappa)$ if $L = 1-\kappa$. As a result, $L = 0$ is always an equilibrium and we are left with two cases: if $r^*(1-\kappa) < \widehat{r}$, $L = 0$—banks are better off holding no liquidity buffers—is the unique equilibrium. Conversely, if $r^*(1-\kappa) > \widehat{r}$, then $L = 0$ and $L = 1-\kappa$ are both equilibria: banks may either hold maximum liquidity buffers or no liquidity buffers at all.

Proof of Proposition 2

Given the assumption that $\rho_1 > (1-\alpha)\rho > 1$ and given that $\lambda > 0$ is a necessary condition for multiple equilibria, social welfare is always larger in the equilibrium where banks hold liquidity.

Proof of Proposition 3

In the equilibrium where banks hold liquidity, i.e., $\lambda + \lambda_{cb} \leq \mu$, expression (11) for social welfare W^n increases with central bank lending λ_{cb}. The optimal policy is then to maximize central bank lending, i.e., $\lambda + \lambda_{cb}^* = \mu$. Similarly, in the equilibrium where banks do not hold liquidity, i.e., $\lambda + \lambda_{cb} > 0$, expression (11) for social welfare W^n decreases with central bank lending λ_{cb}. The optimal policy is then to minimize central bank lending, i.e., to have the central bank act as a borrower of last resort: $\lambda + \lambda_{cb}^* = 0$. In this case, the economy switches to the equilibrium where banks hold liquidity. Hence we still need to check that such policy is time consistent, i.e., that social welfare is still higher with this central bank policy once the economy has switched equilibrium. And indeed one can check that this is the case: given the assumption $\rho_1 > (1-\alpha)\rho$, we always have $W^n(\lambda_{cb} = -\lambda) > W^i(\lambda)$.

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Centrality-Based Capital Allocations*

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We look at the effect of capital rules on a banking system that is connected through correlated credit exposures and interbank lending. Keeping total capital in the system constant, the reallocation rules, which combine individual bank characteristics and interconnectivity measures of interbank lending, are to minimize a measure of system-wide losses. Using the detailed German credit register for estimation, we find that capital rules based on eigenvectors dominate any other centrality measure, saving about 15 percent in expected bankruptcy costs.

JEL Codes: G21, G28, C15, C81.

1. Introduction

"The difficult task before market participants, policymakers, and regulators with systemic risk responsibilities such as the

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> Federal Reserve is to find ways to preserve the benefits of interconnectedness in financial markets while managing the potentially harmful side effects." Yellen (2013)

This paper examines capital requirements that mitigate the harmful side effects of interconnectedness in the context of a model of interbank contagion. Although the model is fairly classical in the way it handles contagion, it uses a very rich data set of credit exposures of a large domestic banking system, the fifth largest system in the world. What we find is that the same nationwide amount of required capital, when distributed in part based on the interconnectedness of the system, performs better in terms of total losses to the system than the same amount of capital when allocated on the basis of banks' individual risk-weighted assets alone. Indeed, a capital allocation based upon our best network centrality measure saves some 15 percent of expected bankruptcy costs, which is our preferred measure of total system losses.

The idea of tying capital charges to interbank exposures and interconnectedness in order to improve the stability of the banking system—i.e., to minimize expected social costs (arising from bailouts, growth effects, or unemployment, for example)—is in the spirit of the regulatory assessment methodology for systemically important financial institutions (SIFIs) proposed by the Basel Committee on Banking Supervision (2011). In contrast to that methodology, however, our study determines an optimal rule for capital charges that is based on interconnectedness measures as well as on the portfolio risk of bank assets, and we then compare the results under the different capital allocations.

We focus on two main sources of systemic risk: correlated credit exposures and interbank connectivity. First, banks' balance sheets can be simultaneously affected by macro or industry shocks, since the credit risk of their non-bank borrowers is correlated. If losses are large, capital of the entire system is eroded, making the system less stable. Second, these shocks can trigger the default of certain financial institutions and, again, erode bank capital further. The second effect is modeled in the interbank market. Since banks are highly connected through interbank exposures, we focus on those negative tail events in which correlated losses of their portfolios trigger contagion in the interbank market.

Our model comes close to the framework proposed by Elsinger, Lehar, and Summer (2006) and Gauthier, Lehar, and Souissi (2012), which combines common credit losses with interbank network effects and externalities in the form of asset fire sales. The aim of our paper is different. We propose a tractable framework to reallocate capital for large financial systems in order to minimize contagion effects and the possible costs of a public bailout. We contrast two different capital allocations: the benchmark case, in which we allocate capital based on the risks in individual banks' portfolios, and a comparison case, where we allocate capital based partly on some interbank network metrics (such as *degree*, *eigenvector*, or *betweenness*) that capture the potential contagion risk of individual banks. Literature has shown that the network structure matters. For instance, Sachs (2014) randomly generates interbank networks and investigates contagion effects in different setups. She finds that the distribution of interbank exposures plays a crucial role for system stability and confirms the "knife-edge" or tipping-point feature (as mentioned by Haldane 2009) of highly interconnected networks.

We compare different capital structures in which the total capital requirement to the entire banking system is constant but the capital charge varies across banks, based on the network metric chosen and the weight we put on it. Both the choice of a metric and the weight are optimized. Among various sensible target functions, to minimize, we select *total expected bankruptcy costs* of defaulted banks. This measure of system losses is especially interesting, as it represents a deadweight social loss and is independent of distributional considerations which would arise if we focused on the losses incurred by a certain group of bank claimants such as depositors.

We use the credit register for the German banking system. It records every bilateral lending relationship in excess of €1.5 million, including interbank lending. The richness of our data set allows us to do two things. First, we can compute centrality measures accurately. Second, we achieve a comparably high precision in exploring the implications of both the joint credit risk and the interconnected direct claims in the banking system. Using a state-of-the-art credit portfolio model, we can derive the joint distribution functions of the shocks to the banks within the system and feed the shocks into the interbank lending network, so that we can simulate how they work their way through the system.

To model the credit risk arising from exposures to the real economy, which we call *fundamental* credit risk, we generate correlated credit losses by means of the risk engine CreditMetrics, which is often used in bank risk management (Bluhm, Overbeck, and Wagner 2003, ch. 2). Based on a multi-factor credit risk model, the engine helps us to deal with risk concentration caused by large exposures to a single sector or highly correlated sectors. Even explicit common credit exposures, caused by firms borrowing from multiple banks, are precisely addressed. CreditMetrics assigns realistic, well-founded probabilities to those scenarios that have particularly large losses across the entire banking system. These bad scenarios are our main focus, since capital across financial institutions is eroded simultaneously and the banking system becomes more prone to interbank contagion.

Moreover, we model interbank contagion as in Rogers and Veraart (2013), which extends Eisenberg and Noe (2001) to include bankruptcy costs. This allows us to measure expected contagion losses and to observe the propagation process. To empirically implement our framework, we use several sources of information: the German central credit register (covering large loans), aggregated credit exposures (small loans), balance sheet data (e.g., total assets), market data (e.g., to compute sector correlations in the real economy or credit spreads), and data on rating transitions (to calibrate the CreditMetrics model). The approach can be applied in any country or group of countries where this type of information is available.

A major advantage of our framework is that policymakers can deal with large banking systems, making the regulation of systemic risk more tractable: while Gauthier, Lehar, and Souissi (2012) state that their model requires substantial numeric effort even with the six Canadian banks considered in their paper, German regulators have to deal with more than 1,500 banking groups, which is possible when taking our approach.

This study is related to several strands of the literature including applications of network theory to economics, macroprudential regulations, and interbank contagion. Cont, Moussa, and Santos (2013) find that not only banks' capitalization and interconnectedness are important for spreading contagion but also the vulnerability of the neighbors of poorly capitalized banks. Gauthier, Lehar, and Souissi (2012) use different holdings-based systemic risk measures (e.g., marginal expected shortfall, ΔCoVaR, Shapley value) to reallocate capital in the banking system and to determine macroprudential capital requirements. Using the Canadian credit register data for a system of six banks, they rely on an "Eisenberg-Noe"-type clearing mechanism extended to incorporate asset fire-sale externalities. In contrast to their paper, we reallocate capital based on centrality measures extracted directly from the network topology of the interbank market. Webber and Willison (2011) assign systemic capital requirements, optimizing over the aggregated capital of the system. They find that systemic capital requirements are directly related to bank size and interbank liabilities. Tarashev, Borio, and Tsatsaronis (2010) claim that systemic importance is mainly driven by size and exposure to common risk factors. In order to determine risk contributions, they utilize the Shapley value. In the context of network analysis, Battiston, Puliga et al. (2012) propose a measure closely related to eigenvector centrality to assign the systemic relevance of financial institutions based on their centrality in a financial network. Similarly, Soramäki and Cook (2012) try to identify systemically important financial institutions in payment systems by implementing an algorithm based on Markov chains. Employing simulation techniques, they show that the proposed centrality measure, SinkRank, highly correlates with the disruption of the entire system. In accordance with the latter two studies, we also find measures that focus on banks "being central," especially eigenvector centrality, to dominate size as a measure of systemic importance.

As the subprime crisis has shown, banks do not have to be large to contribute to systemic risk, especially where banks are exposed to correlated risks (e.g., credit, liquidity, or funding risk) via portfolios and interbank interconnectedness. Assigning risks to individual banks might be misleading. Some banks might appear healthy when viewed as single entities, but they could threaten financial stability when considered jointly. Gai and Kapadia (2010) find that greater complexity and concentration in the network of bank connections can amplify systemic fragility. Anand et al. (2013) extend their model to include asset fire-sale externalities and macroeconomic feedback on top of network structures, in order to stress-test financial systems. These studies illustrate the tipping point at which the financial system breaks down based on the severity of macroeconomic shocks that affect probabilities of corporate default or asset liquidity. Battiston, Gatti et al. (2012) show that interbank connectivity increases systemic risk, mainly due to a higher contagion risk. Furthermore, Acemoglu, Ozdaglar, and Tahbaz-Salehi (2013) claim that financial network externalities cannot be internalized and thus, in equilibrium, financial networks are inefficient. This creates incentives for regulators to improve welfare by bailing out SIFIs.

In our analysis we keep the total amount of capital in the system constant; otherwise, optimization would be simple but silly: more capital for all, ideally 100 percent equity funding for banks. As a consequence, when we require some banks to hold more capital, we are willing to accept that others may hold less capital, as in the benchmark case. Taken literally, there would be no lower limit to capital except zero. However, we also believe that there should be some minimum capital requirement that applies to all banks for reasons of political feasibility, irrespective of their role in the financial network. Implementing a uniform maximum default probability for all banks, as we actually do in our reallocation mechanism, might be one choice.

Finally, we realize that this is just the first step in calculating optimal capital requirements from network positions to prevent systemic risk. Clearly our results are subject to the standard critique that banks will adjust their network position in response to their new capital requirements. This is not a paper of endogenous network formation, but rather a first step in describing how the system could improve its capital allocation with a given network structure. Given the current German structure, we find that those network measures most influential in reducing total system losses are based on eigenvectors of the adjacency matrix, or closeness measures, and to a lesser extent on the number of lenders a bank has, and a measure that combines this number with the indebtedness of the bank to the rest of the system. These measures will all be described in detail in section 2.2. At its best combination with the benchmark capital requirement, the eigenvector measure can reduce the expected systemic losses by about 15 percent. It works by focusing the capital requirements on a few important banks.

The rest of this paper is structured as follows. In section 2 we describe our risk engine that generates common credit losses to banks' portfolios and our interconnectedness measures. In section 3 we describe our data sources and the network topology of the

German interbank market. Section 4 gives an overview of the contagion algorithm and section 5 describes how capital is optimized. In section 6 we present our main results, and we make some final remarks in section 7.

2. Methodology

Our procedure can be summarized in two stages, along with our initial condition. In the initial state, we use each bank's measured portfolio, which is composed of large and small credit exposures (e.g., loans, credit lines, derivatives) to real-economy and interbank (IB) borrowers. On the liability side, banks hold capital, interbank debt, and deposits. Depositors and other creditors are senior to interbank creditors.

Capital is either set to a benchmark case that is based solely on the loss distributions of their portfolios or according to other capital allocations that partly rely on network measures. Details of how portfolio risk is mixed with network measures are explained in section 5.

In the first stage, we simulate correlated exogenous shocks to all banks' portfolios that take the form of returns on individual large loans (where loans that are shared among multiple lenders are accounted for) and aggregated small loans. Due to changes in value of borrowers' assets, their credit ratings migrate (or they default), and banks make profits or losses on their investments in the real-economy sectors. At the end of this stage, in the case of portfolio losses, capital deteriorates and some banks experience negative capital and default. Thus, we are able to generate correlated losses that affect the capital of each bank simultaneously.

In the second stage, we model interbank contagion. To each simulation round of the first stage we apply an extended version (Rogers and Veraart 2013) of the fictitious contagion algorithm as introduced by Eisenberg and Noe (2001), augmented with bankruptcy costs and a macroeconomic proxy for fire sales. Fundamental bank defaults generate losses to other interbank creditors and trigger some new defaults. Hence, bank defaults can induce domino effects in the interbank market. We refer to new bank failures from this stage as *contagious defaults.*

Finally, we repeat the previous stages for different capital allocations. We discuss the optimization procedure in section 5. Moreover, section 2.2 offers an overview of the interconnectedness measures calculated with the help of network analysis and utilized in the optimization process.

2.1 Credit Risk Model

Our credit risk engine is essential to our study for two reasons. First, it leads to our initial set of bank defaults and helps us determine capital with which our banks face the contagion event in a second stage. Just as important to our model is that the risk engine establishes our benchmark capital allocation as described above. Our results turn out to be sensitive to our choice of benchmark capital, so that it is important to get the credit risk engine close to some realistic risk process. Second, to the best of our knowledge, this is the first paper to incorporate correlated losses and defaults in the first stage for a large banking system.[1] As such, it is important to work with our rich data (with whatever limitations it might have) using a risk model consistent with models that could be used by actual banking risk officers. However, we also have to make a few concessions to the data supplied by the Deutsche Bundesbank. In particular, pricing data of the loans is not available, and our study relies only on the loan portion of the bank portfolios and credit exposures arising from derivatives.

In order to model credit risk, we utilize lending information from two data sources at different levels of aggregation: large loans and small loans. These loans are given to the "real economy." Since borrowers of large loans are explicitly known, along with various parameters such as the loan volume, probability of default, and sector, we can model their credit risk with high precision. When simulating defaults and migrations of individual borrowers, we can even account for the fact that loans given by different banks to the same borrower should migrate or default synchronously.

[1]Elsinger, Lehar, and Summer (2006) and Gauthier, Lehar, and Souissi (2012) do model correlated portfolio losses. However, both the Austrian and the Canadian banking systems consist of much fewer banks than the German one.

We cannot keep this level of precision for small loans because we only know their exposures as a lump sum to each sector. Accordingly, we simulate their credit risk on portfolio level.

2.1.1 Large Loans

In modeling credit portfolio risk, we closely follow the ideas of CreditMetrics (Gupton, Finger, and Bhatia 1997; Bluhm, Overbeck, and Wagner 2003). In the form we use, it is a one-period model, and all parameters are calibrated to a one-year time span. We start with a vector $Y \sim N(0, \Sigma)$ of systematic latent factors. Each component of Y corresponds to the systematic part of credit risk in one of the *risk-modeling* (*RM*) sectors (see section 3.1 for details). The random vector is normalized such that the covariance matrix Σ is actually a correlation matrix. In line with industry practice, we estimate correlations from co-movements of stock indices. For each borrower k in RM sector j, the systematic factor Y_j assigned to the sector is coupled with an independent idiosyncratic factor $Z_{j,k} \sim N(0, 1)$. Thus, the "asset return" of borrower (j, k) can be written as

$$X_{j,k} = \sqrt{\rho} Y_j + \sqrt{1 - \rho} Z_{j,k}. \tag{1}$$

The so-called intrasector asset correlation ρ is common to all sectors.[2] The term "asset return" should not be taken literally; i.e., the link between asset returns and loan losses is not established by the contingent-claims analysis of a structural credit model. Rather, the latent factor $X_{j,k}$ is mapped into rating migrations via a threshold model, and it is a rating migration matrix that the model is calibrated to. If a loan does not default, a loss on it may arise from the fact that the credit spread used in the loan-pricing formula is sensitive to the credit rating.

We use sixteen Standard & Poor's rating classes, including notches AAA, AA+, AA, ..., B–, plus the aggregated "junk" class CCC–C. Moreover, we treat the default state as a further rating (D) and relabel ratings as numbers from 1 (AAA) to 18 (default). Let

[2] This assumption could be relaxed but would require the inclusion of other data sources. In the simulations we use a value of 0.20, which is very close to a value reported by Zeng and Zhang (2001). It is the average over their sub-sample of firms with the lowest number of missing observations.

R_0 denote the initial rating of a borrower and R_1 the rating one year later. A borrower migrates from R_0 to rating state R_1 whenever

$$X \in [\theta(R_0, R_1), \theta(R_0, R_1 - 1)],$$

where θ is a matrix of thresholds associated with migrations between any two ratings. For one-year migration probabilities $p(R_0, R_1)$ from R_0 to R_1, which are given by empirical estimates,[3] the thresholds are chosen such that

$$\mathbf{P}\left(\theta(R_0, R_1) < X_{j,k} \leq \theta(R_0, R_1 - 1)\right) = p(R_0, R_1),$$

which is achieved by formally setting $\theta(R_0, 18) = -\infty$, $\theta(R_0, 0) = +\infty$ and calculating

$$\theta\left(R_0, R_1\right) = \Phi^{-1}\left(\sum_{R > R_1} p\left(R_0, R\right)\right), \quad 1 \leq R_0, R_1 \leq 17.$$

The present value of each non-defaulted loan depends on notional value, rating, loan rate, and time to maturity. In this section we ignore the notional value and focus on D, the *discount factor*. A loan is assumed to pay an annual loan rate C until maturity T, at which all principal is due. We set T equal to a uniform value of 4 years, which is the digit closest to the mean maturity of 3.66 estimated from Bundesbank's borrower statistics (BS).[4] Payments are discounted at a continuous rate $r_f + s(R)$, where r_f is the default-free interest rate and $s(R)$ are rating-specific credit spreads. The term structure of spreads is flat. We ignore the risk related to the default-free interest rate and set $r_f = 2\%$ throughout. The discount factor for a non-defaulted, R-rated loan at time t is

$$D\left(C, R, t, T\right) \equiv \sum_{u=t+1}^{T} \left(C + I_{\{u=T\}}\right) e^{-(r_f + s(R))(u-t)}. \tag{2}$$

[3] We use the 1981–2010 average one-year transition matrix for a global set of corporates (Standard & Poor's 2011).

[4] The borrower statistics report exposures in three maturity buckets. Exposure-weighted averages of maturities indicate only small maturity differences between BS sectors. By setting the maturity to four years, we simplify loan pricing substantially, mainly since the calculation of sub-annual migration probabilities is avoided.

If the loan is not in default at time 1, it is assumed to have just paid a coupon C. The remaining future cash flows are priced according to equation (2), depending on the rating at time $t = 1$, so that the loan is worth $C + D(C, R_1, 1, T)$. If the loan has defaulted at time 1, it is worth $(1+C)(1-LGD)$, where LGD is an independent random variable drawn from a beta distribution with expectation 0.39 and standard deviation 0.34.[5] This means the same relative loss is incurred on loan rates and principal. The spreads are set such that each loan is priced at par at time 0:

$$C\left(R_0\right) \equiv e^{r_f + s(R_0)} - 1, \quad D\left(C\left(R_0\right), R_0, 0, T\right) = 1.$$

Each loan generates a return equal to

$$ret\left(R_0, R_1\right) = -1 + \begin{cases} D\left(C\left(R_0\right), R_1, 1, T\right) + C\left(R_0\right) & \text{if } R_1 < 18 \\ \left(1 + C\left(R_0\right)\right)\left(1 - LGD\right) & \text{if } R_1 = 18. \end{cases}$$

Besides secure interest, the expected value of $ret(R_0, R_1)$ incorporates credit risk premia that markets require in excess of the compensation for expected losses. We assume that the same premia are required by banks and calibrate them to market spreads, followed by minor manipulations to achieve monotonicity in the ratings.[6]

Having specified migrations and the revaluation on a single-loan basis, we return to the portfolio perspective. Assuming that the loan index k in (j, k) runs through all sector-j loans of all banks, we

[5] We have chosen values reported by Davydenko and Franks (2008), who investigate LGDs of loans to German corporates, similar to Grunert and Weber (2009), who find a very similar standard deviation of 0.36 and a somewhat lower mean of 0.275.

[6] Market spreads are derived from a daily time series of Merrill Lynch euro corporate spreads covering all maturities, from April 1999 to June 2011. The codes are ER10, ER20, ER30, ER40, HE10, HE20, and HE30. Spreads should rise monotonically for deteriorating credit. We observe that the premium does rise in general but has some humps and troughs between BB and CCC. We smooth these irregularities out, as they might have substantial impact on bank profitability but lack economic reason. To do so, we fit $\mathbf{E}return(R_0)$ by a parabola, which turns out to be monotonous, and calibrate spreads afterwards to make the expected returns fit the parabola perfectly. Spread adjustments have a magnitude of 7 basis points for A– and better, and 57 basis points for BBB+ and worse. Ultimate credit spreads for ratings without notches are AAA: 0.47 percent; AA: 0.66 percent; A: 1.22 percent; BBB: 2.2476 percent; BB: 4.10 percent; B: 8.35 percent; and CCC–C: 16.40 percent.

denote by $R_1^{j,k}$ the rating of loan (j,k), which is the image of asset return $X_{j,k}$ at time 1. If bank i has given a (large) loan to borrower (j,k), the variable $LL_{i,j,k}$ denotes the notional exposure; otherwise, it is zero. Then, the euro return on the large loans of bank i is

$$ret_{\text{large},i} = \sum_{j,k} LL_{i,j,k} ret\left(R_0^{j,k}, R_1^{j,k}\right).$$

This model accounts for common exposures of banks not only to the same sector but also to individual borrowers. If several banks lend to the same borrower, they are synchronously hit by its default or rating migration.

2.1.2 Small Loans

As previously described, for each bank we have further information on the exposure to loans that fall short of the €1.5 million reporting threshold of the credit register, which is the database for the large loans. However, we know the exposures to small loans only as a sum for each RM sector, so we are forced to model its risk portfolio wise. As each individual loan exposure in a sub-portfolio of small loans is limited by definition, a relationship between portfolio size and the degree of diversification is likely to exist. We account for this relationship by making the idiosyncratic part of portfolio risk dependent on portfolio size.

We sketch the setup only; further details are available from the authors on request. Let us consider all small loans in a bank's portfolio that belong to the same sector j; these are the loans that are too small to be covered by the credit register. They are commonly driven by the sector's systematic factor Y_j and idiosyncratic risk, as in equation (1). If we knew all individual exposures and all initial ratings, we could just run the same risk model as for the large loans. It is central to notice that the returns on individual loans in portfolio j would be independent, *conditional* on Y_j. Hence, if the exposures were extremely granular, the corresponding returns would get very close to a deterministic function of Y_j, as a consequence of the conditional law of large numbers.[7]

[7]This idea is the basis of asymptotic credit risk models. The model behind Basel II is an example of this model class.

We do not go that far, since small portfolios will not be very granular; instead, we utilize the central limit theorem for conditional measures, which allows us to preserve an appropriate level of idiosyncratic risk. Once Y_j is known, the total of losses on an increasing number of loans converges to a (conditionally!) normal random variable. This conditional randomness accounts for the presence of idiosyncratic risk in the portfolio.

Our simulation of losses for small loans has two steps. First, we draw the systematic factor Y_j. Second, we draw a normal random variable, where the mean and variance are functions of Y_j that match the moments of the exact Y_j-conditional distribution. The Y_j-dependency of the moments is crucial to preserve important features of the exact portfolio distribution, especially its skewness. That dependency also assures that two banks suffer correlated losses if both have lent to sector j. An exact fit of moments is not achievable for us, as it would require knowledge about individual exposures and ratings of the small loans, but an approximate fit can be achieved based on the portfolio's Herfindahl-Hirschman Index (HHI) of individual exposures. As the HHI is also unknown, we employ an additional large sample of small loans provided by a German commercial bank to estimate the relationship between portfolio size and HHI. The sector-specific estimate provides us with a *forecast* of the actual HHI, depending on the portfolio's size and the sector. The HHI forecast is the second input (besides Y_j) to the function that gives us Y_j-conditional variances of the (conditionally normal) portfolio losses. A detailed analytical calculation of the conditional moments and a description of the calibration process are available from the authors on request.

This modeling step ends up with a (euro) return on each bank's small loans, denoted by $ret_{\text{small},i}$.

2.2 Centrality Measures

In order to assign the interconnectedness relevance/importance to each bank of the system, we rely on several centrality characteristics. The descriptive statistics of our centrality measures are summarized later in table 2. The information content of an interbank network is best summarized by a matrix X in which each cell x_{ij} corresponds to the liability amount of bank i to bank j. As each positive entry represents an edge in the graph of interbank lending, an edge goes from the borrowing to the lending node. Furthermore, the adjacency matrix (A) is just a mapping of matrix X, in which $a_{ij} = 1$ if $x_{ij} > 0$, and $a_{ij} = 0$ otherwise. In our case, the network is directed, and by X we use the full information regarding an interbank relationship, not only its existence. We do not net bilateral exposures. Our network has a *density* of only 0.7 percent given that it includes 1,764 nodes and 22,752 links.[8] This sparsity is typical for interbank networks (see, for example, Soramäki et al. 2007).

As outlined by Newman (2010), the notion of centrality is associated with several metrics. In economics the most-used measures are *out degree* (the number of links that originate from each node) and *in degree* (the number of links that end at each node), *strength* (the aggregated sum of interbank exposures), *betweenness centrality* (based on the number of shortest paths that pass through a certain node), *eigenvector centrality* (centrality of a node given by the importance of its neighbors), or *clustering coefficient* (how tightly a node is connected to its neighbors).[9]

The out degree, one of the basic indicators, is defined as the total number of direct interbank creditors that a bank borrows from:

$$k_i = \sum_{j}^{N} a_{ij}. \tag{3}$$

In economic terms—for example, in the case of a bank default—the *out degree* defines the number of banks that will suffer losses in the interbank market, assuming equal seniority.

Similarly, we can count the number of banks that a bank lends to (*in degree*). *Degree* is the sum of *out degree* and *in degree.*

We furthermore compute each node's *strength*, that is, its total amount borrowed from other banks:

$$s_i = \sum_{j}^{N} x_{ij}. \tag{4}$$

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[8]The *density* of a network is the ratio of the number of existing connections divided by the total number of possible links. In our case of a directed network, the total number of possible links is 1,764 × 1,763 = 3,109,932.

[9]For a detailed description of centrality measures related to interbank markets, see Gabrieli (2011) and Minoiu and Reyes (2013).

In other words, the *strength* of a node is simply a bank's total of interbank liabilities. Similarly, we calculate each bank's interbank assets, which would be labeled the strength of inbound edges in network terminology.

The empirical distribution of degrees shows a tiered interbank structure. A few nodes are connected to many banks. For example, 20 banks (around 1 percent) lend to more than 100 banks each. On the borrowing side, 30 banks have a liability to at least 100 banks. These banks are part of the *core* of the network as defined by Craig and von Peter (2014). In terms of *strength*, 158 banks have a total IB borrowed amount in excess of €1 billion, while only 27 banks have total interbank liabilities in excess of €10 billion. On the assets side, 103 banks lend more than €1 billion and 25 banks have interbank assets in excess of €10 billion.

Opsahl, Agneessens, and Skvoretz (2010) introduce a novel centrality measure that we label *Opsahl centrality*. This measure combines the out degree (equation (3)) with the borrowing strength (total IB liabilities, equation (4)) of each node, using a tuning parameter φ:[10]

$$OC_i = k_i^{(1-\varphi)} \times s_i^{\varphi}.$$

The intuition of Opsahl centrality is that, in the event of default, a node with a high value is able to infect many other banks with high severity. This ability is expected to translate into a higher probability of contagion (conditional on the node's default), compared with other nodes.

Before we define *closeness*, let us define a *path* from node A to B to be a consecutive sequence of edges starting from A and ending in B. Its *length* is the number of edges involved. The (directed) *distance* between A and B is the minimum length of all paths between them. For the definition of *closeness* centrality, we follow Dangalchev (2006):

$$C_i = \sum_{j:j\neq i} 2^{-d_{ij}},$$

[10]In our analysis we set $\varphi = 0.5$, leading to the geometric mean between strength and degree.

where d_{ij} is the distance from i to j, which is set to infinity if there is no path from i to j. This formula has a very nice intuition. If "farness" measures the sum of the distances (in a network sense) of the shortest paths from a node to all of the other nodes, then closeness is the reciprocal of the farness.

Bonacich (1987) proposes an *eigenvalue centrality*, based on the adjacency matrix A. If κ_1 is the largest eigenvalue of A, then eigenvector centrality is given by the corresponding normalized eigenvector v so that $Av = \kappa_1 v$. Eigenvector centralities of all nodes are non-negative.

The *weighted eigenvector centrality* is defined by the eigenvector belonging to the largest eigenvalue of the liabilities matrix X.

As a third version of eigenvectors, we calculate a *weighted normalized* eigenvector based on a modification of X where each row is normalized to sum up to 1 (if it contains a non-zero entry). This normalization ignores the *amount* that a bank borrows from others, once it borrows at all, but accounts for the relative size of IB borrowings.

The *global clustering coefficient,* as in Watts and Strogatz (1998), refers to the property of the overall network, while *local clustering coefficients* refer to individual nodes. This property is related to the mathematical concept of *transitivity.*

$$Cl_i = \frac{\text{number of pairs of neighbors of } i \text{ that are connected}}{\text{number of pairs of neighbors of } i}$$

Here, a neighbor of i is defined as any bank that is connected to it either by lending to or borrowing from it. The local clustering coefficient can be interpreted as the "probability" that a pair of i's neighbors is connected as well. The local clustering coefficient of a node with the degree 0 or 1 is equal to zero. Note that this clustering coefficient refers to undirected graphs where a neighbor to a node is any other node connected to it, and where any link in either direction between two nodes means that they are connected.

The *betweenness centrality* relies on the concept of *geodesics.* A path between two nodes is called geodesic if there is no other path of shorter length. Betweenness centrality simply answers the following question: Of all the geodesics, how many of them go through a given node? More formally, if we let g_{ij} be the number of possible geodesic paths from i to j (there might be more than a single shortest path) and n_{ij}^q be the number of geodesic paths from i to j that pass through node q, then the betweenness centrality of node q is defined as

$$B_q = \sum_{\substack{i,j \\ j \neq i}} \frac{n_{ij}^q}{g_{ij}},$$

where by convention $\frac{n_{ij}^q}{g_{ij}} = 0$ in the case where g_{ij} or n_{ij}^q are zero. The intuition here is that a node of high *betweenness* is more likely to lie on a shortest route that is likely to be taken between two nodes.

We also use *total assets* as a "centrality measure" on which to base the capital allocation. Finally, in addition, we measure the effect of capital allocations based on centrality measures that are summaries of all the other centrality measures: we take the first and second principal component of all of our (normalized) centrality measures.

3. Data Sources

Our model builds on several data sources. In order to construct the interbank network, we rely on the Large-Exposures Database (LED) of the Deutsche Bundesbank. Furthermore, we infer from the LED the portfolios of credit exposures (including loans, bond holdings, and derivatives) to the real economy of each bank domiciled in Germany. This data set is not enough to get the entire picture, since especially the smaller German banks hold plenty of assets falling short of the reporting threshold of €1.5 million for the LED. We therefore use balance sheet data and the so-called borrower statistics.

When calibrating the credit risk model, we rely on stock market indices to construct a sector correlation matrix and utilize a migration matrix for credit ratings from Standard & Poor's. Rating-dependent spreads are taken from the Merrill Lynch corporate spread indices.

3.1 Large-Exposures Database (LED)

The Large-Exposures Database represents the German central credit register.[11] Banks report exposures to a single borrower or a borrower unit (e.g., a banking group) which have a notional exceeding a threshold of €1.5 million. The definition of an exposure includes bonds, loans, or the market value of derivatives and off-balance-sheet items.[12] In this paper, we use the information available at the end of 2011:Q1. The interbank market consists of 1,764 active lenders.[13] Including exposures to the real economy, they have in total around 400,000 credit exposures to more than 163,000 borrower units.

Borrowers in the LED are assigned to 100 fine-grained sectors according to the Bundesbank's customer classification. In order to calibrate our credit risk model, we aggregate these sectors to sectors that are more common in risk management. In our credit risk model, we use EURO STOXX's nineteen industry sectors (and later its corresponding equity indices). Table 1 lists risk-management sectors and the distribution characteristics of the probabilities of default (PDs) assigned to them. These twenty-one sectors represent the *risk-model* (*RM*) *sectors* of our model.

There are two additional sectors (households, including nongovernmental organizations, and the public sector) that are not

[11]The Bundesbank labels this database as *Gross- und Millionenkreditstatistik*. A detailed description of the database is given by Schmieder (2006).

[12]Loan exposures also have to be reported if they are larger than 10 percent of a bank's total regulatory capital. If such an exposure falls short of €1.5 million, it is not contained in our data set of large exposures. Such loans represent a very small amount compared with the exposures that have to be reported when exceeding €1.5 million; they are captured in the borrower statistics, though, and hence part of the "small loans"; see section 3.2.

It is also important to notice that, while the data are quarterly, the loan volume trigger is not strictly related to an effective date. Rather, a loan enters the database once its actual volume has met the criterion at some time throughout the quarter. Furthermore, the *definition of credit* triggering the obligation to report large loans is broad: besides *on-balance-sheet* loans, the database conveys bond holdings as well as *off-balance-sheet* debt that may arise from open trading positions, for instance. We use *total exposure* of one entity to another. Master data of borrowers contains its nationality as well as assignments to *borrower units*, when applicable, which is a proxy for the joint liability of borrowers. We have no information regarding collateral in this data set.

[13]Each lender is considered at an aggregated level (i.e., as "Konzern"). At the single-entity level, there are more than 4,000 different lending entities that report data.

Table 1. Risk-Model (RM) Sectors

No.	Risk Model Sector	No. of Borrowers	Volume Weight	Default Probabilities (Percent)					
				5%	25%	50%	75%	95%	Mean
1	Chemicals	3,200	0.9%	0.008	0.19	0.59	1.54	6.66	1.66
2	Basic Materials	14,419	1.5%	0	0.27	0.85	2.05	10.00	2.20
3	Construction and Materials	17,776	1.3%	0	0.12	0.66	1.85	7.95	1.99
4	Industrial Goods and Services	73,548	15.1%	0	0.23	0.77	2.07	13.00	2.57
5	Automobiles and Parts	1,721	0.7%	0.001	0.31	1.05	3.00	14.98	2.91
6	Food and Beverage	13,682	0.8%	0.001	0.27	0.82	1.85	8.00	1.92
7	Personal and Household Goods	21,256	1.3%	0	0.17	0.74	1.99	14.90	2.75
8	Health Care	16,460	1.0%	0	0.03	0.12	0.86	3.84	0.98
9	Retail	25,052	1.6%	0	0.17	0.79	2.67	11.40	2.37
10	Media	2,534	0.2%	0	0.17	0.45	1.71	7.90	1.81
11	Travel and Leisure	8,660	0.7%	0	0.36	1.17	2.92	20.00	3.16
12	Telecommunications	299	0.8%	0	0.12	0.36	2.32	6.32	1.82
13	Utilities	15,679	3.2%	0	0.09	0.39	1.26	6.77	1.62
14	Insurance	1,392	4.1%	0.029	0.03	0.09	0.66	4.82	1.15
15	Financial Services	23,634	22.5%	0.021	0.03	0.05	0.57	4.82	1.07
16	Technology	2,249	0.2%	0	0.20	0.50	1.60	4.68	1.31
17	Foreign Banks	3,134	22.1%	0.003	0.03	0.09	0.88	7.95	1.40
18	Real Estate	56,451	11.4%	0	0.10	0.51	1.68	8.31	1.82
19	Oil and Gas	320	0.5%	0.038	0.22	0.81	2.96	12.86	3.03
20	Households (incl. NGOs)	79,913	1.3%	0	0.05	0.35	1.24	6.00	1.34
21	Public Sector	1,948	9.2%	0	0	0	0	0	0
	Total	388,327	100.0%						1.5

Notes: Volume weight refers to credit exposure.

linked to equity indices. We consider exposures to the public sector to be risk free (and hence exclude them from our risk engine) since the federal government ultimately guarantees all public bodies in Germany. Households include credit risk according to the PDs in the data set. Similar to other sectors, their intrasector correlation ρ equals 20 percent such that all banks' losses in the households sector are correlated through the same systematic factor. However, this factor is uncorrelated to the ones of other sectors.

Information regarding borrowers' default probabilities is included as well in the LED. We report several quantiles and the mean of sector-specific PD distributions in table 1. Since only internal-ratings-based (IRB) banks and savings and loan (S&L) banks report this kind of information, borrowers without a reported PD are assigned random PDs drawn from a sector-specific empirical distribution.

3.2 Borrower and Balance Sheet Statistics

While the LED is a unique database, the threshold of €1.5 million of notional is still a substantial restriction. Although large loans build the majority of money lent by German banks, the portfolios of most German banks would not be well represented by them. That does not come as a surprise, as the German banking system is dominated (in numbers) by rather small S&L and cooperative banks. Many banks hold few loans large enough to enter the LED, though these banks are, of course, much better diversified. For two-thirds of banks, the LED covers less than 54 percent of the total exposures. We need to augment the LED with information on smaller loans.

Bundesbank's borrower statistics (BS) data set reports lending to German borrowers by each bank on a quarterly basis. Focusing on the calculation of money supply, it reports only those loans made by banks and branches situated in Germany; e.g., a loan originated in the London office of a German bank would not enter the BS, even if the borrower is German. Corporate lending is structured in eight main industries, of which two are further split up.[14]

[14]The main sectors are agriculture, basic resources and utilities, manufacturing, construction, wholesale and retail trade, transportation, financial intermediation and insurance, and services.

Loans to households and non-profit organizations are also reported.[15]

While lending is disaggregated into various sectors, the level of aggregation is higher than in the LED, and sectors are different from the sectors in the risk model. We treat this mismatch by a linear mapping of exposures from BS to RM sectors. Detailed information on the mapping is available on request.

In addition to borrower statistics, we use figures from the monthly balance sheet statistics, which is also run by the Bundesbank. These sheets contain lending to domestic insurances, households, non-profit organizations, social security funds, and so-called other financial services companies. Lending to foreign entities is measured by a total figure that covers all lending to non-bank companies and households. The same applies to domestic and foreign bond holdings which, if large enough, are also included in the LED.

3.3 Market Data

Market credit spreads are derived from a daily time series of Merrill Lynch option-adjusted euro spreads covering all maturities, from April 1999 to June 2011. The codes are ER10, ER20, ER30, ER40, HE10, HE20, and HE30.

Asset correlations used in the credit portfolio model are computed from EURO STOXX weekly returns of the European sector indices for the period April 2006–March 2011, covering most of the financial crisis. The European focus of the time series is a compromise between a sufficiently large number of index constituents and the actual exposure of the banks in our sample, which is concentrated on German borrowers but also partly European wide.

The credit ratings migration matrix is provided by Standard & Poor's (2011).

[15] A financial institution has to submit BS forms if it is a monetary financial institution (MFI), which does not necessarily coincide with being obliged to report to the LED. There is one state-owned bank with substantial lending that is exempt from reporting BS data by German law. As it is backed by a government guarantee, we consider this bank neutral to interbank contagion.

3.4 The German Interbank Market

In this section we explore the German market for interbank lending in more detail. In the existing literature, Craig and von Peter (2014) use the German credit register to analyze the German interbank market. They find that a *core-periphery* model can be well fitted to the German interbank system: core banks build a complete sub-network (i.e., there exist direct links between any two members of the subset), while periphery banks are less connected by lending. The core-periphery structure turns out to be very stable through time. Roukny, Georg, and Battiston (2014) use the same data source, spanning the period 2002–12. Providing a thorough analysis of how German interbank lending develops over time, they find most of the characteristics to be very stable, including the distributions of various centrality measures utilized in our paper. Because of these findings, complemented by our own analysis for the period 2005–11, we neglect the time dimension completely and focus on a single point of time.[16]

At the end of 2011:Q1, 1,921 MFIs were registered in Germany, holding a total balance sheet of €8,233 billion.[17] The German banking system is composed of three major types of MFIs: 282 commercial banks (including 4 big banks and 110 branches[18] of foreign banks) that hold approximately 36 percent of total assets, 439 saving banks (including 10 *Landesbanken)* that hold roughly 30 percent of the system's assets, and 1,140 credit cooperatives (including 2 regional institutions) that hold around 12 percent of market share. Other banks (i.e., mortgage banks, building and loan associations, and special-purpose vehicles) are in total sixty MFIs and represent approximately 21 percent of the system's balance sheet.

Our interbank (IB) network consists of 1,764 active banks (i.e., aggregated banking groups). These banks are actively lending and/or borrowing in the interbank market. They hold total assets worth €7,791 billion, from which 77 percent represent large loans and 23 percent small loans.

[16]Tables with these measures are available on request.

[17]Source: Deutsche Bundesbank's Monthly Report, March 2011.

[18]If a foreign bank runs a branch in Germany, the branch has to report large loans to the LED. Subsidiaries of foreign banks are treated as German banks.

Table 2 presents the descriptive statistics of the main characteristics and network measures of the German banks utilized in our analysis. The average size of a bank-individual IB exposure is around €1 billion. As figures show, there are few very large total IB exposures, since the mean is between the 90th and 95th percentile, making the distribution highly skewed. Similar properties are observed for total assets, the total of large loans and out degrees, supporting the idea of a tiered system with few large banks that act as interbank broker-dealers connecting other financial institutions (see, e.g., Craig and von Peter 2014).[19]

4. Modeling Contagion

As introduced in section 2, we differentiate between *fundamental defaults* and *contagious defaults* (see also Elsinger, Lehar, and Summer 2006 or Cont, Moussa, and Santos 2013, for instance). Fundamental defaults are related to losses from the credit risk of "real-economy" exposures, while contagious defaults are related to the interbank credit portfolio (German only).[20]

Moreover, we construct an *interbank clearing mechanism* based on the standard assumptions of interbank contagion (see, e.g., Upper 2011): First, banks have *limited liability*. Next, interbank liabilities are senior to equity but *junior* to non-bank liabilities (e.g., deposits).[21] Losses related to bank defaults are *proportionally* shared

[19]One aspect that needs to be mentioned here is that the observed IB network is not the complete picture, since interbank liabilities of German banks raised outside Germany are not reported to the LED. For example, the LED captures a loan made by Goldman Sachs to Deutsche Bank only if it is made by Goldman Sachs' German subsidiary. This aspect might bias downwards centrality measures of big German banks that might borrow outside Germany.

[20]Loans to foreign banks are included in sector 17 of the "real-economy" portfolio. Their losses are correlated through a common systematic factor, as for loans to the real economy, and their PDs are taken from the LED. However, if a foreign bank has a branch registered in Germany (or multiple of them) and if that branch appears as a lender in the LED, a loan to that foreign bank (or the branch) does not belong to sector 17 but is part of our interbank network. This is so because both the foreign parent bank and the German branch are matched to the same borrower unit, as explained in section 3.1. Subsidiaries of foreign banks simply appear as German banks.

[21]As Upper (2011) points out, deposits by non-banks are senior to some interbank liabilities in the German banking system, but not to all of them. Our

Table 2. Interbank (IB) Market and Network Properties

	Quantiles							Mean	Std. Dev.
	5%	10%	25%	50%	75%	90%	95%		
Total IB Assets[a]	7,591	13,089	35,553	100,450	310,624	868,299	1,647,666	990,433	7,906,565
Total IB Liabilities[a]	2,640	6,053	19,679	61,450	180,771	527,460	1,212,811	990,433	7,782,309
Total Assets[a]	37,798	63,613	160,741	450,200	1,290,698	3,412,953	7,211,608	4,416,920	37,938,474
Total Large Loans[a]	8,719	17,293	60,692	208,475	675,199	2,054,840	4,208,323	3,424,445	30,221,363
Total Small Loans[a]	8,906	34,932	85,741	217,516	550,855	1,287,390	2,253,149	992,475	8,748,757
Out Degree	1	1	1	2	4	9.1	16	13	82
In Degree	1	1	4	9	14	19	25	13	37
Total Degree	2	3	5	11	18	27	38	26	111
Opsahl Centrality	51.5	80.6	165.8	345.9	791.6	2,071.2	4,090	3,342	24,020
Eigenvector Centrality	0.000003	0.000019	0.000078	0.000264	0.001092	0.004027	0.009742	0.003923	0.023491
Weighted Betweenness	0	0	0	0	0	401.5	6,225.8	10,491	82,995
Weighted Eigenvector	0.000004	0.000012	0.000042	0.000142	0.000611	0.002217	0.004839	0.003148	0.023607
Closeness Centrality	253.2	328.8	347.8	391.8	393.6	411.5	427.4	371.22	69.13
Clustering Coefficient	0	0	0	0.00937	0.04166	0.12328	0.16667	0.0379	0.0677
Number of banks[b]	1,764								
Number of links	22,752								

Notes: Data point: 2011:Q1.
[a]In thousands euro.
[b]Number of banks active in the interbank market.

among interbank creditors, based on the share of their exposure to total interbank liabilities of the defaulted bank. In other words, its interbank creditors suffer the same loss given default.[22] Finally, non-bank assets of a defaulted bank are liquidated at a certain discount. This extra loss is referred to as *fire sales* and is captured by *bankruptcy costs,* defined in section 4.1. The clearing mechanism follows the idea of Eisenberg and Noe (2001) which, however, is not designed to include bankruptcy costs. To account for these costs, we follow Rogers and Veraart (2013), who propose a simple algorithm which converges to the fixed point with minimum losses.

When a group of banks default, they trigger losses in the interbank market. If interbank losses (plus losses on loans to the real economy) exceed the remaining capital of the banks that lent to the defaulted group, this can develop into a domino cascade. At every simulation when interbank contagion arises, we follow Rogers and Veraart (2013) to compute losses that take into account the above assumptions.

More formally, first recall that each bank makes a (euro) return on its large and small loans, defined in section 2.1. We switch the sign and define *fundamental losses* as

$$L_i^{\text{fund}} \equiv -\left(ret_{\text{large},i} + ret_{\text{small},i}\right).$$

Each bank incurs total portfolio losses L_i equal to its fundamental losses and losses on its interbank loans:

$$L_i = L_i^{\text{fund}} + L_i^{\text{IB}}, \tag{5}$$

where L_i^{IB} is yet to be determined. A bank defaults if its capital K_i cannot absorb the portfolio losses. We define the default indicator as

$$D_i = \begin{cases} 1 & \text{if} K_i < L_i, \\ 0 & \text{otherwise.} \end{cases}$$

attempts to find out the exact relationship failed. Thus, we consider the most pessimistic approach from the interbank creditors' point of view. If this assumption were relaxed and, for instance, replaced by proportional loss sharing among *all* creditors of a bank, the effects of interbank contagion would probably weaken.

[22]We do not have any precise information related to collateral or the seniority of claims among interbank loans.

Below, bankruptcy costs are modeled so that their (potential) extent BC_i is known before contagion; i.e., they are just a parameter of the contagion mechanism, but only accrue when $D_i = 1$.

Total portfolio losses and bankruptcy costs are now distributed to the bank's claimants. If capital is exhausted, further losses are primarily borne by interbank creditors, since their claim is junior to other debt. Bank i causes its interbank creditors an aggregate loss of

$$\Lambda_i^{\mathrm{IB}} = \min\left(l_i, \max\left(0, L_i + BC_i D_i - K_i\right)\right),$$

which is zero if the bank does not default. The Greek letter signals that Λ_i^{IB} is a loss *on the liability side* of bank i, which *causes* a loss on the assets of its creditors.

The term x_{ij} denotes interbank liabilities of bank i against bank j, and the row sum $l_i = \sum_{j=i}^{N} x_{ij}$ defines total interbank liabilities of bank i. This gives us a *proportionality matrix* π to allocate losses, given by

$$\pi_{ij} = \begin{cases} \frac{x_{ij}}{l_i} & \text{if } l_i > 0; \\ 0 & \text{otherwise.} \end{cases}$$

If the loss amount Λ_i^{IB} is proportionally shared among the creditors, bank j incurs a loss of $\pi_{ij}\Lambda_i^{\mathrm{IB}}$ because of the default of i. Also, the bank i we have started with may have incurred interbank losses; they amount to

$$L_i^{\mathrm{IB}} = \sum_{k=1}^{N} \pi_{ji}\Lambda_j^{\mathrm{IB}}, \tag{6}$$

which provides the missing definition in equation (5). This completes the equation system (5)–(6), which defines our allocation of contagion losses.

Let us write the system in vector form, for which we introduce $l = (\sum_{j=i}^{N} x_{ij})_i$ as the vector of interbank liabilities, $\wedge$ as the element-wise minimum operator, and $\tilde{B}$ as a diagonal matrix with bankruptcy costs BC_i on the diagonal. Default dummies are subsumed in the vector D so that the product $\tilde{B}D$ defines *actual* bankruptcy costs, i.e., the ones that become real. Losses in the IB market *caused* by bank i and incurred by the other banks can then be written as

$$\Lambda^{IB} = l \wedge \left[L + \tilde{B}D - K\right]^{+}.$$

With Π being the proportionality matrix, interbank losses—now on the asset side—amount to

$$L^{\mathrm{IB}} = \Pi^{\top}\Lambda^{\mathrm{IB}}.$$

We consider the total portfolio losses $L = L^{\mathrm{fund}} + L^{\mathrm{IB}}$ (not containing bankruptcy costs) as a solution.[23] Altogether, we have to solve the equation

$$L = \Phi\left(L\right) \equiv L^{\mathrm{fund}} + \Pi^{\top}\left(l \wedge \left[L + \tilde{B}I_{[L>K]} - K\right]^{+}\right),$$

where the indicator function and the relational operator are defined element by element. According to our definition of default, the operator Φ is left-continuous on $\mathbb{R}^{N}$.

Rogers and Veraart (2013) show that a simple repeated application of the monotonic operator Φ to L^{fund} generates a sequence of losses that must converge to a unique loss vector L^{∞}, simply because the sequence is monotonic in each dimension and the solution space is compact. Since the operator Φ is left-continuous in our setup, L^{∞} is also a fixed point. As shown by Rogers and Veraart (2013), it has minimum losses among all fixed points.

4.1 Bankruptcy Costs

In our analysis, we are particularly interested in bankruptcy costs (henceforth BCs), since they represent a deadweight loss to the economy. We model them as the sum of two parts. The first one is a function of a bank's total assets, because there is empirical evidence for a positive relationship between size and BCs of financial institutions; see Altman (1984). The second part incorporates fire sales and their effect on the value of the defaulted bank's assets. For their

[23] We could also search for a solution for $L^{all} \equiv L + \tilde{B}D$, which turns out to be equivalent but more complicated.

definition, recall that we want to model BCs such that their extent is known before contagion, which is why we make them exclusively dependent on the *fundamental* portfolio losses L_i^{fund}. If that loss of bank i exceeds capital K_i, the bank's creditors suffer a loss equal to $\max(0, L_i^{\text{fund}} - K_i)$. In the whole economy, fundamental losses add up to

$$\overline{L}_{\text{fund}} \equiv \sum_i \max\left(0, L_i^{\text{fund}} - K_i\right).$$

It is this total fundamental loss in the system by which we want to proxy lump-sum effects of fire sales. The larger $\overline{L}_{\text{fund}}$, the more assets will the creditors of defaulted banks try to sell quickly, which puts asset prices under pressure. We proxy this effect by defining a system-wide relative loss ratio λ that is a monotonic function of $\overline{L}_{\text{fund}}$. In total, if bank i defaults, we define BCs as the sum of two parts related to total assets and fire sales:

$$BC_i \equiv \phi\left(TotalAssets_i - L_i^{\text{fund}}\right) + \lambda\left(\overline{L}_{\text{fund}}\right) \max\left(0, L_i^{\text{fund}}\right). \quad (7)$$

We consider ϕ to be the proportion of assets lost due to litigation and other legal costs. In our analysis we set $\phi = 5\%$.[24] It is for convenience rather than for economic reasons that we set the monotonic function λ equal to the cumulative distribution function of $\overline{L}_{\text{fund}}$. Given this choice, the larger total fundamental losses in the system are, the closer λ gets to 1.[25]

In the optimization process, we minimize a measure of system losses (i.e., the target function). The mechanism of contagion proposed by us has several sets of agents, each of whom suffers separate kinds of losses. There are many conflicting arguments regarding

[24]Our results remain robust also for other values $\phi \in \{1\%, 3\%, 10\%\}$. Alessandri et al. (2009) and Webber and Willison (2011) use contagious BCs as a function of total assets, and set ϕ to 10 percent. Given the second term of our BC function that incorporates fire-sales effects, we reach a stochastic function with values between 5 percent and 15 percent of total assets.

[25]We acknowledge that real-world BCs would probably be sensitive to the amount of interbank credit losses, which we ignore. This simplification, however, allows us to calculate potential BCs before we know which bank will default through contagion, such that we do not have to update BCs in the contagion algorithm. If we did, it would be difficult to preserve proportional loss sharing in the Eisenberg-Noe allocation.

which agent's losses the regulator should particularly be interested in—for instance, those of depositors (as a proxy for "the public" that is likely to be the party that ultimately bails banks out) or even those of bank equityholders (who are at risk while offering a valuable service to the real economy). While all of them may be relevant, our primary target function is the *expected BCs*, which is just the sum of the expected BCs of defaulted banks:

$$EBC = \mathbf{E}\sum_{i} BC_i D_i, \tag{8}$$

where D_i is the default indicator of bank i. BCs are a total social deadweight loss that does not include the initial portfolio loss due to the initial shock. While this is a compelling measure of social loss, there are distributional reasons that it might not be the only measure of interest.

Losses of equation (8) are free of distributional assumptions. However, some amount of BCs can be acceptable as a side effect of otherwise desirable phenomena (e.g., the plain existence of bank business), such that minimizing expected BCs does not necessarily lead to a "better" system in a broader sense. For example, minimum expected BCs might entail an undersupply of credit more harmful to the real economy than the benefits from low BCs.

The *expected total loss to equityholders* and the *expected total loss to non-bank debtholders* are therefore at least of interest, if not justifiable alternative target functions. Also, their sum appears as a natural choice for a target function, this way treating the interests of bank owners and non-bank debtholders as equally important. However, it can easily be shown that this sum is equivalent to our target function, the expected BCs.

It is important to note that we consider banks as institutions only, meaning that any loss hitting a bank must ultimately hit one of its *non-bank* claimants. In our model, these are simply non-bank debtors and bank equityholders, as we split bank debt into non-bank and interbank debt only. Counting total losses on the asset side of banks' balance sheets (or just their credit losses) makes little sense anyway, as they involve interbank losses and therefore a danger of double-counting.

We considered all of the above losses in our simulations, but we report only those related to equation (8) with the purpose of exposition in this paper.

5. Optimization

In this section, we define the way we reallocate capital. Several points should be made about it.

First, the rules themselves are subject to a variety of restrictions. These include the fact that the rules must be simple and easily computed from observable characteristics, and they should preferably be smooth to avoid cliff effects. Simplicity is important not just because of computational concerns. Simple formal rules are necessary to limit discretion on the ultimate outcome. Too many model and estimation parameters set strong incentives for banks to lobby for a design in their particular interest. While this is not special to potential systemic risk charges, it is clear that those banks that will most likely be confronted with increased capital requirements are the ones with the most influence on politics. Vice versa, simplicity can also help to avoid arbitrary punitive restrictions imposed upon individual banks. In this sense, the paper cannot offer deliberately fancy first-best solutions for capital requirements.

Second, as noted in the Introduction, the rules must keep the total capital requirement the same so that we do not mix the effects of capital reallocation with the effect of increasing the amount of capital in the entire system.

Finally, for reasons of exposition, we focus on capital reallocations based on a single centrality measure. While we did explore more complicated reallocation rules that were optimized over combinations of centrality measures, these reallocations gave only marginal improvements and so are not reported.

We introduce a range of simple capital rules over which our chosen loss measure, the expected BCs, is minimized. We minimize over two dimensions, the first being the choice of a centrality measure and the second being represented by a gradual deviation from a VaR-based benchmark allocation towards an allocation based on the chosen centrality measure.

In our benchmark case, capital requirements focus on a bank's individual portfolio risk (and not on network structure). For our analysis we require banks to hold capital equal to its portfolio VaR on a high security level of $\alpha = 99.9\%$, which is in line with the level used in Basel II rules for the banking book.[26] There is one specialty of this VaR, however. In line with Basel II again, the benchmark capital requirement treats interbank loans just as other loans. For the determination of bank i's benchmark capital $K_{\alpha,i}$ (and *only* for this exercise), each bank's German interbank loans (on the asset side of the balance sheet) are merged with loans to foreign banks into portfolio sector 17, where they contribute to losses just as other loans.[27]

In the whole system, total required capital adds up to $TK_\alpha \equiv \sum_i K_{\alpha,i}$. To establish a "level playing field" for the capital allocation rules, TK_a is to be the same for the various allocations tested.

The basic idea is that we give banks a—hypothetical—proportional capital relief from their benchmark capital, which we then redistribute according to a rule in which capital is scaled up or down by a centrality measure.

Given C_i to be one of the centrality measures introduced in section 2.2, we subtract a fraction β from each bank's benchmark capital $K_{\alpha,i}$ for redistribution. Some required capital is added back, again as a fraction of $K_{\alpha,i}$, which is proportional to the centrality measure:

$$K_{\text{simple},i}(\beta) \equiv K_{\alpha,i}(1 - \beta + \beta a C_i). \tag{9}$$

The parameter a is chosen such that total system capital remains the same as in the benchmark case, which immediately leads to

$$a = \frac{\sum_j K_{\alpha,j}}{\sum_j K_{\alpha,j} C_j}, \quad \text{for all } \beta.$$

[26]To check the numerical stability of our results, we reran several times the computation of VaR measures at quantile $\alpha = 99.9\%$. For this computation we employed a new set of one million simulations and kept the same PDs for loans where unreported values had been reported by random choices. Results are very similar, with an average variance of under 2 percent. VaR measures at 99 percent have a variance of under 0.5 percent.

[27]Default probabilities for these loans are taken from the Large-Exposures Database in the same way as for loans to the real economy.

This simple capital rule is not yet our final allocation because it has a flaw, although it is almost exactly the one we use in the end. Among those banks for which capital decreases in β (these are the banks with the lowest C_i), some banks' capital buffer may get so small that its probability of default (PD) rises to an unacceptable level. We want to limit the PDs (in an imperfect way) to 1 percent, which we assume to be politically acceptable. To this end, we require each bank to hold at least capital equal to bank i's VaR at $\alpha = 99\%$, which we denote by $K_{\min,i}$. In other words, we set a floor on $K_{\text{simple},i}(\beta)$. The VaR is again obtained from the model used for benchmark capital, which treats IB loans as ordinary loans and hence makes the upper PD limit imperfect.[28]

If we plainly applied the floor to $K_{\text{simple},i}(\beta)$ (and if the floor was binding somewhere), we would require more capital to be held in the system than in the benchmark case. We therefore introduce a tuning factor $\tau(\beta)$ to reestablish TK_α. The final capital rule is

$$K_{\text{centr},i}\left(\beta\right) \equiv \max\left(K_{\min,i}, K_{\alpha,i}\left[1-\beta+\beta\,\tau\left(\beta\right)\,a\,C_i\right]\right). \qquad (10)$$

For a given β, the tuning factor $\tau(\beta)$ is set numerically by root finding. To anticipate our results, tuning is virtually obsolete. Even if 30 percent of benchmark capital is redistributed—which is by far more than in the optimum, as will turn out—we find $0.999 < \tau(\beta) \leq 1$ throughout, and there is a maximum of only fourteen banks for which the floor becomes binding.

In general, the approach is not limited to a single centrality measure. As regards the formal approach, we could easily replace C_i in equation (10) with a linear combination of centrality measures $\sum_k a_k C_i^k$ and optimize the a_k along with β; the degree of freedom would be equal to the number of centrality measures included. However, optimization quickly becomes prohibitively expensive, as every step requires its own extensive simulation. We carry out a couple of

[28] If banks held exactly $K_{\min,i}$ as capital, actual bank PDs after contagion could be below or above 1 percent, depending on whether quantiles of portfolio losses in a risk model where interbank loans are directly driven by systematic factors are larger than in the presence of contagion (but without direct impact of systematic factors). However, the probability of bank defaults through *fundamental* losses cannot exceed 1 percent, given that asset correlations in the factor model are positive.

bivariate optimizations, focusing on the centrality measures found most powerful in one-dimensional optimizations. Improvements over the one-dimensional case are negligible and therefore not reported.

In this section we have dealt only with capital *requirements*. To assess their consequences on actual systemic risk, we also have to specify in which way banks intend to obey these requirements. In practice, banks hold a buffer on top of required capital in order to avoid regulatory distress. However, as our model runs over one period only, we do not lose much generality when we abstract from additional buffers and assume banks to hold exactly the amount of capital they are required to hold according to the capital rule in force; data on banks' actual capital holdings are not directly involved.

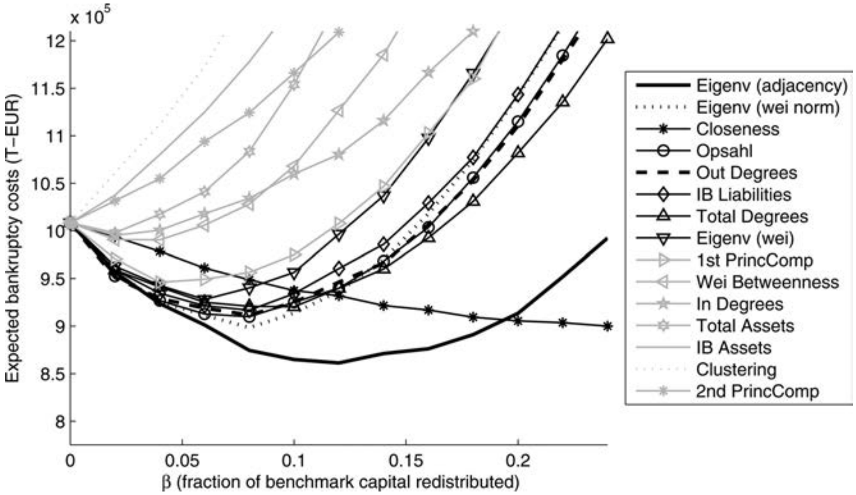
Depending on the capital regime supposed, varying amounts of capital must be reconciled with the other parts of the balance sheet. Our central assumption is that all positions given by data remain the same throughout this paper. There is especially no reaction of the interbank lending network to capital; endogenous interbank lending or borrowing is beyond the scope of our paper.

For implementation, assume a bank holds (interbank and non-bank) loans of size $Loans$ on the asset side, while it has interbank debt liabilities $Liab^{IB}$. These positions are given by data and kept fixed. In addition, the bank holds a varying, rules-dependent amount of capital K. If the bank does not excessively fund itself by interbank borrowing, $Loans$ will exceed $Liab^{IB} + K$. In that case, the liabilities gap $Loans - Liab^{IB} - K$ is assumed to be funded by non-bank debt. If, in contrast, the gap is on the asset side, the bank has no additional liabilities and the gap is closed by an investment in riskless assets such as cash. In other words, funding by non-bank creditors or cash are the only adaptive positions; the balance sheet is complete if we assume

$$\begin{aligned} Liab^{NB} &= \max\left(0, Loans - Liab^{IB} - K\right) \\ Cash &= \max\left(0, Liab^{IB} + K - Loans\right). \end{aligned}$$

If K moves up or down, there is no effect on lending to the real economy (and the corresponding credit losses) or interbank lending.

Figure 1. Comparison of Centrality-Based Capital Allocations



Note also that there is no dynamic aspect of these adjustments in our analysis, as we simply compare alternative static choices.

6. Results

Our main results from the reallocation of capital are depicted in figure 1. Table 3 presents the corresponding optimum values in numbers. As defined in (8), the target function that we compare across centrality measures is the total expected bankruptcy costs. Our benchmark allocation (based only on VaR($\alpha = 99.9\%$)) is represented by the point where $\beta = 0$. As β increases, more of the capital is allocated to an allocation rule based upon the centrality measure as described in equation (10). The extreme right end of the diagram still allocates 75 percent of the capital based on the original VaR($\alpha = 99.9\%$). To allocate less would probably be difficult to support politically and, as can be seen in the figure, covers the area for the minimum losses in all cases but one. Even in this case, the minimum for the closeness centrality is very close to the minimum in the plotted range.

Table 3. Total Expected Bankruptcy Costs after Contagion, Applying Optimized Centrality-Based Capital Allocation

Centrality Measure	Expected BCs (T-EUR)	Saving (Percent)	Optimal Beta (Percent)
Eigenvector (Adjacency)	861,000	14.6	12
Eigenvector (Weighted Normalized)	898,000	10.9	8
Closeness	900,000	10.7	24
Opsahl Centrality	910,000	9.8	8
Out Degree	912,000	9.6	8
IB Liabilities	917,000	9.1	8
Degree	920,000	8.7	10
Eigenvector (Weighted)	928,000	8.0	6
First Principal Component	946,000	6.2	4
Weighted Betweenness	991,000	1.8	4
In Degree	995,000	1.3	2
Total Assets	998,000	1.0	2
IB Assets	1,008,000	0.0	0
Clustering	1,008,000	0.0	0
Second Principal Component	1,008,000	0.0	0
(Benchmark, Purely VaR Based)	1,008,000	—	—

Notes: Expected BCs include fundamental and contagious defaults. Saving in percent refers to the benchmark case. β has been optimized in bins of 2 percent size.

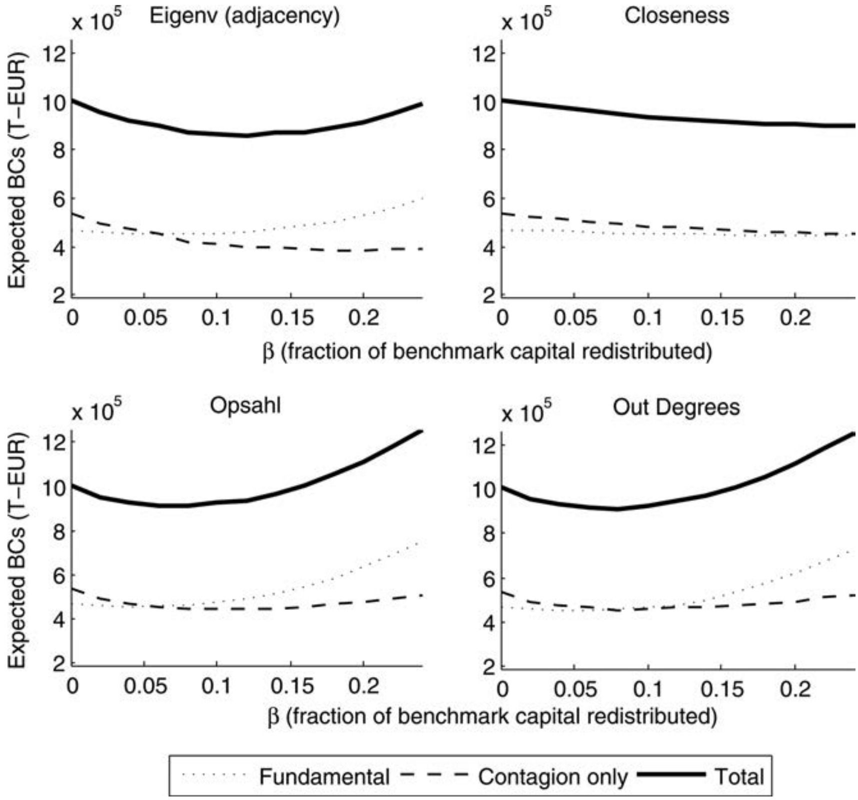
Several patterns are clearly evident in the diagram and supported by findings in table 3. The first observation in figure 1 is that some centrality measures are completely dominated by others. Over the region of $0 \leq \beta \leq 24\%$, capital reallocations based on three of the centrality measures were destructive to the system over the entire region: clustering, IB assets, and the second principal component.

Capital allocations based on all other centrality measures help to improve the stability of the banking system in terms of expected total bankruptcy costs over at least some of the region of β.

One measure stands out among all of them: the adjacency eigenvector. A reallocation of about 12 percent of baseline capital to one based on the adjacency eigenvector saves the system 14.6 percent in system losses as measured by expected BCs. Radically giving 24 percent of the allocation to one based on closeness saves the system less (10.7 percent), but these two capital allocations behave differently from the rest in two senses. First, they are more effective at reducing losses, meaning that the next most effective group of centrality measures, Opsahl, weighted eigenvector, out degree, total degree, and weighted normalized eigenvector, stabilize the system so that it reduces losses between 9 percent and 10 percent, in contrast to 14.6 percent. Second, they all do so at a level of capital reallocation that involves only 8 percent being reallocated from the benchmark to the centrality-based allocation. The two most successful reallocations redistribute more. Finally, the rest of the centrality measures generate even smaller savings at even smaller amounts redistributed. Because the allocations based on closeness and the adjacency eigenvector perform best, we focus on them in the discussion that follows (although the weighted normalized eigenvector actually performs second best, we skip it from further analyses because of its similarity to the adjacency eigenvector). To a lesser extent, we also discuss the effect of the next-best-performing allocations, Opsahl centrality and out degree.

Figure 2 presents expected BCs under the best-performing centrality measures for both pre- and post-contagion losses. The case of closeness stands out from the other three. For closeness, the fundamental defaults mimic the baseline case throughout the range of capital reallocation. They barely increase despite changes in the distribution of bank defaults. As β increases, the decline in losses from contagion is not matched by an increase in pre-contagion losses, and the total losses decrease. The best-performing allocation, based on the adjacency eigenvector, for the smaller range of β, does not increase the fundamental losses much over the benchmark and gives striking savings in post-contagion losses compared with all other measures. It does exactly what one would expect from a capital reallocation based on a wider set of information: strongly reduce the cascading losses at a small expense of fundamental ones. Once the fundamental losses start increasing steeply, at an inflection point of about $\beta = 15\%$, the total costs rise rapidly as well. Below this value, the increase in fundamental costs is relatively smooth, just as the fall-off in benefits from the post-contagion savings are smooth. This reflects the large range of β where the capital reallocation is very

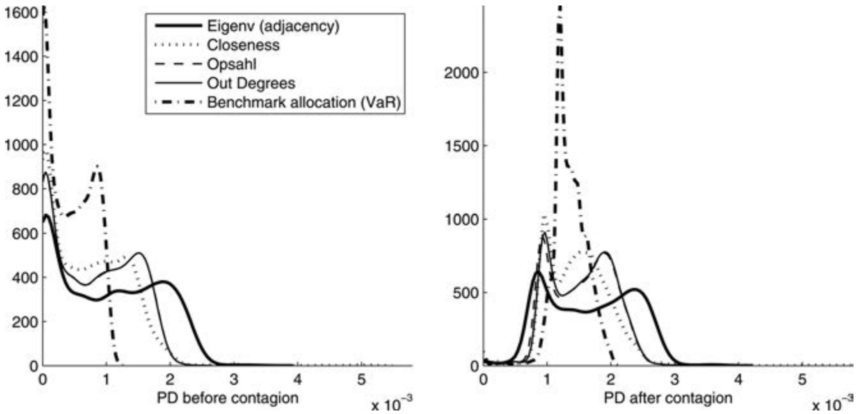
Figure 2. Expected Bankruptcy Costs: All Defaults, Fundamental Defaults, and Contagious Defaults



Notes: The y-axes represent expected bankruptcy costs (as measured by equation (7)) from fundamental defaults, contagious defaults, and all defaults, under different capital allocations. On the x-axis, β represents the redistributed fraction of benchmark capital, VaR($\alpha = 99.9\%$).

effective. The other two measures are similar to the behavior of the allocation based on the adjacency eigenvector. As before, the inflection points of fundamental losses lead to a minimum, but featuring some differences. First, the post-contagion losses stop decreasing at around the same value of β; second, the inflection points are sharper; and finally, all of this happens at smaller values of β, and with smaller declines in post-contagion bankruptcy costs. These are less effective measures upon which to base capital reallocations.

Figure 3. Frequency Distributions of Individual Bank PDs



Notes: On the y-axis is presented the estimated density of the distribution of bank PDs. On the x-axis are represented PDs (per bank). Results were obtained with 500,000 simulations.

Figure 3 displays frequency distributions of all banks' default probabilities before and after contagion in the benchmark case (VaR-based capital)[29] and compares them with distributions generated by the best centrality-based allocations. These four capital reallocations are taken at their optimal β, according to the values presented in table 3. All densities show a similar picture for the fundamental defaults ("PD before contagion"). The reallocations all spread the distribution to the right on fundamental defaults. Indeed, fundamental defaults for the best basis, the adjacency eigenvector, spread the fundamental defaults most to the right. We know from the costs of the fundamental defaults that total bankruptcy costs remain the same. They were redistributed such that more (presumably smaller) banks defaulted to save a few whose default triggers potentially larger bankruptcy costs. This is most pronounced for the adjacency-eigenvector-based capital allocation, but it is true for all the other three measures as well: pre-contagion default frequencies shift to the right with a longer and fatter tail than in the benchmark

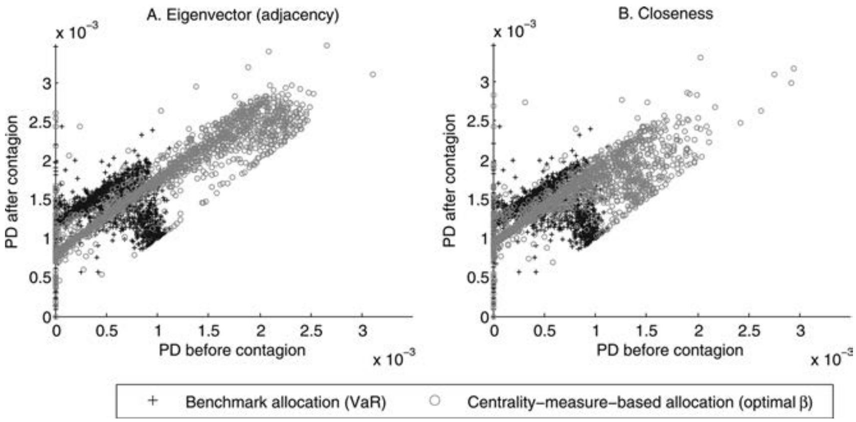
[29]Recall that the VaR used for capital is not identical with the actual loss quantile in the model that includes contagion, be it before or after contagion; see section 5.

case. This is not surprising, as the PDs before contagion are limited to 0.1 percent by construction (cf. footnote 28); any exceedance is caused by simulation noise. The best allocations based on the other three centrality measures lie somewhere in between the fat-tailed adjacency-eigenvector-based distribution and the thin-tailed benchmark. Still, the lesson from the left-hand side of figure 3 is that the capital allocations based on each of our centrality measures in the initial set of defaults sacrifice a large number of less relevant banks by shifting capital to the relevant banks. There is also, of course, a relationship to size, but we cannot present related graphs for confidentiality reasons.

Post-contagion probabilities of default on the right-hand side of figure 3 show further interesting patterns with respect to the benchmark case. The capital reallocation based on each of our centrality measures continues to sacrifice more of the (presumably) smaller banks in order to reduce the probability of default, post-contagion, for the larger banks. The end result of this is a distribution that is considerably wider in its default probability both pre- and post-contagion. The cost in terms of the banks that are more likely to fail is made up through a few banks (otherwise suffering—or elsewhere causing—large losses, in expectation) that are less likely to fail during the contagion phase of the default cycle. It is remarkable that each of our reallocations behave in this way. The extra capital gained from the reduction in the benchmark capital rule which focuses on pre-contagion default has not reduced post-contagion defaults across the board for any tested reallocation. Instead, in contrast to benchmark allocation, our centrality-based capital rules perform less consistently (at least in this sense), sacrificing many defaults to save those which matter in terms of our loss function.

Figure 3 can also be used as a validation of the "traditional" way of measuring the risk of interbank loans, that is, by treating them as in the benchmark case; cf. section 5. In the latter case, they are part of an ordinary industry sector and driven by a common systematic factor. This treatment is very much in line with the approach taken in the Basel III framework. The bank PDs sampled in figure 3 are default probabilities from the model including contagion. If the bank-individual loss distributions generated under the "traditional" treatment were a perfect proxy of the ones after contagion, we should observe the histogram of PDs after contagion in

Figure 4. Relationship between Default Probabilities of Individual Banks Before and After Contagion



Notes: PDs are not to be interpreted as real; e.g., actual capital holdings of German banks have not found entry into their calculation.

the VaR-based benchmark case to be strongly concentrated around 0.1 percent. Instead, the PDs are widely distributed and even on average 35 percent higher than that possibly concluded from the label "99.9 percent VaR." While the link to the Basel framework is rather of a methodological nature, our analysis clearly documents that interbank loans are special and that correlating their defaults by Gaussian common factors may easily fail to capture the true risk. As there are, however, also good reasons to remain with rather simple "traditional" models, such as those behind the Basel rules, our modeling framework lends itself to a validation of the capital rules for interbank credit. This exercise is beyond the scope of this paper.

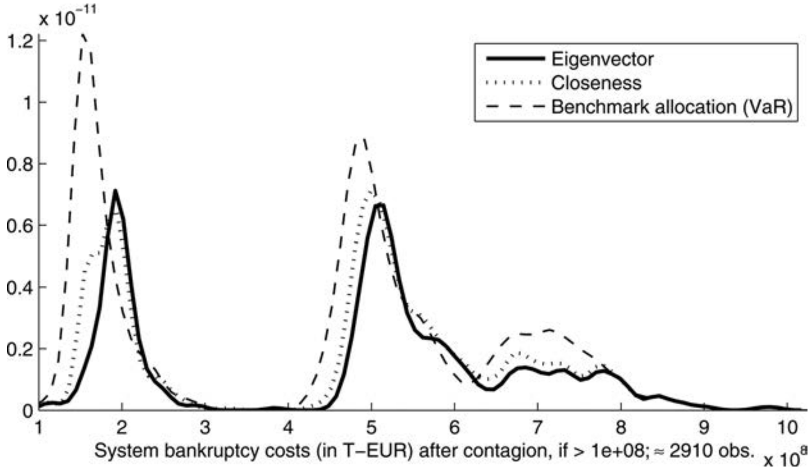
In figure 4, each observation represents a bank for which we calculate the probability of fundamental defaults (x-axis) and the PD including both fundamental and contagious defaults (y-axis). (Obviously, there is nothing lower than the 45-degree line in these diagrams.) In the case of the VaR-based benchmark allocation (black markers), the relationship is clearly non-linear. Most banks, although their fundamental PD is effectively limited to 0.1 percent, experience much higher rates of default due to contagion. Suggested by the graph, there seems to be a set of around thirty events where the system fully breaks down, leading to the default of most banks, irrespectively of their default propensity for fundamental reasons. The benchmark capital requirement does a very good job in limiting the probability of fundamental defaults to 0.1 percent, which is what causes the relationship between fundamental and total default probabilities to be non-linear.

In contrast to the benchmark capital, the optimized capital allocation based on our best-performing measure, the adjacency eigenvector, has a stronger linear relationship between fundamental and total PD, although with heteroskedastic variance that increases with fundamental default probability. Indeed, it looks as if the probability of total default could be approximated by the probability of fundamental default plus a constant. This leads us to a conclusion that imposing a capital requirement based on the adjacency eigenvector causes many banks to have a higher probability of default than in the baseline case, but because these tend to be smaller banks, they impose smaller bankruptcy costs on the system as a whole. The reallocation based on closeness does this less. There are more banks with a lower default probability in the post-contagion world than with the adjacency-eigenvector-based allocation. The closeness allocation induces less of a linear relationship between fundamental and total default probabilities. The lesson here is much the lesson of figure 3: the sacrifice of a lot of small banks to reduce the system losses caused by default of the few banks which are most costly. The additional information of these diagrams is that the same banks sacrificed in the pre-contagion phase are those banks sacrificed in the contagion phase. This relationship is strongest for our best-performing allocation basis, the adjacency eigenvector.

In order to get the full picture, we now focus on the distribution of bankruptcy costs. We provide in figure 5 the tail distribution of BCs for benchmark capital and for capital based on the adjacency eigenvector and closeness, plotted for BCs exceeding €100 billion (note that the lines are ordinary densities plotted in the tail; they are not tail conditional). One is cautioned not to place too much emphasis on the BCs being multi-modal. The default of an important bank might trigger the default of smaller banks which are heavily exposed to it, creating a cluster.

Several things are apparent from figure 5. Both closeness and the adjacency eigenvector perform better than the benchmark in

Figure 5. Kernel Density of BCs Greater than €100 Billion

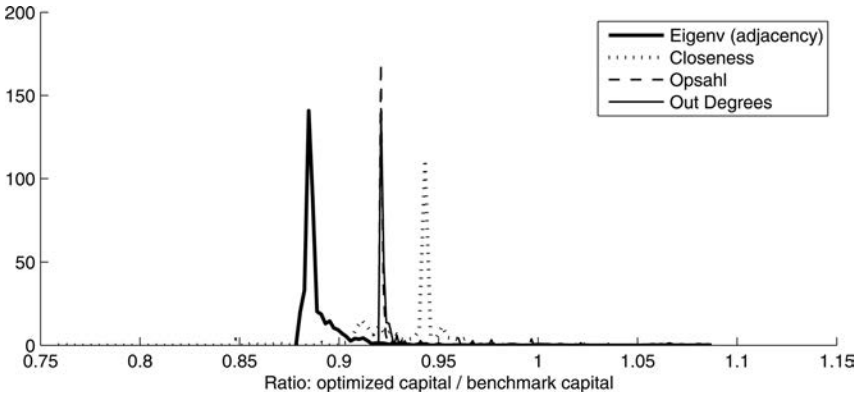


Notes: This figure zooms into a detail of unconditional densities. Densities for BCs smaller than €100 billion are almost identical.

precisely those catastrophic meltdowns where we would hope they would help. The benchmark is dominated by both reallocations at each of the three modes exhibited by the benchmark allocation. Second, the optimal adjacency eigenvector reallocation dominates closeness, although to a lesser extent than the savings from the benchmark allocation. Our optimal capital rule, based on the adjacency eigenvector, shows the best performance in the area where the banking authority would like capital requirements to have teeth. Finally, all rules perform equally poorly for extreme BCs of greater than €780 billion. When the catastrophe is total, allocating an amount of capital that is too small does not make much difference. Almost the entire capital is used and plenty of banks fail.

At this point the question arises whether a capital reallocation combining two centrality measures might perform better than one based on a single measure. Indeed, it could not perform worse, by definition. However, figure 5 shows one of the problems with this logic. Although the two centrality measures perform differently in the end, and despite their low correlation compared with other combinations of centrality measures, the way in which they reshape the loss tail in

Figure 6. Relative Changes of Required Capital for Different Capital Allocations



Notes: The horizontal axis is capital under the optimal capital allocations (on the various centrality measures) divided by capital in the VaR-based benchmark case. The maximum is truncated at the 99.5 percent quantiles.

figure 5 is rather similar; in a sense, there is a lack of "orthogonality" in their impact on the loss distribution. As a consequence, the resulting optimum from the combined allocation rule leads only to a 0.2 percent improvement in expected BCs. We also combined other centrality measures and never observed an improvement; all optimal choices were boundary solutions that put full weight on only one of the two centrality measures.

Finally, figure 6 shows, under various capital allocations, bank-individual ratios of centrality-based capital divided by VaR-based benchmark capital. The first observation for all of the measures is that ratios involve a cut to the capital requirement for the vast majority of banks, and the cut is highly concentrated at the same amount within the centrality measure. Each centrality measure cuts a different amount for the majority of the banks, except that Opsahl and out degree have very similar effects in the distribution of their capital requirements. The adjacency eigenvector cuts most drastically, by 12 percent of benchmark capital, and closeness is least drastic, at a 5 percent decrease for the vast majority of banks.

To conclude, we infer for each allocation that the capital reallocation is a comparably "mild" modification of the benchmark case for almost all of the banks because the extra capital allocated to some banks is not excessive. Another intuitive inference is that the other centrality measures might mis-reallocate capital. For example, let's say that benchmark capital for a bank represents 8 percent of the total assets. Forcing this bank to hold thirteen times more capital under the new allocation rule would mean it would have to hold more capital than total assets. Due to this misallocation likelihood, we infer that more constraints should be set in order to achieve better-performing allocations using centrality measures. We leave this extra mile for future research. Clearly, our general approach to capital reallocation is focused on a few particular banks for each of the centrality measures, simply because the measures focus on them. Beyond that, we cannot say much without revealing confidential information about individual banks.

For most of our centrality-based capital reallocations, there is a reduction of the expected BCs in the whole system, at least over a range of capital redistributed. In the allocations we examined most closely, these new requirements function on the same principle of shifting capital away from those banks that were presumably small and had little effect on contagion towards a few banks that had a large effect. The shift has the outcome one might expect: more banks are likely to fail in the fundamental defaults phase of our experiment, even in those instances where total costs due to bankruptcy do not increase during this phase. The less expected outcome is that even in the post-contagion phase, more banks fail under the capital reallocation. However, failed banks have a lower systemic cost in terms of bankruptcy, on average, than those banks that are saved through the reallocation. Under some circumstances, this is true even in the pre-contagion phase of defaults. Our two most effective reallocations, based on the adjacency eigenvector and closeness, give considerable savings in terms of total bankruptcy costs: 14.6 percent and 10.7 percent, respectively. The reallocations based solely on these measures perform just about as well as when the capital requirement is based on a combination of both.

7. Conclusion

In this paper we present a tractable framework that allows us to analyze the impact of different capital allocations on the financial stability of large banking systems. Furthermore, we attempt to provide some empirical evidence of the usefulness of network-based centrality measures. Combining simulation techniques with confidential bilateral lending data, we test our framework for different capital reallocations. Our aim is twofold: first, to provide regulators and policymakers with a stylized framework to assess capital for systemically important financial institutions; second, to give a new direction to future research in the field of financial stability using network analysis.

Our main results show that there are certain capital allocations that improve financial stability, as defined in this paper. Focusing on the system as a whole and defining capital allocations based on network metrics produces results that outperform the benchmark capital allocation which is based solely on the portfolio risk of individual banks. Our findings come as no surprise when considering a stylized contagion algorithm. The improvement in our capital allocations comes from the fact that they take into account the "big picture" of the entire system where interconnectedness and centrality play a major role in triggering and amplifying contagious defaults. As for the best network measure, we find that the capital allocation based on the adjacency eigenvector dominates any other centrality measure tested. These results strengthen the claim that systemic capital requirements should depend also on interconnectedness measures that take into account not only individual bank centrality but also the importance of their neighbors. In the optimal case, by reallocating 12 percent of capital based on eigenvector centrality, expected system losses (measured by expected bankruptcy costs) decrease by almost 15 percent from the baseline case.

As shown by Löffler and Raupach (2013), market-based systemic risk measures can be unreliable when they assign capital surcharges for systemically important institutions (as can other alternatives such as the systemic risk tax proposed by Acharya et al. 2012). What we propose in this paper is a novel tractable framework to improve system stability based on network and balance sheet measures. Our study complements the methodology proposed by Gauthier, Lehar, and Souissi (2012). As in that paper, we take into account the fact that market data for all financial intermediaries does not exist when dealing with large financial systems. Instead we propose a method that relies mainly on the information extracted from a central credit register.

We are not providing further details on how capital reallocation in the system could be implemented by policymakers. This aspect is complex, and the practical application involves legal and political issues. Further, we assume the network structure to be exogenous. In reality, banks will surely react to any capital requirement that is based on measurable characteristics by adjusting the characteristics. Such considerations are beyond the scope of the paper. Future research is needed to measure the determinants of endogenous network formation in order to make a more precise statement about the effects of a capital regulation as suggested in this paper.

Further future research could go in several directions. For example, bailout rules used for decisions on aid for banks that have suffered critical losses could be based on information gained from centrality measures. How this bailout mechanism would be funded and the insurance premium assessed to each bank are central to this line of research. Finally, the method can be extended by including information on other systemically important institutions (e.g., insurance companies or shadow banking institutions), although further reporting requirements for those institutions would be necessary.

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Discussion of "Centrality-Based Capital Allocations"*

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1. Introduction

Since the global financial crisis of 2007–9, a growing literature has focused on whether the complex web of interactions within the financial system can function as a mechanism for the propagation and amplification of shocks. This body of work, which for the most part models the interdependencies between different financial institutions by the means of a network, studies how stress at a few institutions can spread to others via interbank linkages, leading to system-wide crises.

Even though motivated by recent events, the financial networks literature has mostly focused on theoretical (and highly stylized) models of interbank contagion. In fact, aside from a few notable exceptions, there has been little work to document the detailed structures of real-world interbank networks and empirically assess the importance of different contagion channels emphasized by this literature.

The recent work by Alter, Craig, and Raupach (in this issue) belongs to the small set of papers that try to fill this important void. The paper relies on a rich data set of credit exposures in the German banking system to recover the detailed patterns of interbank linkages. More importantly, however, by building on a variant of the contagion model of Eisenberg and Noe (2001) and utilizing the interbank network information, it explores whether certain network-based capital reallocation policies—i.e., policies that determine each

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bank's capital requirements as a function of the bank's location in the network, while keeping the total capital in the system constant—can increase financial stability. The main results of the paper suggest that capital reallocation rules that are based on the financial institutions' so-called eigenvector centralities can reduce the extent of contagious defaults in a meaningful way and, hence, enhance the overall stability of the system.

2. Some Key Challenges

As mentioned above, the paper by Alter, Craig, and Raupach is part of the literature whose main aim is to provide a quantitative assessment of regulatory policies that are based on the intricate details of the financial network. In what follows, I will try to outline what I believe are some of the key challenges that such quantitative studies face in employing network-based tools in devising regulatory policies.

2.1 Endogeneity of Financial Networks

First and foremost, it is important to keep in mind that financial institutions enter into contracts with one another voluntarily. This means that financial interlinkages, and hence the structure of the resulting networks, are themselves equilibrium objects that are determined endogenously. As a result, network-based interventions that do not treat the network structure as part of the equilibrium are subject to the Lucas critique: the introduction of such policies may affect the banks' lending and borrowing incentives and, hence, alter the underlying network of financial interlinkages.

Thus, a proper assessment of the implications of network-based policies (such as the capital reallocation policies studies by Alter, Craig, and Raupach) needs to be coupled with a theory of network formation that takes the lending and borrowing incentives of the banks into account. Some recent papers, such as Zawadowski (2013), Acemoglu, Ozdaglar, and Tahbaz-Salehi (2014), Babus (2014), Erol and Vohra (2014), and Farboodi (2014) have taken preliminary steps towards understanding how financial networks are formed. However, developing frameworks that can serve as the basis for quantitative evaluations of network-based regulatory policies requires further progress in this direction.

2.2 Network Centralities

The paper's analysis relies on two key ingredients: (i) a structural model of interbank contagion that determines how shocks to a given financial institution propagate over the network of financial liabilities; and (ii) a host of different centrality measures (such as eigenvector centrality, Opsahl centrality, etc.) that capture the relative importance of different banks in the financial network. These two ingredients, however, may be inconsistent with one another, in the sense that the structural model of interbank contagion may point to a notion of systemic importance that is different from the off-the-shelf measures of network centrality used in the paper. Such a possibility means that the choice of network centrality measures (and, hence, the policies that are based on such measures) should be informed by the underlying model of microeconomic spillovers between the banks.

To demonstrate the importance of micro-interactions in determining the relevant notion of systemic importance, it is useful to consider a simple model in which spillover effects between different institutions are linear. In particular, suppose that

$$L_i = \sum_{j=1}^{n} \pi_{ji} L_j + L_i^{\text{fund}}, \tag{1}$$

where, following the paper's notation, L_i^{fund} denotes bank i's "fundamental" losses on loans to the real economy, L_i denotes its total losses, and $\pi_{ji} \geq 0$ captures the extent to which losses to a bank j spill over to bank i. For simplicity, also assume that the column sums of the interaction matrix $\pi = [\pi_{ji}]$ are equal to $\alpha < 1$. Denoting the total losses in the economy by $L^{\text{agg}} = \sum_{i=1}^{n} L_i$, one can show that

$$\frac{\partial L^{\text{agg}}}{\partial L_i^{\text{fund}}} = v_i,$$

where v_i is the *eigenvector centrality* of bank i, defined as the i-th element of the top (left) eigenvector of $\pi' + \frac{(1-\alpha)}{n}\mathbf{1}\mathbf{1}'$, with $\mathbf{1}$ denoting the vector of all ones.[1] This simple result shows that when interbank

[1] For a detailed derivation of this result, see Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015a).

interactions are linear, banks with higher eigenvector centralities are indeed the more systemically important institutions: negative shocks to the real assets of such banks would lead to larger increases in system-wide losses.

Such a result, however, may no longer hold if interbank spillover effects are non-linear. To see this, consider the following variant of the interaction model studied in the paper,

$$L_i = \min \left\{ l_i, \max \left\{ \sum_{j=1}^{n} \pi_{ji} L_j + L_i^{\text{fund}} - k_i, 0 \right\} \right\}, \qquad (2)$$

where l_i denotes bank i's total interbank liabilities and k_i is the capital held by the bank. Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015b) show that if interbank spillovers are governed by (2), the proper notion of network centrality is indeed distinct from eigenvector centrality: shocks to banks with identical sizes and eigenvector centralities may still have dramatically different effects on the extent of contagion.

The stylized examples above highlight that network statistics that are meant to serve as the basis for network-based capital reallocation policies should not be divorced from the structural model of interbank contagion. Rather, the design of such policies should be informed by the underlying microeconomic interactions between banks.

2.3 Equilibrium Multiplicity

My final comment concerns the fact that many models of contagion over financial networks exhibit multiple equilibria. For example, in the model used by Alter, Craig, and Raupach, the solution concept is a collection of mutually consistent repayments on interbank loans, called a clearing vector. The key observation here is that when bankruptcy costs are large enough, the clearing vector of a given financial network may not be unique. To address this issue, the paper selects the clearing vector for which the number of bank defaults is minimized. This is a perfectly reasonable exercise in equilibrium selection in the presence of multiplicity, as it would lead to the efficient outcome among all possible equilibria. Yet, at the same time, it also presents a challenge for policies that are based on identifying systemically important financial institutions in the network: the set of systemically important financial institutions and, hence, the optimal capital reallocation rules, may change significantly depending on the equilibrium selected.

To see this more concretely in the context of the model used in the paper, consider a stylized financial network consisting of two fully connected components of sizes m and n, where $m < n$. Also suppose that banks in each component have no financial liabilities to banks in the other component. Given the complete symmetry between banks within a component, it is easy to see that, under the best equilibrium, banks in the smaller component are more systemically important: a relatively small shock to one such bank can lead to the default of all m banks in that component, whereas an equally sized shock can be absorbed by banks' excess capital if it hits a bank in the larger component. This result, however, is no longer true under the worst equilibrium, in which bank failures and contagion can happen simply due to coordination failures and self-fulfilling expectations. In particular, in the least efficient equilibrium, a shock to a bank in the larger component would lead to $n > m$ defaults, implying that banks in the larger component are more systemically important.

This simple example highlights that quantitative evaluation of network-based regulatory policies (such as the ones advocated in the paper) should take the possibility of equilibrium multiplicity into account. It is not always the case that policies that are optimized for a certain equilibrium would perform equally well under the model's alternative equilibria.

3. Concluding Remarks

In summary, the paper by Alter, Craig, and Raupach in this issue provides a comparison of different network-based capital reallocation rules that are aimed at enhancing financial stability. It obtains a number of interesting results, in particular, on the quantitative relevance of capital reallocation rules based on financial institutions' eigenvector centralities. While, in my opinion, a thorough assessment of such policies requires a more comprehensive approach than the one pursued in the current paper, I believe that the paper takes a first and important step in the right direction.

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Multi-Polar Regulation

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The financial crisis has brought about a fundamental rethink of both the source and scale of systemic risk in the financial system and the regulatory framework needed to guard against them. The papers by Alter, Craig, and Raupach (this issue) and Kharroubi (this issue) speak to some of the risks and the regulatory response that might be most appropriate to mitigate them. But underlying both is a more fundamental question about the emerging framework for regulatory policy—multi-polar regulation. This commentary considers the impact and cumulative consequences of multiple regulatory constraints on banks' asset allocation. Using a simple framework, these effects are shown to be complex and interconnected. The impact of this regime shift, on analytical models and real-world behavior, remains largely uncharted territory. This defines a whole new, and exciting, research frontier.

JEL Codes: G00, G01, G02, G28, G18, G12, E50, E60, E61.

The financial crisis has brought about a fundamental rethink of both the source and scale of systemic risk in the financial system and the regulatory framework needed to guard against these risks. The papers by Alter, Craig, and Raupauch (this issue) and Kharroubi (this issue) speak to different types of systemic risk and the regulatory response that might be most appropriate to mitigate them.

The first paper discusses how best to calibrate the new systemic capital surcharges that will be applied to the world's largest, most complex banking organizations, using empirically calibrated network theory. The second discusses, in a theoretic setting, the externalities associated with inadequate holdings of private-sector liquid assets. Both are valuable additions to what is a burgeoning literature on the appropriate setting of, respectively, capital and liquidity regulation (for example, Admati and Hellwig 2013).

Yet underlying both is a more fundamental question about the emerging framework for regulatory policy. Post-crisis, what we have seen is much more than just a recalibration of existing regulatory tools. Rather, we have witnessed a regulatory regime shift from what might be described as *uni-polar* regulation, centered around risk-based measures of capital adequacy, to *multi-polar* regulation with multiple regulatory constraints at play.

I want to discuss the microeconomic rationale for such a multi-polar regulatory approach, before considering some of the behavioral questions it poses, both to policymakers and academics.

1. The Benefits of Multi-Polar Regulation

It is not difficult to see why regulation has moved in a multi-polar direction. The crisis brought home the real-world significance, and quantitative importance, of a number of frictions or externalities in the financial system. Many of these externalities had been identified prior to the crisis, both by academics and policymakers (for example, Brunnermeier et al. 2009). But experience during the Great Moderation, when both the economy and the financial system experienced remarkable tranquility, called into question their real-world significance. That meant these frictions, and their macroeconomic implications, did not attract widespread attention among either academics or policymakers.

It was well known pre-crisis that financial market liquidity has many of the properties of a public good: its collective benefit in ensuring the smooth functioning of financial markets outweighs the individual benefits from its provision (Cifuentes, Ferrucci, and Shin 2005, Haldane 2009). Its public-good nature gives rise to the possibility of liquidity being underprovided by the market when left to its own devices, particularly at times of crisis. There is a liquidity externality. That externality was exposed during the financial crisis, which generated an acute, widespread, and lengthy liquidity squeeze (Brunnermeier 2009).

There may also be externalities which operate on the assets side of banks' balance sheets. For example, the absence of funding due to a liquidity squeeze may prompt asset fire sales by banks and other financial institutions, exacerbating illiquidity pressures in financial markets in a procyclical loop (Brunnermeier and Pedersen 2009, Gai et al. 2013). Or it may prompt the truncation of credit provision by banks, causing a credit crunch which damages the wider economy in a procyclical loop (Aikman et al. 2014). Both of these negative externalities were in evidence during the crisis.

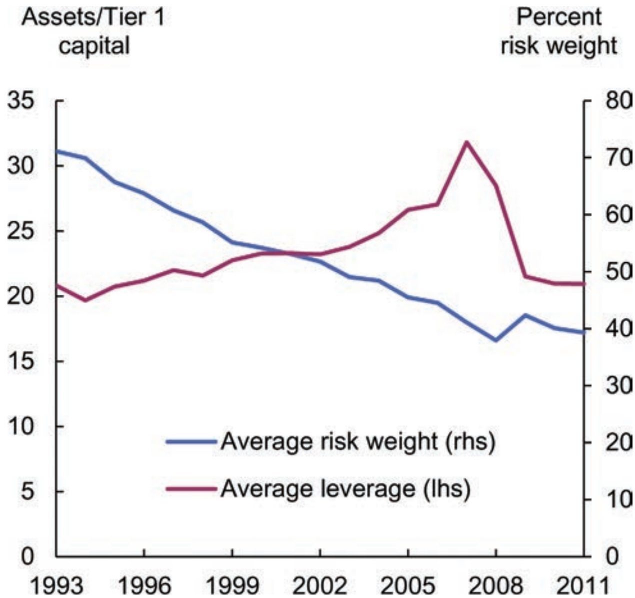
These procyclical loops, or negative externalities, in financial behavior are not confined to crises. For example, credit provision may also be procyclical during the upswing, generating a credit boom. This might arise, for example, because banks optimize over relative, rather than absolute, returns, causing herding in credit provision (Aikman et al. 2014). Or it may arise from banks suffering from collective disaster myopia (Gennaioli, Shleifer, and Vishny 2015). The pre-crisis credit boom appears to have been driven by both such financial frictions.

Highly interconnected systems are also often subject to externalities, specifically network externalities (Acemoglu, Ozdaglar, and Tahbaz-Salehi 2015). In financial networks, these might arise from default or margins cascades due to counterparty exposures (Gai, Haldane, and Kapadia 2011). These network cascades can result in even modestly sized shocks rippling through the system, in an amplifying wave thus having much larger, systemic implications (Haldane and May 2011). These network cascades, and associated tipping points in financial market dynamics, were a common feature during the financial crisis.

Finally, there are market distortions which arise as a result of policy interventions themselves. For example, intervention to support the (liquidity or capital) of a bank provides incentives to increase risk taking (Farhi and Tirole 2012). This moral hazard channel was particularly important, pre-crisis, for banks and other institutions deemed "too big to fail" (Alfonso, Santos, and Traina 2014). It generated private incentives for banks to inflate their balance sheets beyond levels that were optimal from a societal perspective (Haldane 2013).

A more subtle form of regulatory-induced market distortion arises from banks using their own internal models to generate risk weights in order to meet risk-weighted capital standards. This provides incentives to "game" these risk weights—to adjust them downwards to lower the regulatory hurdle (Haldane and Madouros 2012). For example, despite the rapid rise in pre-crisis leverage and risk

Figure 1. Average Risk Weights Since 1996



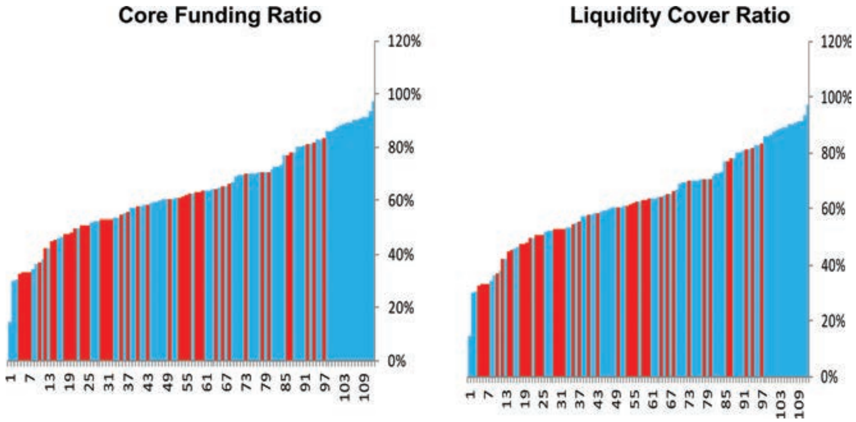
Source: *The Banker* and Bank of England calculations.

taking, measured risk weights fell secularly among the world's largest banks (figure 1).

The policy response to these various distortions within the financial system has been to apply the regulatory equivalent of the Tinbergen rule (Tinbergen 1952). This is to require that there be at least as many regulatory instruments as there are financial frictions. At least in some theoretical models, this approach is a sensible one. For example, something akin to the Tinbergen rule often emerges from modern dynamic stochastic general equilibrium models with financial frictions (for example, Smets 2014).

Prior to the financial crisis, there was no internationally agreed regime for liquidity regulation. Now there is, with a core funding ratio (the so-called net stable funding ratio) and a maturity mismatch ratio (the so-called liquidity coverage ratio) about to be implemented at an international level. This is an externality-based regulatory requirement, which recognizes both the public-good

Figure 2. Core Funding and Liquidity Cover Ratios



Source: Capital IQ, SNL Financial, published accounts, Laeven and Valencia (2010) and Bank of England calculations.
Notes: The classification of bank failure is based on Laeven and Valencia (2010), updated to reflect failure or government intervention since August 2009. Total assets have been adjusted on a best-efforts basis to achieve comparability between institutions reporting under U.S. GAAP and IFRS.

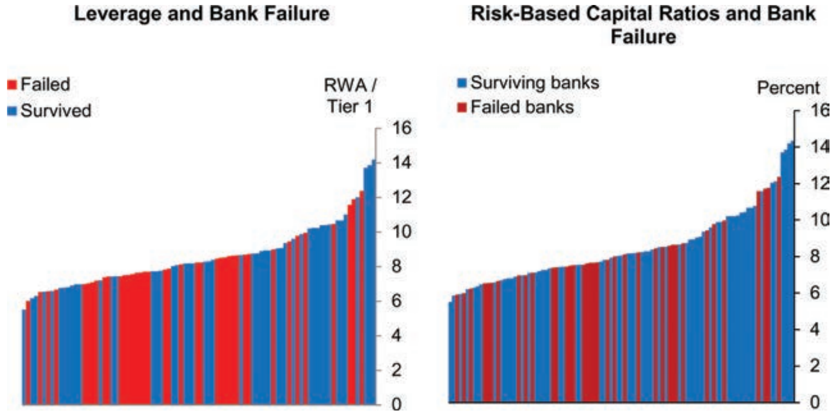
benefits of private liquid asset holdings and the moral hazard costs associated with public liquidity provision.

Figure 2 plots the core funding ratio and the liquidity mismatch ratio for a selection of the world's largest banks in the pre-crisis period. There is a strong correlation between these measures and the subsequent incidence of bank failure. In other words, had either regulatory measure been in place pre-crisis, it is plausible to think incidences of failure or stress among the world's largest financial firms would have been somewhat lower; the liquidity externality would have been to some extent internalized.

A second example of a new regulatory constraint, agreed at an international level, is the leverage ratio. Leverage ratios, too, are set to be implemented in the next few years. The motivation for introducing them was also externality based: as a safeguard against the funding liquidity risk associated with rapid balance sheet expansion, and as a bulwark against the gaming of risk weights (Haldane 2013).

Figure 3 looks at the leverage ratios of the world's largest banks in the pre-crisis period. As with liquidity ratios, there is a strong

Figure 3. Leverage and Risk-Based Capital



Source: Capital IQ, SNL Financial, published accounts, Laeven and Valencia (2010) and Bank of England calculations.
Notes: The classification of bank failure is based on Laeven and Valencia (2010), updated to reflect failure or government intervention since August 2009. Total assets have been adjusted on a best-efforts basis to achieve comparability between institutions reporting under U.S. GAAP and IFRS.

association between high leverage and subsequent bank failure (Haldane and Madouros 2012). Or, put differently, had leverage constraints been in place pre-crisis, it is plausible to think there would have been fewer failures among the world's largest financial firms during the crisis.

A third new regulatory constraint is the so-called systemic capital surcharge. In the future, this will be levied on the world's largest, most complex, most interconnected banking institutions. It has been proposed that these surcharges apply to each of the new solvency standards for banks—risk-based capital requirements (Basel Committee on Banking Supervision 2013), leverage requirements (Bank of England 2014), and total loss-absorbing capacity (TLAC) requirements (Financial Stability Board 2014a). The surcharges have been accompanied by a strengthening of resolution regimes, particularly for large, complex, cross-border institutions (Financial Stability Board 2014b).

These new requirements are intended to reduce the probability of failure among the world's largest banks and/or to reduce the systemic impact of their failure. In other words, they are intended to reduce the network externalities, such as default cascades and asset fire sales, otherwise associated with large bank failure. In that process, they should also reduce the moral hazard otherwise associated with institutions which are perceived as “too big to fail” (Haldane 2013).

A final, new set of regulatory requirements aims to lean against the externalities associated with procyclical credit booms and busts. Specifically, the capital conservation and countercyclical capital buffers have been agreed internationally as a macroprudential policy tool (Basel Committee on Banking Supervision 2009). The latter raises banks’ capital requirements in upswings to curb credit booms, and lowers them during downswings, to smooth out procyclical swings in credit.

In short, all of the elements of the new international regulatory framework can be seen as a response to a theoretically well-defined, and quantitatively important, set of financial externalities. Regulation has adhered to Tinbergen’s rule; it has become multi-polar.

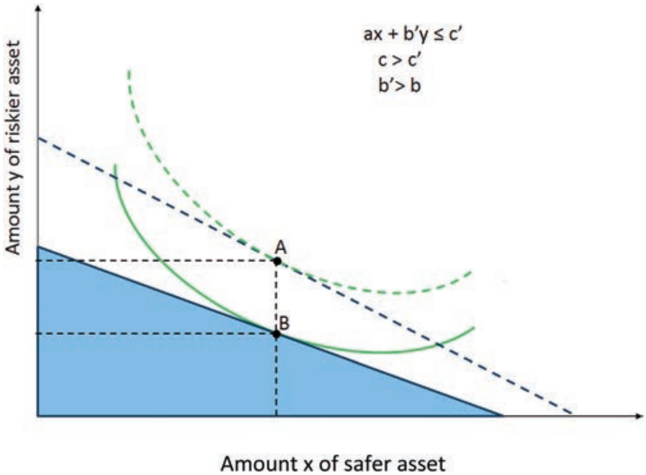
2. The Costs of Multi-Polar Regulation

Abiding by the Tinbergen rule is optimal in a world where both the financial system and the impact of regulation on it is reasonably well understood. In practice, there is considerable uncertainty, as distinct from risk, about the impact of these new regulatory constraints on banks’ behavior and business models, both individually and in combination.

It is possible to begin to explore the behavioral impact of these multiple regulatory constraints using a very simple, stylized model of banks’ decision making (adapted from Duffie 2013). In particular, imagine a bank making a portfolio decision between risky assets of amount x and safer assets of amount y (where $x + y = 1$). Risky and safe assets attract risk weights a and b to meet a risk-weighted capital requirement c (where $ax + by < c$).

For simplicity, it is assumed that a bank cannot raise extra equity capital to meet its requirements. Instead, when faced with regulatory constraints, it is required to adjust its asset portfolio, either

Figure 4. Higher Minimum Requirements



in aggregate or in the safe and risky assets mix. It is assumed that, at least in the short run, the Modigliani/Miller theorem is violated.[1]

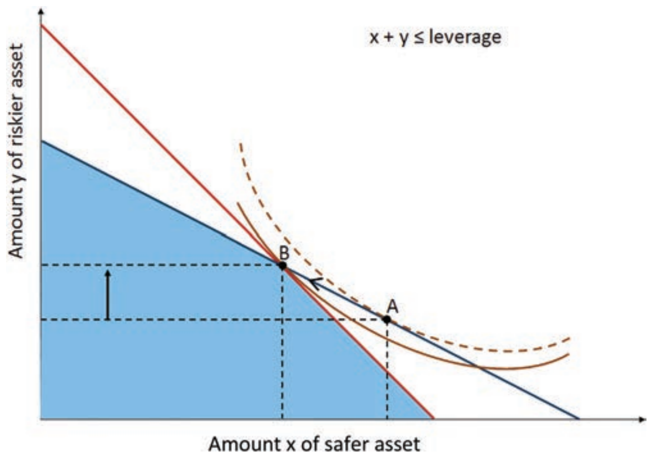
Imagine now that a new regulatory regime is introduced which both raises banks' average capital requirements ($c' > c$) and raises risk weights on banks' riskier assets ($b' > b$). This is, in effect, Basel III. The impact of this on banks' portfolio choice is shown in figure 4. Banks' asset opportunity set shifts inwards (reflecting higher capital requirements) and tilts (reflecting higher risk weights on riskier assets); it is now shown by the shaded area.

For given bank risk preferences, shown by the indifference curve in figure 4, banks' optimal portfolio allocation shifts from point A to point B. The introduction of Basel III has two effects: banks' overall asset portfolio shrinks and, within this, there is a shift in asset mix away from risky and towards safer assets.

Now imagine adding a second regulatory leverage constraint to the mix—a leverage constraint, l (where $x + y < l$). This differs from the risk-weighted capital constraint because safe and risky

[1]Clearly, if the Modigliani-Miller theorem applied, it is not clear that a bank would wish to adjust its assets rather than its liabilities (Admati and Hellwig 2013).

Figure 5. Adding Leverage Ratios



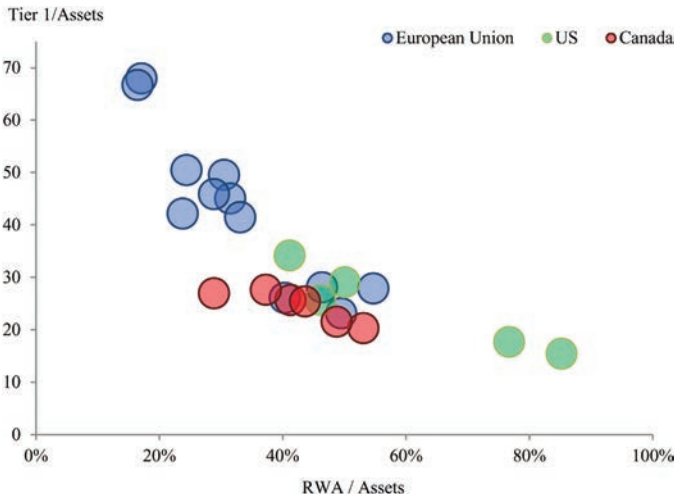
assets are now equally weighted. This leverage requirement constrains banks' asset opportunity set further, as shown by the shaded areas in figure 5.

The impact of leverage constraints on banks' portfolio behavior depends crucially on their risk preferences and, hence, business model. For banks with a high degree of risk tolerance, whose optimal portfolio allocation lies to the left of point B, the leverage constraint is slack; it has no impact on their optimal asset allocation.

For banks with a low risk tolerance, however, the impact can be more significant. For example, for a bank whose initial portfolio allocation is given by point A in figure 5, the effect of a leverage constraint is to cause them to shift to point B. This is associated not only with a smaller aggregate balance sheet but also with a shift from safe towards riskier assets—there is "risk shifting."

There is evidence, pre-crisis, of such risk shifting having been important. In particular, U.S. and Canadian banks that were subject to a leverage ratio requirement tended on average to hold assets with a higher average risk weight than European banks not subject to the leverage ratio (figure 6). More generally, the relative importance of risk-based capital and leverage requirements, and thus how it affects banks' portfolio allocation, will depend crucially on banks' risk preferences and business models.

Figure 6. Leverage Ratios and Risk Taking



Now consider adding a third regulatory restriction to the equation, a liquidity ratio, n, proportional to banks' assets $(d+e(x+y) > n)$ where d is a fixed liquid asset requirement and e defines its relationship to total balance sheet size. This further shrinks banks' opportunity set, to the shaded area shown in figure 7. Its impact on banks' portfolio behavior will again depend on their risk preferences. In the example in figure 7, the optimal portfolio allocation shifts from point A to point B.

This new equilibrium is associated not only with a smaller aggregate balance sheet but also with a portfolio switch towards safe assets—there is not "risk shifting" but instead "safety shifting." In other words, liquidity and leverage requirements may act in opposite directions in their impact on banks' risk-taking incentives, with the relative importance depending on banks' business model.

As a final example, consider the effects of dynamic, countercyclical adjustments in banks' capital requirements. In particular, imagine a credit boom which results in regulators raising banks' countercyclical capital buffers, in line with the new macroprudential framework of Basel III. Taken in isolation, this would cause banks' asset opportunity set to shift inwards and their asset allocation to move from point A to point B in figure 8.

Figure 7. Adding Liquidity Ratios

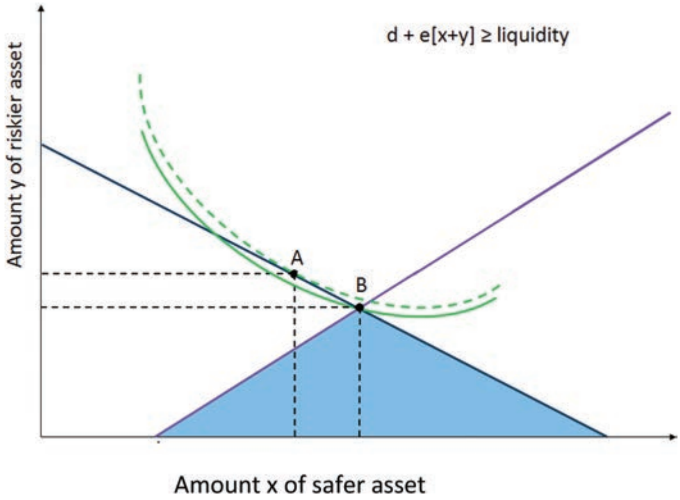
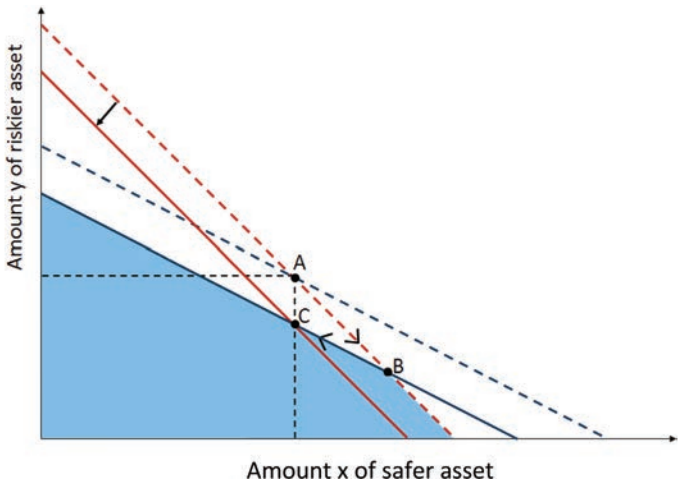


Figure 8. Dynamic Adjustment in Capital and Leverage



This is associated with a contraction in banks' balance sheets, but also a significant shift in banks' portfolio allocation towards safer assets—"safety shifting." While the former might be desirable, the latter is an unintended consequence of the interplay between risk-based capital and leverage requirements, the relative importance of which now switches.

If instead banks' capital and leverage requirements were adjusted proportionately, banks would move their asset allocation from point A to point C as countercyclical requirements are tightened. At point C, banks' balance sheets are constrained, but the mix of risky and safe assets is now broadly unchanged.

The avoidance of unintended changes in asset mix is one reason why some regulators have determined that countercyclical regulatory policy should be associated with proportionate movements in banks' leverage and risk-based requirements. For example, in 2014 the Bank of England's Financial Policy Committee (FPC) set out how it intended to make operational the Basel countercyclical capital buffer.[2] This will involve proportional movements in banks' leverage and risk-based capital requirements over the cycle.

The aim in setting out this analysis is not to provide a comprehensive account of how different regulatory constraints will affect banks' behavior, statically or dynamically. Rather, it is to show that these effects are complex and interconnected. While all of the new constraints are likely to constrain banks' asset opportunity set to some degree, their precise impact on asset allocation is likely to differ according to asset mix and risk preferences. On occasions, new regulatory constraints may have conflicting impacts on banks' portfolio choices.

3. Future Research and Policy Questions

What implications does this carry for future policy and research? On the research front, few macroeconomic models at present are well equipped to deal with the multiple financial frictions which played out during the crisis. This limits their usefulness for understanding the effects of multiple regulatory constraints on banks' behavior, much less the interconnections between these regulatory instruments.

This underscores the importance of continuing to develop coherent, optimizing models containing both banks and financial frictions.

[2] See Financial Policy Committee (2014).

These would enable the effects of multiple, interacting regulatory instruments to be evaluated. There has recently been some progress in that direction, with many of the frictions discussed earlier being examined individually. But it is early days in nesting these frictions in a common framework.

For policymakers, this analysis underlines the importance of carrying out a comprehensive, system-wide evaluation of the impact of new regulatory constraints on the topology of the financial system. For understandable reasons, reform has proceeded on a friction-by-friction, regulatory rule-by-rule basis. The system-wide impact of these multiple constraints now needs to be assessed.

Applying the Tinbergen rule has resulted in a considerably more complex regulatory architecture than any seen previously. This complexity is an understandable response to new risks. It may not, however, always be the ideal response to uncertainties resulting from the crisis and the regulatory response to it. Alternative, simpler regulatory approaches might be more robust to such uncertainty (Hansen and Sargent 2007).

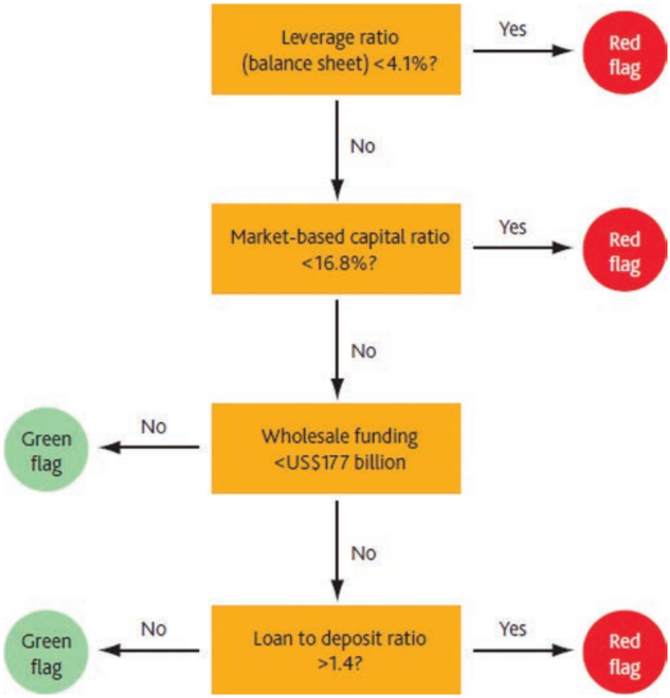
One such approach would to evaluate simple regulatory decision rules when assessing banks' vulnerability. One approach, which has been found valuable in such fields as medicine and law, is to use so-called fast-and-frugal trees (Gigerenzer, Hertwig, and Pachur 2011, Aikman et al. 2014). These are very simple decision trees for guiding regulatory intervention when there is considerable uncertainty about the true signal.

As one example, figure 9 shows a simple fast-and-frugal tree for assessing bank vulnerability. This involves a mix of solvency and liquidity metrics, calibrated to past experience. But these metrics are combined in a simple regulatory decision schema. While not fail safe, these simple heuristic approaches might be an effective regulatory cross-check on complex, discretionary approaches to evaluating bank risk.

4. Conclusion

Since the crisis, regulation has become multi-polar. But the impact of this regime shift on analytical models and real-world behavior remains largely uncharted territory. This defines a whole new, and exciting, research frontier.

Figure 9. Fast-and-Frugal Tree for Assessing Bank Vulnerability



Source: Aikman et al. (2014).

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