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Autonomously Interacting Banks☆

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Abstract

The great financial turmoil that started 2007 has brought bank regulation back into the political debate. There is talk about imposing new regulations on banks and other financial intermediaries. Yet, we are not convinced that it is completely understood how the existing regulation affects systemic stability, let alone what the effect of new proposed rules would be.

In order to better understand these issues, we study the interaction of heterogeneous financial agents in a market that features several properties we believe to be realistic. Our agents develop heterogeneous views about the correct valuation of a risky asset. Some agents (banks) operate with substantial leverage and thus bankruptcy is a possibility. Agents may engage in fire sales, either because they face real financial trouble, or because they are forced to by regulation. Moreover, through their trading activities, agents exert externalities on each other's balance sheets due to mark-to-market. Through this mechanism, fire sales can lead to contagion, and one failing bank can cause several more to follow suit.

Keywords: bank regulation, BIS capital adequacy requirements, Basel II, Basel III, leverage ratio, default rate, systemic stability, fire sales, contagion, autonomous agents, simulation.

JEL classification: C63, G21, G28.

1. Introduction

The great turmoil that financial markets and institutions have gone through since mid-2007 has brought bank regulation to the forefront of political and academic debate again. Various issues are being discussed, such as the role of hedge funds (Kambhu et al., 2007) and rating agencies (Calomiris, 2009b; White, 2010), the fragility of valuation models (Daníelsson, 2008), the effects of

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securitization (Keys et al., 2008; Hellwig, 2009) and deposit insurance (Calomiris, 2009a), excessive risk taking due to governance problems in banks (Kashyap et al., 2008), too much leverage in banks' balance sheets (Admati et al., 2011), loose monetary policy (Taylor, 2009), a global savings glut (Bernanke, 2005; Bernanke et al., 2011), and several more, including male dominance in finance (Walby, 2009). In the political arena, there seems to be wide agreement that "more regulation" is needed.[1] Among academics, the opinions are more diverse.

In this situation we would like to take a step back. We are not convinced that it is well understood how existing regulations affect the stability of the financial system. Thus, instead of topping the existing rules with new ones, we would like to first investigate what the old rules do.

To this avail, we greatly simplify our model of the real world. Our approach is to simulate the interaction of different kinds of agents in an artificial market. General equilibrium models with heterogeneous agents that exceed a certain complexity are impossible to solve formally, and very difficult to solve numerically. Thus, we will populate our artificial market not with fully optimizing agents, but with agents that follow simple, yet sensible rules of thumb. And instead of solving for a fixed point, we will simulate market prices by equating supply and demand in a trading book, whose outcome, together with new shocks, will generate new buy and sell orders in the next period.

Our simulations feature three types of agents, whom we call *commercial banks*, *shadow banks*, and *investment funds*, respectively, because they are subject to different restrictions and follow different strategies. Our agents live in a rather simple world. First of all, our market features only one risky asset — think of it as a diversified portfolio of assets that feature some idiosyncratic as well as market risk. Secondly, in each period our agents make just one decision, namely how to invest their funds.

Our agents are really caricatures of their real-life counterparts because they are so simple. Yet, we believe they are good caricatures in the sense that they behave in ways that we would expect a commercial bank, an shadow bank, or an investment fund to react. The advantage of using a stochastic simulation of rudimentary behavior rules rather than finding a general equilibrium in the usual sense is that this procedure allows us to consider much more diversity regarding agents and details of the environment. So, we simplify by making our agents simpler than their fully optimizing cousins whom we know from general equilibrium theory. This simplification allows us to consider more complicated environments

[1] A particularly vocal politician pushing in this direction is German Chancellor Angela Merkel: see for instance her speech at World Economic Forum in Davos, 2011 (`http://www.bundeskanzlerin.de/nn_700276/Content/DE/Rede/2011/01/2011-01-28-davos.html`), where she said: "Wir haben uns vorgenommen, dass wir im Finanzbereich jedes Produkt, jeden Akteur und jede Region auf der Welt einer Regulierung unterwerfen.", in English, "It is our intention to subject every product, every agent and every region in the world in the field of finance to regulation."

that could not be handled in a general equilibrium model of the traditional type. On balance, we believe this approach will provide more, or at least, alternative insights.

The interaction of simple, but diverse agents in an artificial market environment gives rise to considerable complexity. By changing parameters that capture either the composition of the population or various regulatory requirements, we can investigate through Monte Carlo simulations what the likely effects of a parameter is on particular outcomes, such as, for example, default rates or size distribution of banks.

In this paper, we focus on analyzing the systemic effect of different implementations of capital adequacy requirements. Our first focus is on the now traditional risk-weighted capital adequacy requirements in the spirit of the Basel-II accord. We study how such restrictions affect the profitability of financial intermediaries, their failure probabilities, and the likelihood of fire sales. If capital adequacy requirements increase or decrease fire sales, they also have an effect on the statistical properties of the market price of the risky asset, so we investigate that as well.

The second topic are unweighted capital adequacy requirements — so-called leverage ratio restrictions. This kind of regulation has recently become commonplace in the Basel-III accord. We study the effects of this regulation, on its own and in conjunction with Basel-II style requirements.

Third, we consider extending capital adequacy requirements to so far unregulated entities. The shadow banking industry — investment banks and hedge funds — is sometimes identified as being the catalyst of the financial crisis, because these entities are often large, run a substantial leverage, and are largely unregulated; hence the call to extend regulation to this segment as well. We study whether expanding the scope of regulation will enhance systemic stability. The answer is not obvious *a priori*, because extending regulation to as of yet unregulated shadow banks makes market participants behave more homogeneously, which could well exacerbate instability.

2. The Model

2.1. Methodology

When results from analytical models are hard (or impossible) to come by, simulation can be a promising way forward. While Monte Carlo simulations are a well-proven and useful technique in any quantitative economist's toolbox, agent-based simulations (ABS) are merely a special case. ABS typically models microscopic behavior and then investigates how this aggregates into macroscopic phenomena. Within financial economics, Kim and Markowitz (1989) used a simulation to show how simple mechanical portfolio readjustment strategies can trigger market crashes like the one in 1986. Later contributions like those by Kirman (1993) or Lux and Marchesi (2000) have demonstrated how volatility clustering can result in markets where heterogeneous agents individually change their behavior, while Gode and Sunder (1993) have shown that, to some degree, appropriate market structures can compensate for mistakes made by less informed market participants. More recently, an ever increasing range of models has been introduced that help to test and evaluate competing concepts and theories in order to understand the dynamics of economic decision making, and provide a diagnostic environment for “windtunnel testing” of frameworks and policies. Tesfatsion and Judd (2006) offer a broad introduction to the field as well as specialized presentations of applications to financial economics.

2.2. Agents, assets, and the fundamental price process

Our market is populated by three types of agents: commercial banks, shadow banks, and investment funds. The main thrust of the analysis focuses on the performance and stability of commercial banks, so we discuss them first. There is, of course, interaction between these three classes of agents, which means that an understanding of their behavioral types is crucial to understanding the performance and stability of the commercial banking sector.

Shadow banks and investment funds can be seen as variations of commercial banks. They do not act differently from a functional perspective, but we endow them with parameters that make them behave differently from a quantitative perspective. We discuss these variations below in Sections 2.8 and 2.9.

There are only two assets: a risky asset, and cash, which is risk-free. Cash earns no interest in our model, so the return rate on the risky asset should really be interpreted as the excess return, or risk premium, on the risk-free investment. Moreover, since there is only one risky asset, one should think of this as a diversified portfolio of individual risky investments.

The risky asset’s fundamental price follows a geometric random walk with normally distributed innovations and a drift. The drift captures the long-run expected size of the equity risk premium. More concretely, let f_t denote the log fundamental value of the risky asset,

$$f_{t+1} = f_t + \mu - \frac{\sigma^2}{2} + \eta_t, \qquad \text{where } \eta_t \sim N(0, \sigma_\eta^2). \tag{1}$$

f is a discrete version of a Brownian motion with an annual volatility of 5% and a drift of 2%.[2] We simulate 240 daily steps, which roughly approximates the number of working days in a year. Accordingly, $\sigma_\eta = 5\%/\sqrt{240}$, and $\mu = 2\%/240$.

[2]Recall that there is no return on cash, so the return on the risky asset is really a risk premium. Setting $\mu = 2\%$ thus means that we assume that the long-term expected risk premium is two percent. One could argue extensively about the appropriate choice here. Choosing a higher value for μ and also for σ_η is of course possible, but might require different calibrations in other parts of the model in order to achieve believable results; these do not differ in substance from the results we report.

2.3. *Market price, private signals, and modes of expectation formation*

Let p_t denote period t's log market price. This price can deviate from the fundamental value, as it is the result of the interaction of individual agents through the order book, see below. In each period, agents receive independent noisy signals about the fundamental value of the risky asset,

$$s_{i,t} = (f_t - p_t)\frac{1}{c} + \varrho\varepsilon_{i,t-1} + \varepsilon_{i,t}, \qquad \text{where } \varepsilon_{i,t} \sim N(0, \sigma_\varepsilon^2). \tag{2}$$

c is a parameter that describes how quickly agents expect the market price to converge to the fundamental value. The model is calibrated for one period to be equivalent to one working day, and we set $c = 60$, indicating that agents expect the market price to attain the fundamental value within one quarter of a year (sixty working days). The signal $s_{i,t}$ can be interpreted as the outcome of the research that a bank does. This research is not always accurate, but we assume that it contains some (imperfect) information. We set σ_ε such that the volatility of the signal is $5\%/\sqrt{240}$. Also, with $\varrho > 0$, agents have some inertia in the formation of their views about the future. The model is calibrated at a daily frequency, so we believe that yesterday's views may still influence today's views, even if new information becomes available. We set $\varrho = 0.25$ throughout, which we believe to be a low value. In any case, ϱ does have quantitative effects on the results, but does not change the qualitative findings.

Then the agent i expects the market price in the next period to be

$$E_i[p_{t+1}|s_{i,t}] = p_t + \mu + s_{i,t}. \tag{3}$$

Thus, there is a built-in reversion of the market price to the fundamental value. Deviations can occur, and are sometimes large, but the fundamental value is not meaningless, because agents interpret it as an attractor to the market price.

2.4. *Balance sheet structure and portfolio management*

The agents in our model have balance sheets with a very simple structure. There are just four items. On the asset side, there is one risky asset (R) and cash (C). The liability side consists of equity (E) and leverage (L). We control the amount of free equity at the beginning of the simulation with a parameter we call "free equity quota," and which is denoted with ϕ. We make simulations with ϕ taking values between 1% and 7%. On top of that, banks will have required equity based on capital adequacy regulation (more on that later). The rest is leverage. During the course of the simulation, the leverage ratio might change, depending on what happens to the asset side. If we were to simulate the behavior of banks over a longer horizon, we would model how the bank actively manages its liability side, by issuing new debt, buying back stock, or, if necessary, issuing new equity. In our short-run model, we ignore such considerations. Issuing debt or equity is not a decision that is done on a daily basis, so we let the liability side just develop passively. The initial conditions will matter a great deal, though.

The portfolio on the asset side, in contrast, is managed more actively. Based on their private signals (2) and the price change they expect (3), agents want to increase or decrease the share of the risky asset in their portfolio. On average, they invest 50% of their balance sheet in the risky asset and hold 50% in cash. In fact, the structure on the asset side can also be read as an indicator of the bank's exposure. Large "risky" positions are a sign that the bank is willing to take risks in order to earn extra profits and risk premia; a large "cash" position, on the other hand can also signal that the bank hedges its risk at the cost of not earning more than the safe return. This also justifies how banks can readjust up to several per cent of their assets over night. We chose a starting point of 50-50 so that banks are free to move in either direction.

From one period to the next, gains and losses will occur. Depending on the development of the market price that clears the order-book, and the various exposures of the individual banks, these gains and losses will be quite unequally distributed. Any gains or losses on the risky asset are translated into changes of equity. A bank is in distress if equity becomes negative. It will then start to sell the risky asset in order to satisfy its bond holders. The bank is bankrupt if equity is negative and no risky asset remains to be sold. In this case, the remaining cash goes to the debt holders and all activity of this bank ceases.

2.5. Order book

Agents adjust their asset side by placing buy and sell orders (the rules they use to do this will be explained a little later). An order consists of a pair of numbers, indicating the offered or required price, together with the maximum quantity the agent is willing to trade. There is no profit-making market maker in the model. Instead, the equilibrium price in a period is computed as the point at which the aggregate demand and supply schedules intersect. All ask prices below this market clearing price are satisfied, as are the bid prices that exceed the market clearing price.

Agents place orders either because they want or because they must. Voluntary trading is based on the agents' expectations. A buy order is placed at $E_i[p_{t+1}]$ minus a spread, and a sell order at $E_i[p_{t+1}]$ plus a spread. Order volumes are limited and depend on agent type; shadow banks can produce the highest turnover, commercial banks and pension funds the lowest. The not-so-voluntary case of trading occurs when a bank is insolvent, or regulation forces it to reduce its risk exposure; Section 2.6 discusses this in detail. Fire sales are always placed at $E_i[p_{t+1}]$ with no spread in order to increase the probability of execution.

The market price is the result of the mechanics of the order book, and can thus deviate from the fundamental value of the risky asset. The market price is really the result of the interaction of agents' orders, which themselves are the result of the individual signals the banks receive, and the current status of their balance sheets.

It is important, however, to realize that there is no explicit bilateral matching of trades. There are no OTC deals that could give rise to counter-party or settlement risk. Instead, all the interactions of agents take place in an anonymous fashion, through the central trading book. Of course, the orders that an agent places might affect the resulting equilibrium price, which, in turn, will affect the balance sheets of other agents. In such cases, agents exert some externalities on each other. But this interaction is only indirect through market prices. Thus, systemic failure in this model is never due to network effects, but can only be due to contagion via the valuation of assets according to market prices.

The market clearing mechanism harbours a potentially important source of risk for the agents. An agent can never be sure which of his trades will go through when placing them. Thus, it is possible that an agent needs several rounds of trading in order to achieve the desired the balance sheet structure. This problem becomes much more acute in periods when liquidity dries up.

2.6. Risk-weighted capital adequacy regulation

We model the risk-weighted capital adequacy regulation as introduced in the Basel-II accord as a constraint on the relation between equity and the amount of risky assets a bank holds. Equity must be at least βR, where β is a parameter that we set between 0% and 10%. βR is the required equity, i.e., the minimum amount of equity in the balance sheet that is required by the regulation. Any equity the bank holds in excess of the required amount is called free equity.

Consider a bank that has a 6% equity quota, $E/(C + R) = 6\%$, that holds 50% in the risky asset, $R/(C + R) = 50\%$, and that is subject to a risk-weighted capital adequacy regulation of $\beta = 8\%$. This bank satisfies the regulation, because its equity share (6%) exceeds the required equity share, $\beta R/(C + R) = 4\%$. Now, suppose the price of the risky asset drops by 10%. The bank experiences a loss of 5% of its balance sheet, all of which will be borne by the equity holders. Thus, equity is reduced from 6% to roughly 1% of the balance sheet.[3] Equity is still positive, so the bank is not bankrupt, but it now violates the required capital adequacy regulation.

This fact prompts the bank to adopt a new mode of operation. We assume that, in order to fulfill the regulation, the bank then adopts more aggressive tactics to sell the risky asset. This means two things: Firstly, even if the portfolio manager wanted to increase the share of risky asset (for instance, because he has received a good signal), he would not be allowed to do so. Secondly, any sell orders would be made without the usual spread for the ask price in order to increase the probability

[3] Let the size of the balance sheet before the crash be 100. After the crash, it is $C+(1-10\%)R = 95$. Thus, the share of the risky asset to the balance sheet is automatically reduced by the crash to 45/95, or 47%. Accordingly, the bank is now required to hold only 4.7% equity. Its equity after the crash, however, is only $6 - 5 = 1$, and its equity quota is therefore $1/95 = 1.05\%$, which is less than it is supposed to have.

that they are executed. We say that the bank engages in *fire sales*. Notice that fire sales exert a negative externality on the balance sheets of the other agents in the market. The lower ask prices tend to decrease the market price, which depresses the valuation of all agents' risky positions. Fire sales are thus capable of producing contagion.

Now, when comparing different levels of β, it is not convincing to assume that banks would simply add the equity that is required onto of their free equity quota that they are willing to hold when no requirements are set by the regulator. Suppose the bank willingly holds 6% equity, and we increase β from 0% to 8% (and thus effectively require the bank to hold a minimum of 4% of equity), it is not clear whether the bank would increase its equity at all, because even without regulation it holds more than the regulator requires. Thus, we might expect the bank to simply substitute free equity for required equity.

On the other hand, the bank might not want to hold only required amount of equity. Maybe, it wants to make sure that it has a little in excess of the requirement, knowing that any loss would immediately put it in a fire sale position in order to meet the regulator's demand.

To capture this, we introduce a further parameter. ϕ, the *free equity quota*, denotes the share of equity the bank keeps in excess of what the regulatory requirement. Moreover, if there is no regulation, it keeps an additional share of κ. We call this the *conditionally free equity quota*. The bank is willing to substitute the conditionally free equity if the regulator requires additional equity, but it will not substitute the free equity, ϕ. Thus, at the beginning of the simulation, the bank's equity share will be

$$\phi + \max\{\kappa, \beta/2\}. \tag{4}$$

If $\beta/2 < \kappa$, the regulatory equity requirement is not binding. In this case, some conditionally free equity will be transformed into required equity. Conditionally free equity is used up only if $\beta/2 > \kappa$. In this case, the bank starts the simulation with more equity as a result of the enhanced regulatory requirement.

2.7. *Leverage ratio capital adequacy regulation*

Unlike the risk-weighted requirement, the leverage ratio restriction requires a minimum amount of equity that is based on the size of the balance sheet and irrespective of the composition of the assets. The required equity is $\lambda(R + C)$. Accordingly, the bank's equity share at the beginning of the simulation is then

$$\phi + \max\{\kappa, \lambda, \beta/2\}. \tag{4*}$$

As in the previous case, a bank starts with an equity share of $\phi + \kappa$ in case the conditionally free equity exceeds the requirements of any of the regulations. If $\lambda > \kappa$ (or $\beta/2 > \kappa$), the initial equity is increased accordingly.

2.8. *Shadow Banks*

Shadow banks are very much like commercial banks in how they manage their risk exposure, but there are quantitative differences. First of all, the capital adequacy regulation does not apply to them, so they start the simulation with an equity share of $\phi + \kappa$. Second, their maximum turnover ratio is twice as high as that of commercial banks (i.e., 2% instead of 1% of the balance sheet). Third, shadow banks may vary their share of the risky asset in the range of 0% to 100%, whereas commercial banks may only buy (sell) risky assets if they have at least 25% (at most 75%) cash. Thus, shadow banks are simply fast-moving, unregulated banks.

2.9. *Investment Funds*

Investment funds are the simplest kinds of agents we consider. They are 100% equity-financed, and they manage their asset side just like commercial banks do. Essentially, they behave like extremely well capitalized, unregulated commercial banks.

These investment fund agents represent, in real life, investment funds, pension funds, and possibly also the aggregate of individual investors. These agents cannot go bankrupt in our model because they have no leverage. As a consequence, they never engage in fire sales. Investment funds thus tend to stabilize the market by providing a basic excess demand for the risky asset when it is under-priced, and they provide an excess supply of the risky asset when the asset is over-priced. Therefore, they provide a basic insurance for banks, and also tend to lessen the likelihood of bubbles.

2.10. *Size distribution*

Our market consists of 120 agents, namely 30 commercial banks, 30 shadow banks, and 60 investment funds. The sizes of the balance sheets are not equally distributed. To get a somewhat realistic size distribution, we take the distribution of the balance sheets of the thirty largest commercial banks in the USA from the latest available "Call Report" (FFIEC, 2009). This distribution is highly skewed: the four largest banks constitute more than half the sum of the thirty largest banks. We take this empirical distribution and apply it to the sizes of the balance sheets of our artificial commercial banks. For lack of better data, we use this same distribution also for the shadow banks and for the investment funds. We have also experimented with more equally distributed sizes, but have found that the quantitative effects on the results are small.

2.11. *Short-term interaction versus long-term development*

Before discussing the results, let us make clear that our model is not intended to describe the development of the banking industry over a long period of time. Rather, it should simulate the banking industry for about one year. One period in our model is supposed to correspond to one day. We simulate 240 days (one year's worth of working days) and look at the results at the end of this period.

Simulating the development of the banking industry over a longer period of time would require a model where banks manage their liability side much more actively. They would issue or redeem shares or bonds, pay dividends, and would thus manage the size of their balance sheets. This is not the topic of the present paper. Instead, we use a given, calibrated distribution of balance sheet sizes and only study the daily interaction of these banks through the market mechanism.

2.12. Monte Carlo simulation

We vary various parameters across simulations in order to be able to evaluate their effects. For each set of parameter, we run one thousand simulations, where different seeds are used for the pseudo-random number generator that is responsible for creating the fundamental value process, (1), the individual signals (used in (2)). In addition, we run antithetic innovations for the fundamental price process in order to reduce Monte Carlo noise. Moreover, because we use the exact same fundamental price and individual signals, we get paired observations, where everything is exactly the same, except for the parameters of the model that we want to vary.

3. Results

3.1. General features of the unregulated market

We first consider the situation with no capital adequacy requirements, $\beta = 0\%$, and let the free equity quota ϕ vary from 1% to 7%, in 1% steps (we keep $\kappa = 0\%$ at this stage). Remember that the fundamental price has a drift of 2% and an annual volatility of 5%, and the exposure of banks is on average 50%. A 1% equity ratio is therefore clearly very narrow, and we should expect many defaults.

Of course, in our simulations (as well as in reality), not all banks will default simultaneously. After all, they behave heterogeneously to some extent. They adapt their exposure to the risky asset in reaction to their private signal, and so some banks end up being more lucky than others. Moreover, in the simulation, the market price is not identical to the fundamental value, but is only weakly attracted by the fundamental value. Banks tend to increase their exposure when the risky asset is undervalued and vice versa. This should help the ones that are lucky enough to get accurate signals to avoid bankruptcy more often.

Table 1 shows the average failure rates of both types of banks as a function of ϕ. Banking is clearly an extremely risky business with only 1% or 2% of equity. Even with 3%, still more that 10% of all banks fail within a year. At this stage, there seems to be little difference between commercial and shadow banks. The higher turnover of the shadow banks seems to neither help nor harm them, and in fact, correlation of bankruptcy between the two types of banking industry is very high.

Table 1: Failure probabilities of banks in an unregulated market, for different levels of the free equity quota ϕ.

free equity quota (ϕ)	1%	2%	3%	4%	5%	6%	7%
average share of banks with negative equity							
commercial banks	50.6%	25.1%	10.8%	4.28%	1.15%	0.17%	0.02%
shadow banks	50.4%	25.0%	10.8%	4.32%	1.34%	0.29%	0.09%
correlation of shares of the two types of banks with negative equity							
	0.998	0.997	0.991	0.983	0.953	0.807	0.882

Table 2: Market returns of the risky asset, with unregulated banks, for different levels of the free equity quota ϕ.

free equity quota (ϕ)	1%	2%	3%	4%	5%	6%	7%
market return on risky asset							
median	-3.03%	1.69%	1.83%	1.85%	1.85%	1.85%	1.85%
mean	-13.0%	-3.57%	0.17%	1.36%	1.83%	1.93%	1.94%
standard deviation	18.3%	13.2%	8.71%	5.79%	4.34%	4.03%	4.00%
skewness	-0.183	-1.34	-2.25	-2.17	-0.613	0.024	0.088
kurtosis	1.28	3.46	8.38	11.5	5.85	3.16	2.97

Note: These are averages across simulations of intertemporal moments.

Imminent failure of a bank will prompt it to get rid of its risky assets. It will engage in fire sales, thereby drawing down the market price and exercising a negative externality on the balance sheets of competing banks. Banks with solid balance sheets, however, can profit from fire sales in that they can purchase the risky asset at a discount. In any event, individual problems are likely to affect the development of the market price. Table 2 collects statistics pertaining to the market price of the risky asset as a function of the free equity quota ϕ. Remember that the fundamental value has an annual drift of 2%, and an annual volatility of 5%. The median return of the market price of the risky asset is 1.8% (for $\phi \geq 3\%$). The mean return is similar to the median if ϕ is relatively large (5% or more). Interestingly, the market price is somewhat less volatile than the fundamental value (only about 4%) if $\phi \geq 6\%$. Moreover, the distribution appears to be more or less Gaussian for large values of ϕ. As the share of free equity ϕ is reduced, market returns become more volatile, negatively skewed, and leptokurtic. We see the effects here that fire sales have on the market as a whole. By affecting the market price so badly, these fire sales exert a negative externality on all the agents that are still in the market.

Equity reduces the failure probability of banks. This benefit, however, is bought at the expense of the return on equity. Conversely, although highly leveraged bank is less likely to survive, if it does survive, its return on equity can be very high, simply because it has so little equity. Table 3 reports the median, the mean, and the standard deviation of returns on equity of the commercial and shadow banking industry, as well as for investment funds which have no leverage by definition. Note that we compare the equity that a particular industry has at the end of the simulation to the equity that this industry started with, so all the failed banks'

Table 3: Return on equity (ROE) of the commercial banking industry, the shadow banking industry, and investment funds for different levels of the free equity quota ϕ, no regulation.

free equity quota (ϕ)	1%	2%	3%	4%	5%	6%	7%
commercial bank industry							
median	-97.0%	42.9%	30.9%	23.3%	18.6%	15.5%	13.3%
mean	58.8%	39.2%	28.7%	23.0%	19.2%	16.3%	14.1%
standard deviation	191%	106%	71.5%	52.6%	40.8%	33.3%	28.4%
shadow bank industry							
median	-74.3%	18.1%	27.7%	21.0%	16.8%	14.0%	12.0%
mean	56.8%	37.1%	27.1%	21.8%	18.0%	15.2%	13.1%
standard deviation	191%	106%	71.3%	52.5%	41.0%	33.7%	28.8%
investment fund industry							
median	-1.43%	0.88%	0.98%	0.98%	0.98%	0.98%	0.98%
mean	-9.05%	-2.55%	-0.20%	0.66%	0.95%	1.00%	1.00%
standard deviation	12.2%	8.29%	5.18%	3.16%	2.20%	2.01%	1.99%

Note: These are moments across simulations of intertemporal averages.

Table 4: Mean return on capital of the commercial banking industry, the shadow banking industry, and investment funds for different levels of the free equity quota ϕ, no regulation.

free equity quota (ϕ)	1%	2%	3%	4%	5%	6%	7%
commercial bank industry	0.59%	0.78%	0.86%	0.92%	0.96%	0.98%	0.99%
shadow bank industry	0.57%	0.74%	0.81%	0.87%	0.90%	0.91%	0.92%
investment fund industry	-9.05%	-2.55%	-0.20%	0.66%	0.95%	1.00%	1.00%

Note: These are moments across simulations of intertemporal averages.

equity is removed in this comparison. As a consequence, there is no survival bias in these statistics, since we do not only look at the surviving banks. Considering the mean, we clearly see that ROE dramatically increases as we decrease the banks' equity. This should not be surprising, since the denominator becomes ever smaller. It is somewhat surprising to compare the commercial with the shadow banking industry. When taking just the mean and the standard deviation of ROE as a guide, it appears that the commercial banking industry has a slight advantage. The faster speed of the shadow banks seems only to make them somewhat more volatile, without actually increasing their mean performance.

Figure 1 shows in more detail what happens. It depicts kernel estimates (across simulations) of average ROE of commercial banks, conditional on the equity quote of the banking industry. With only 1% equity share, the distribution is extremely volatile, highly skewed, and reaches stellar heights in the right tail. The upper graph depicts ROE of the industry; the lower graph depicts ROE only of the surviving commercial banks. We see the catastrophic simulations where a large number, or maybe even all banks, have failed, by comparing the left tails of these two graphs.

So, banks that try to maximize ROE will aim to hold very little equity. From an economic point of view, that does not make much sense, though. Table 4 reports the mean returns on capital. We stick to the rightmost column first, where $\phi = 7\%$.

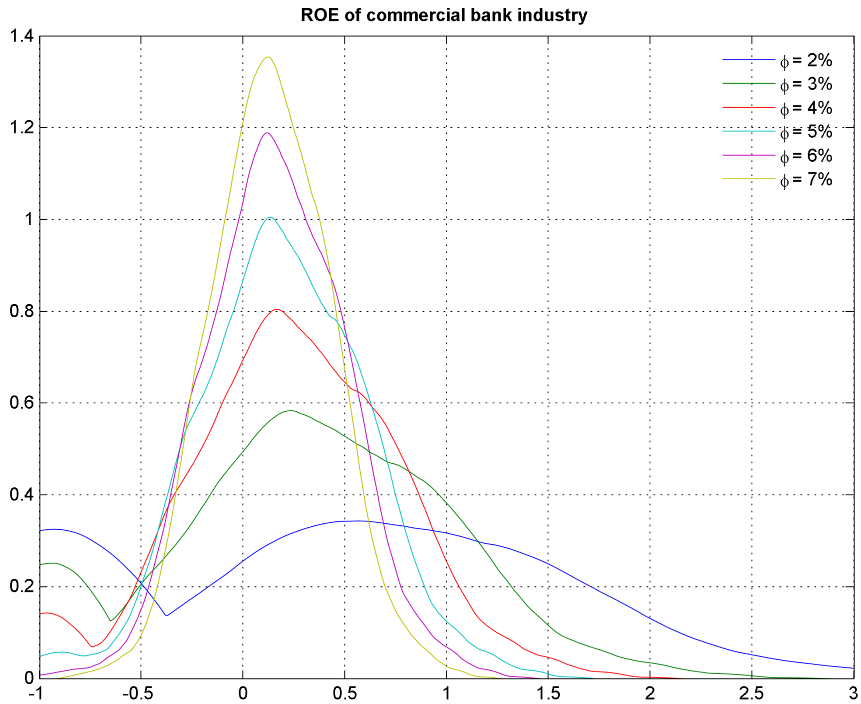

Figure 1: Kernel estimates of annualized returns on the risky asset, conditional on free equity quotas, ϕ. The dead banks are clearly visible in the left tail.

Well capitalized commercial banks achieve roughly 1% return on their invested capital. That makes sense given our calibration. We have no risk-free interest rate, a bank's exposure to the risky asset amounts to half of its balance sheet total on average, and this asset has a drift of 2%. Hence, the bank on average realizes a return on capital of 1%. Again, we see that shadow banks are slightly less efficient. Investment funds perform best in this situation. They make 1% on their capital. They have an average exposure of 50% to the risky asset, and this asset has a drift of 2%. This gives rise to the 1% return on the capital on the investment funds.

As equity in the banking industry is reduced, market crashes and bankruptcies become more common. This affects the return on capital for all financial intermediaries, but investment funds are affected particularly badly. If ϕ is only 3% or less, the return on capital invested in investment funds even becomes negative. Table 4 has one clear message: more equity in the banking sector is uniformly better.

3.2. The effect of Basel-II in a Basel-II-only environment

We now introduce risk-weighted capital adequacy requirements for commercial banks. As explained before in Section 2.6, the rule requires banks to hold sufficient equity against their risky assets. Required equity is equal to βR, where β is some percentage point. Total equity consists of required equity and free equity.

The rationale for this regulation is to force banks to hold sufficient equity in order for them to be able to absorb potential losses that their risky assets might incur. Before the bank actually defaults, it will first find that it is unable to meet the required capital regulation. At this point, the bank has negative free equity, and it will engage in fire sales. Because equity is (probably) still positive at this point, bankruptcy can be held off for longer than would be the case without the β-regulation. Thus, the regulation is there to force the bank to take action before its equity is gone. However, there is a drawback to this kind of regulation. Because it induces fire sales earlier, it might trigger a downward movement of the market more quickly than the situation without regulation, and this in turn could cause contagion.

The regulation is designed to make it more costly for banks to hold a large amount of risk on their asset side. As a result, one would expect an optimizing bank to hold a smaller share of risky assets where these have to be covered with equity. Even though the banks in our simulations are not optimizing, the same effect is visible in our simulations to some extent. Figure 2 depicts kernel estimates of the share of the risky asset on the balance sheet for surviving commercial banks (at the end of the simulation), conditional on different values of β. One can see that this share is reduced by more demanding risk-weighted capital requirements.

In the following, we fix the free equity quota ϕ at 2%, and the conditionally free equity quota κ also at 4%. We investigate the effects of imposing risk-weighted equity quotas β between 0% and 10%, in 2% intervals. Table 5 reports the main results. The first part of the table shows how the composition of equity in the

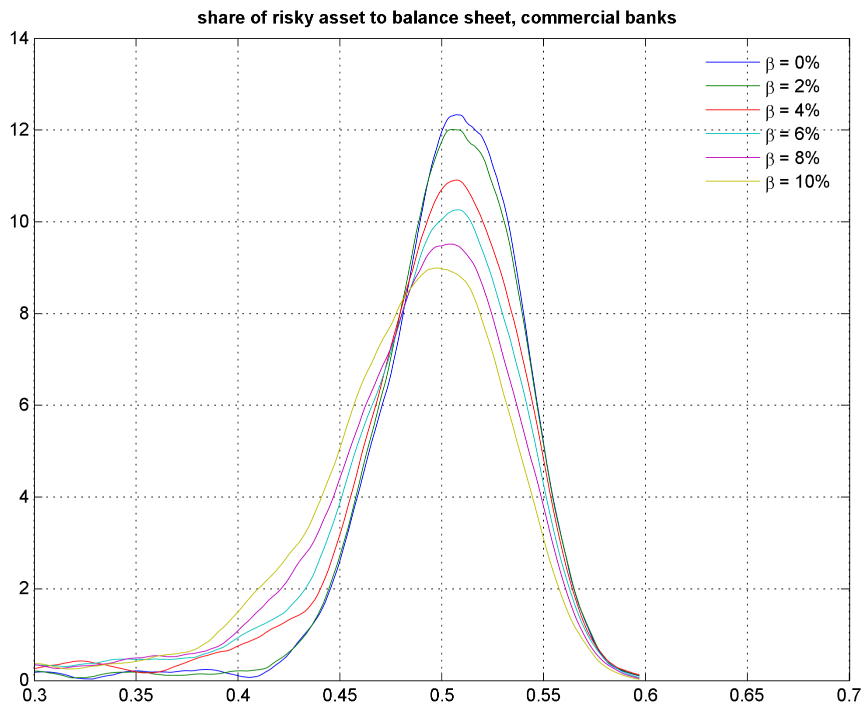

Figure 2: Kernel estimates of the share of the risky asset in the balance sheet of commercial banks, for different levels of risk-weighted equity regulations, β. ϕ and κ are fixed at 2%.

Table 5: Effects of risk-weighted capital adequacy requirement (β). Free equity quota ($\phi = 2\%$) and conditionally free equity quota ($\kappa = 2\%$) are fixed.

risk-weigthed capital adequacy (β)	0%	2%	4%	6%	8%	10%
commercial banks' equity share (at start of simulation)						
total	4%	4%	4%	5%	6%	7%
free equity	2%	2%	2%	2%	2%	2%
conditionally free equity	2%	1%	0%	0%	0%	0%
required equity	0%	1%	2%	3%	4%	5%
banks in trouble						
commercial banks with negative equity	4.29%	6.90%	14.1%	12.7%	10.8%	8.70%
… with negative free equity	4.29%	7.59%	17.4%	17.0%	16.7%	15.1%
shadow of banks with negative equity	4.32%	6.60%	14.4%	14.2%	13.8%	12.4%
market return on risky asset*						
median	1.85%	1.85%	1.82%	1.79%	1.72%	1.75%
mean	1.36%	0.81%	-1.11%	-1.10%	-0.99%	-0.76%
standard deviation	2.93%	2.97%	3.08%	3.08%	3.07%	3.05%
skewness	-0.059	-0.103	-0.241	-0.244	-0.226	-0.200
kurtosis	3.18	3.33	3.81	3.87	3.79	3.70
return of investment funds**						
median	0.98%	0.98%	0.98%	0.96%	0.89%	0.95%
mean	0.66%	0.31%	-0.94%	-0.92%	-0.84%	-0.70%

* These are averages across simulations of intertemporal moments.
** These are moments across simulations of intertemporal means.

commercial banks changes as a result of regulation. For $\beta \leq 4\%$, conditionally free equity is substituted for required capital, but the the total equity share remains unchanged at 4%. Only when β is increased further does the equity share of commercial banks increase. The equity share of shadow banks is unaffected by β because this regulation does not apply to them.

The second section of Table 5 reports the average failure probabilities of banks. Banks with negative equity are effectively in liquidation, and it is very unlikely that they will eventually be saved. Banks with negative free equity are still operative, but they are in conflict with the regulatory rules.[4] These banks conduct fire sales of their risky asset in order to reduce their required equity, which tends to depress the market.

We see that as we increase β from 0% up to 4%, the failure probabilities of commercial banks *increase*. Up to that point, conditionally free equity is transformed into required equity, but the total equity share is not changed. Required equity is clearly much less able to absorb losses than (conditionally) free equity is, simply because the regulator requires this equity to be on the balance sheet. Thus, if free equity is substituted for required equity, the bank is far more likely to

[4]The distinction between negative equity and negative free equity is irrelevant for shadow banks, because these entities are not subject to capital adequacy regulation.

conduct fire sales. This depresses the market as a whole (see the section "Market return on the risky asset" of Table 5) and increases the prevalence of bankruptcy. We also see that the unregulated shadow banks are exposed to the same negative externality. As commercial banks are subject to tighter equity requirements, the unregulated shadow banks also are more likely to fail.

When β is increased beyond 4%, the situation changes. At that point, the regulation actually becomes binding in the sense that it forces banks to hold more equity. This stabilizes the market to some extent. Failure probabilities (of commercial and shadow banks) decline slowly as we increase β further.

It seems that risk-weighted capital adequacy regulation is not a very effective policy for stabilizing the banking industry. When we increase β, the situation first deteriorates before it improves. Once the capital requirements are sufficiently demanding to be beneficial, stabilization sets in only very slowly. Compare right-most column of Table 5 ($\beta = 10\%$) with the left-most ($\beta = 0\%$). When $\beta = 0\%$ (the leftmost column), commercial banks and shadow banks have a 4% equity share. The failure probability of commercial and shadow banks is about 4.3%. In the rightmost column, when $\beta = 10\%$, shadow banks still have 4%, because they are unregulated. Commercial banks, however, now hold 2% free equity plus 5% required equity, for a total of 7%. There is more equity in the industry now. And yet, banks are much more likely to fail: 8.7% of commercial banks end up being insolvent (negative equity) — twice as many as when no equity was required by the regulator. The failure probability of the (unregulated) shadow banks is increased almost three-fold by the regulation that is imposed on commercial banks.

The last section of Table 5 reports the devastating effect the fire sales — induced by this regulation — have on investment funds. Their median return rates are hardly affected by β, but the mean returns that the investment funds achieve plummet as we increase β from 0% to 4%, and remain low as β is increased further. The investment funds ultimately bear the cost of the fire sales that are induced by this regulation.

In Section 3.1 we considered various levels of free equity. We now study the effect of simultaneously changing the capital adequacy requirement β and the conditionally free equity quota κ.[5] Table 6 reports the effects of these parameter changes on the failure probabilities of the two types of banks in our model. Recall that at the beginning of the simulation, commercial banks have an equity share of $\phi + \max\{\kappa, \beta/2\}$. As an example, consider $\kappa = 2\%$ and $\beta = 0\%$ (the left-most shaded cell in the top section of Table 6). Both types of banks have 4% equity in this scenario. Commercial banks fail with 4.28% probability; shadow banks fail with 4.32% probability. As β is slightly increased, the equity share stays the same, because free excess equity is simply substituted for required equity. Notice how failure rates increase up to 14.1% for commercial banks as we move to the right

[5] We keep ϕ fixed at 2%, so banks start with 2% more equity than the regulator requires, as a cushion, so that they do not have to conduct fire sales as soon as small losses occur.

Table 6: Failure probabilities of banks for different combinations of the conditionally free equity quota κ and the risk-weighted equity requirement β. ϕ is fixed to 2%. For commercial banks, β-regulation is binding in the upper triangle matrix. In the greyed-out cells, the equity ratio at the beginning of the simulation is equal to 4%.

commercial banks in trouble						
rows: κ, columns: β	0%	2%	4%	6%	8%	10%
0%	25.1%	25.2%	25.0%	26.3%	27.1%	25.6%
1%	10.8%	17.8%	17.9%	18.1%	17.6%	15.9%
2%	4.28%	6.90%	14.1%	12.7%	10.8%	8.71%
3%	1.15%	1.92%	4.45%	9.51%	7.35%	4.73%
4%	0.17%	0.39%	0.64%	2.11%	4.31%	1.69%
5%	0.02%	0.03%	0.08%	0.25%	0.60%	1.13%
shadow banks in trouble						
rows: κ, columns: β	0%	2%	4%	6%	8%	10%
0%	25.0%	26.0%	26.6%	28.9%	30.7%	31.1%
1%	10.8%	17.7%	18.8%	19.9%	20.7%	20.6%
2%	4.32%	6.60%	14.4%	14.2%	13.8%	12.4%
3%	1.34%	2.03%	4.67%	10.8%	9.03%	7.46%
4%	0.29%	0.42%	0.91%	3.15%	5.70%	4.39%
5%	0.09%	0.09%	0.18%	0.40%	1.42%	2.38%

in the area of the shaded cells. Even though shadow banks are unregulated, their failure probability also increases up to 14.4%, because they are negatively affected by the fire sales of the failing commercial banks.

When $\beta \geq 4\%$, the risk-adjusted equity requirement becomes binding in the sense that banks start with more equity to satisfy their initial needs for free equity. If β is increased beyond this point, failure rates of both types of banks start to decrease again. Notice that at $(\kappa, \beta) = (3\%, 10\%)$, commercial banks have an equity share of 7%, but shadow banks, which are unregulated, still have only 5% equity. Shadow banks, however, profit from the greater stability of the commercial banks, and fail less often.

Consider a situation now where regulation is changed, but we look at scenarios where the equity share of commercial banks stays the same (i.e., 4%). From $(\kappa, \beta) = (2\%, 4\%)$, we now move upwards in the table. At $(\kappa, \beta) = (0\%, 4\%)$, commercial banks still have 4% equity at the beginning of the simulations, but shadow banks have only 2%, namely $\phi + \kappa = 2\% + 0\%$. This makes shadow banks prone to failure, and now it is the fire sale of the failing shadow banks that exerts a negative externality on commercial banks and also increases their failure rates.

Overall, our simulations lead us to a very negative verdict on risk-weighted capital adequacy requirements. Such regulation is not effective in stabilizing commercial banks or shadow banks, it reduces the profitability of commercial banks and of investment funds, and increases the likelihood of fire sales and market crashes. It seems to have only costs but no benefits.

One should also keep in mind that we do not even take into account the fact that risk-weighted rules are to some extent manipulable by the banks. Complex assets that are not traded in a liquid fashion are marked-to-model, and banks are often allowed to provide their own models that are used for that purpose. It is, of course, problematic if banks can tamper with the models that generate the regulatory value of their assets, as this may undermine the regulation. Also, when competitors are known to have to conduct fire sales, competitors might be tempted to lower they bid prices and anticipate the effects of the lower liquidity in the market. All these aspects are not present in our simulations, and still the results are not good.

3.3. The effect of a leverage ratio restriction without Basel-II

In this section, we study the replacement of the risk-adjusted capital adequacy requirement by an unconditional maximum leverage ratio. We assume that equity must be at least $\lambda(C + R)$, where λ is the unweighted equity quota required by the regulator. Because the model is calibrated so that, on average, $C \approx R$ over the long run, a λ which is half as large as β should result in about the same amount of required equity on average. Thus, we can compare, for instance, the results with $\beta = 10\%$ and $\lambda = 0\%$ to the results with $\beta = 0\%$ and $\lambda = 5\%$.

Unlike a binding risk-weighted equity requirement, which triggers a fire sale of the risky asset, a bank can more easily adapt to a binding leverage ratio restriction. All it needs to do is to shrink its balance sheet by reducing leverage at the expense of cash. As long as the bank is liquid, it can do that. If cash is scarce and the bank's assets are invested 100% in the risky asset, only then do fire sales become necessary in order to repay debt and decrease leverage. Thus, the leverage ratio restriction is much less likely to trigger a fire sale. However, in theory it also tends to make the asset side more risky. Yet this effect did not materialize in our simulations.

Table 7 reports the effects of the leverage ratio restrictions on various aspects of the simulated market. First of all, as with the β-regulation, increasing λ first makes the likelihood of failure worse for commercial banks as well as shadow banks. Increasing λ from 0% to 2% ($= \kappa$) increases failure rates for commercial banks from 4.28% to 7.32%, and for shadow banks from 4.32% to 7.27%. Increasing λ beyond κ, however, tends to stabilize the industry again (failures rates drop to 3.26% and 5.32%, for commercial and shadow banks, respectively). The λ-regulation seems somewhat more effective than the β-regulations for achieving the stated goal. Moreover, this type of regulation seems to have only benign effects on the return characteristics of the risky asset (the second section of the table).

The leverage ratio restriction also has very little effect on the profitability of (unregulated) shadow banks, measured as return on equity or return on capital. The profitability of (fully funded) investment funds and the regulated commercial banking industry are somewhat more strongly negatively affected by this type of regulation.

Table 7: Effects of unweighted equity requirement (λ). Free equity quota ($\phi = 2\%$) and conditionally free equity quote ($\kappa = 2\%$) are fixed.

unweigthed capital requirement (λ)	0%	1%	2%	3%	4%	5%
banks in trouble						
commercial banks with negative equity	4.28%	5.22%	7.32%	5.68%	4.35%	3.26%
… with negative free equity	4.28%	6.01%	9.53%	8.18%	7.40%	6.72%
shadow of banks with negative equity	4.32%	5.08%	7.27%	6.30%	5.84%	5.32%
market return on risky asset*						
median	1.36%	1.23%	0.72%	0.96%	1.08%	1.20%
mean	1.85%	1.85%	1.83%	1.83%	1.85%	1.85%
standard deviation	2.93%	2.93%	2.96%	2.95%	2.94%	2.93%
skewness	-0.059	-0.060	-0.093	-0.078	-0.069	-0.060
kurtosis	3.18	3.16	3.28	3.23	3.20	3.17
return on equity**						
commercial bank industry						
median	23.3%	23.3%	23.1%	18.5%	15.4%	13.3%
mean	23.0%	22.4%	20.2%	15.8%	12.7%	10.8%
shadow bank industry						
median	21.0%	21.0%	20.7%	20.9%	21.0%	21.0%
mean	21.8%	21.3%	19.3%	20.2%	20.6%	21.0%
investment fund industry						
median	0.98%	0.98%	0.97%	0.98%	0.98%	0.98%
mean	0.66%	0.58%	0.26%	0.41%	0.49%	0.56%
return on capital**						
commercial banks	0.92%	0.90%	0.81%	0.79%	0.76%	0.76%
shadow banks	0.87%	0.85%	0.77%	0.81%	0.82%	0.84%
investment funds	0.66%	0.58%	0.26%	0.41%	0.49%	0.56%

* These are averages across simulations of intertemporal moments.
** These are moments across simulations of intertemporal means.

3.4. *Interaction of Basel-II legislation and leverage ratio restriction*

The Basel-III accord contains both kinds of regulation, namely risk-weighted as well as unweighted equity requirements. The rationale for this double regulation appears to be that the risk-weighted requirement would be the right way to go. Unfortunately, it is a regulation that is prone to manipulation by the banks in so far as its assets are not traded on liquid markets, and that must therefore be marked-to-model. The unweighted equity requirement should therefore act as a safety net, beyond which manipulation is not possible.[6]

We have seen, however, that the risk-weighted regulation does not work well in our simulations, even though the banks of our model have no room for manipulation. Our simulations therefore cast doubt on this rationale.

In this section, we investigate how such double requirement works in the simulations. For a commercial bank, required equity is the maximum of the equity that is required by the risk-weighted constraint, βR, and by the leverage ratio restriction, $\lambda(C+R)$. On top of this, it also holds free equity $\phi(C+R)$. Moreover, at the beginning of the simulation, $C = R$, so commercial banks have an equity share of $\phi + \max\{\kappa, \beta/2, \lambda\}$ at the start of the simulation. Shadow banks are unregulated and start the simulation with an equity share of $\phi + \kappa$. We set ϕ and κ equal to 2% in all further simulations.

Table 8 reports the resulting failure probabilities. The top section reports failure probabilities of the regulated commercial banks. This table is partitioned into three parts. The upper-left area of the table, with smaller values of β and λ, are cases where neither the risk-weighted nor the unweighted capital adequacy regulation leads the banks to increase their equity share. In this region, conditionally free equity (κ) is substituted for required capital. In this part, banks' equity share is $\phi + \kappa$, and we call this the "κ-area." In the upper-right area of the table, the risk-weighted requirement (β) is binding, so banks' initial equity share is $\phi + \beta/2$. We call this the "β-area." Finally, in the lower-left region of this table, the unweighted capital requirement is binding and the initial equity share of banks is equal to $\phi + \lambda$. We call this the "λ-area." The remaining two sections of this table report the failure probabilities of (unregulated) shadow banks and the average market return rates of the risky asset.

It is quite significant that bankruptcy rates increase dramatically as we approach the β-area from the left. They are highest at the intersection between the κ- and the β-areas. This is where the risk-weighted rule just becomes binding; however the situation does not yet impel the banks to start out with more equity.

[6] Basel Committee on Banking Supervision (2009) is very explicit on this rationale. It states in the executive summary: "The Committee will introduce a leverage ratio as a supplementary measure to the Basel II risk-based framework with a view to migrating to a Pillar 1 treatment based on appropriate review and calibration. This will help contain the build up of excessive leverage in the banking system, introduce additional *safeguards against attempts to game the risk based requirements*, and help address model risk." (emphasis added).

Table 8: Failure probabilities of banks and average market performance of the risky asset for different combinations of risk-weighted (β) and unweighted (λ) equity requirement β. Free and conditionally free equity quotas are fixed ($\phi = 2\%$, $\kappa = 2\%$). For commercial banks, in the upper-left area, neither the β- nor the λ-regulation are binding. In the upper-right area, the β-regulation binds, but λ-regulation does not. Finally, in the lower-left area, the λ-regulation is binding, but β is not. We see how the regulatory environment of commercial banks affects their own failure probabilities, but also spills over into failure probabilities of shadow banks.

commercial banks in trouble

rows: λ, columns: β	0%	2%	4%	6%	8%	10%
0%	4.28%	6.90%	14.1%	12.7%	10.8%	8.70%
1%	5.22%	6.55%	13.7%	12.5%	10.8%	8.65%
2%	7.32%	7.32%	12.6%	12.4%	10.6%	8.64%
3%	5.68%	5.68%	6.30%	11.3%	10.3%	8.59%
4%	4.35%	4.35%	4.35%	5.59%	9.82%	8.46%
5%	3.26%	3.26%	3.26%	3.34%	4.84%	8.41%

shadow banks in trouble

rows: λ, columns: β	0%	2%	4%	6%	8%	10%
0%	4.32%	6.60%	14.4%	14.4%	13.8%	12.4%
1%	5.08%	6.33%	14.0%	14.1%	13.8%	12.4%
2%	7.27%	7.27%	12.9%	14.0%	13.8%	12.4%
3%	6.30%	6.30%	6.78%	13.1%	13.6%	12.4%
4%	5.84%	5.84%	5.84%	7.18%	12.9%	12.3%
5%	5.32%	5.32%	5.32%	5.41%	7.30%	12.0%

average market return

rows: λ, columns: β	0%	2%	4%	6%	8%	10%
0%	1.36%	0.81%	-1.11%	-1.09%	-0.99%	-0.76%
1%	1.23%	0.97%	-0.92%	-1.02%	-0.98%	-0.75%
2%	0.72%	0.72%	-0.61%	-0.94%	-0.96%	-0.72%
3%	0.96%	0.96%	0.84%	-0.68%	-0.89%	-0.70%
4%	1.08%	1.08%	1.08%	0.78%	-0.71%	-0.67%
5%	1.20%	1.20%	1.20%	1.18%	0.72%	-0.57%

All the conditionally free equity is transformed into required equity, and that seems to be a particularly dangerous situation.

Within the β-area itself we see that increasing β further can improve things a little. Playing around with λ has virtually no effect, because this regulation rarely becomes binding over time.

A similar story applies to the the unweighted requirement. As we approach the λ-area from the top, bankruptcy rates increase dramatically, because conditionally free equity is progressively transformed into required equity. The bankruptcy rate again reaches a local maximum when $\lambda = \kappa$. Increasing λ further then improves the situation because it forces more equity on banks. Within the λ-area, changing β has again almost no effect because this regulation is not binding.

The situation of the commercial banks affects the market of the risky asset (the third part of the table) to the same degree, and, through this externality, also the shadow banks (the second part of the table). Shadow banks are uniformly more likely to default than commercial banks, but a decrease or increase in the failure probability of commercial banks has more or less a one-to-one effect on the failure probabilities of shadow banks. The two sectors are very highly correlated.

The β-area is far worse than the λ-area. The story, as we interpret it, runs as follows: when banks fail the risk-weighted requirement (β-regulation) they start to conduct fire sales in order to reduce their required capital. This behavior depresses the market and exerts a significant negative externality on other commercial and shadow banks (and on investment funds). It seems that — via this mechanism — fire sales can trigger more fire sales, and thus produce quite a calamity. In the λ-area, in contrast, the unweighted capital regulation is more binding. If a bank fails to meet the terms of this regulation, it will shrink its balance sheet by paying off debt-holders with cash. This may also trigger subsequent fire sales to some extent, but these fire sales will be smaller in quantity and more spread out over time, thereby avoiding an overall market crash. We conclude that, given these results, unweighted equity requirements appear to be the much better strategy for the regulator than the risk-weighted requirements.

3.5. *Regulating shadow banks*

Shadow banks are sometimes named as one of the sources of the recent instability. These institutions are large, have a substantial amount of leverage, often act quickly (we model this as a higher turnover), and are thus believed to exacerbate market movements. They are also much less regulated than ordinary commercial banks.

An obvious experiment is thus to impose the same regulations upon them that apply to commercial banks; that is, weighted and unweighted capital adequacy restrictions. The only difference between a commercial and a shadow bank is then the faster turnover and the greater room for maneuver that these banks have in terms of steering their balance sheet. Other than that, they are identical to commercial banks, and we should therefore expect them to behave very similarly.

Table 9: Failure probabilities of banks and average market performance of the risky asset for different combinations of risk-weighted (β) and unweighted (λ) equity requirement β. Free and conditionally free equity quotas are fixed ($\phi = 2\%$, $\kappa = 2\%$). Shadow banks are subject to the same regulations as commercial banks

commercial banks in trouble

rows: λ, columns: β	0%	2%	4%	6%	8%	10%
0%	4.28%	14.1%	38.1%	43.3%	46.5%	46.2%
1%	6.98%	11.9%	37.3%	42.7%	45.8%	45.9%
2%	13.1%	13.1%	36.4%	42.3%	45.1%	45.3%
3%	9.23%	9.23%	13.1%	41.0%	44.1%	44.5%
4%	5.21%	5.21%	5.21%	14.7%	42.4%	43.1%
5%	2.61%	2.61%	2.61%	4.05%	14.2%	41.3%

shadow banks in trouble

rows: λ, columns: β	0%	2%	4%	6%	8%	10%
0%	4.32%	13.6%	37.6%	42.4%	43.9%	40.1%
1%	6.83%	11.3%	35.9%	40.3%	40.2%	35.7%
2%	12.6%	12.6%	35.1%	40.4%	40.6%	37.3%
3%	8.93%	8.93%	12.4%	39.2%	40.2%	37.4%
4%	5.10%	5.10%	5.10%	13.4%	39.4%	36.9%
5%	2.89%	2.89%	2.89%	3.83%	11.8%	35.8%

average market return

rows: λ, columns: β	0%	2%	4%	6%	8%	10%
0%	1.36%	-0.88%	-8.65%	-11.2%	-12.8%	-13.6%
1%	1.09%	0.19%	-6.12%	-8.95%	-10.9%	-12.2%
2%	-0.05%	-0.05%	-5.79%	-8.52%	-10.5%	-11.9%
3%	0.46%	0.46%	-3.52%	-7.94%	-10.1%	-11.5%
4%	0.97%	0.97%	0.97%	-1.24%	-9.58%	-11.0%
5%	1.23%	1.23%	1.23%	0.90%	-1.97%	-10.4%

Clearly, there are countervailing effects here. If unregulated shadow banks are a force that exacerbate fundamentally benign market movements, then putting them on a leash would stabilize the system as a whole. Yet, by regulating them in the same way as ordinary banks, we run the risk of having almost all agents on the same side of the market if the price changes slightly, which can turn a small shock into a full-blown crash.

The main results of these simulations are reported in Table 9. The results uncover that this second effect, namely the instability due to forced homogeneous behavior, indeed presents a great danger. It appears that in cases where some banks are regulated and others are not, they are able to provide mutual insurances for each other. If a commercial bank is in trouble and needs to get rid of its risky assets in a hurry, it is glad if it can find an unregulated hedge fund that is happy to pick up these assets at a discount. If the hedge fund were regulated, it might

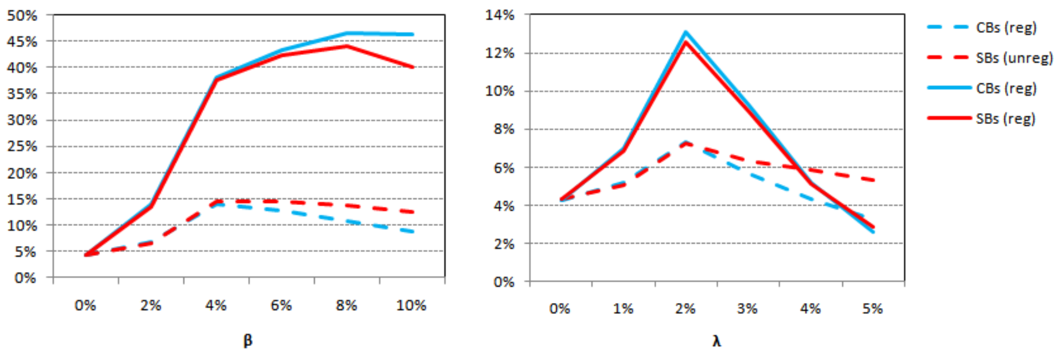

Figure 3: Average share of banks with negative equity. The graph depicts information that is also contained in Tables 8 and 9. Blue lines refer to commercial banks, red lines to shadow banks. Dashed lines apply if only commercial banks are regulated, but shadow banks are not. Solid lines apply if all bank types are regulated in the same fashion. The chart on the left depicts the effect of increasingly tough risk-weighted capital adequacy requirements (β); in this chart, $\lambda = 0$. The chart on the right depicts the effect of increasingly tough unweighted capital adequacy requirements (λ); in this chart, $\beta = 0$. Throughout, $\phi = 2\%$ and $\kappa = 2\%$.

not be allowed to do this, and the market would crash, taking with it the bank that was originally in trouble, and possibly other banks as well.

This story applies to fire sales, where risk-weighted equity requirements (β) are able to induce fire sales. Therefore, imposing this regulation on shadow banks as well ought to be dangerous. Indeed, by comparing the effects of the β-regulation as reported in Table 9, where all bank types are regulated, to the corresponding numbers in Table 8, where only commercial banks are subject to the regulation, we see that a universal β-regulation is highly destabilizing. Consider for the moment the situation with no unweighted capital requirements, $\lambda = 0\%$. If $\beta = 10\%$, then, according to Table 8, the failure rate of commercial banks is 8.7%; for shadow banks it is 12.4%. If shadow banks are also subject to this regulation, the failure rate of commercial banks increases to 46.2%, and shadow banks crash with a probability of 40.1%. Clearly, this type of regulation does not achieve what it set out to do.

Tables 8 and 9 clearly show the devastating effect of a universally applied β-regulation. By forcing banks to conduct fire sales, and at the same time not allowing a significant segment of financial market participants to purchase in a fire sale situation, the market is doomed to crash and the banking industry becomes very vulnerable. In a situation where only commercial banks are regulated, fire sales already reduce liquidity in the market and bias the order book towards the sell side. With universally applied regulations, this affect is even magnified, and the system has a much higher chance of reaching the tipping point towards a crash.

Figure 3 shows information of Tables 8 and 9, but focuses on either exclusively risk-weighted or exclusively unweighted capital adequacy requirements. Here, we see that universal λ-regulation is also problematic, though to a lesser extent than a universal risk-weighted regulation. For low values of λ — as long as banks are still substituting conditionally free with required equity —, a more demanding leverage ratio restriction is particularly bad if it applies not only to commercial but also to shadow banks. However, as λ is increased further, the benefits set in much quicker if the rule applies universally. Indeed, the situation with the least amount of bankruptcy is achieved if there is a high universal unweighted capital requirement but no or very low risk-weighted requirement. In the parameter space that we have investigated, this would amount to $\lambda = 5\%$ and $\beta \leq 4\%$, applicable to commercial and shadow banks as well. In this case, commercial banks fail with a probability of 2.61% and shadow banks fail with a probability of 2.89%.

4. Conclusions

We investigate the interaction of financial intermediaries by way of simulations. We model the entities as autonomous agents. They behave in rather simple ways, but their interaction gives rise to complex phenomena. Our simulations allow us to draw a few clear conclusions.

Finding #1: Only free equity is good equity. Equity that is required by regulation is unable to absorb losses and is thus effectively similar to leverage. The most effective way of making banks more secure would be to provide them with incentives to willingly hold more equity. But of course, one cannot *force* banks to hold more *free* equity. The introduction of equity ratios that are contingent on the state of the bank or of the economy, as introduced in the Basel III accord, makes therefore a lot of sense. If some of the required capital can be spent in times of crisis, then this regulatory equity is again able to absorb losses. This point was forcefully made by Kashyap et al. (2008). The idea of loss-absorbing regulatory equity has also entered new regulation in Switzerland that proposes the introduction of conditionally convertible debt (CoCo). This is debt that converts into equity if the balance sheet of the bank weakens too much.

Finding #2: A non-binding equity requirement cannot stabilize the system. Imposing a 10% equity share on a bank that willingly holds 20% makes the bank more unstable, because it only transforms truly free equity into equity that is required by the regulator. However, truly free equity is much better able to absorb losses for a bank that is a going concern. Required equity may help protect bond holders' interests once the bank is liquidated, but then the systemic loss has already materialized. On the other hand, requiring 10% equity from a bank that willingly holds only 1% is likely to make it safer, because it will force this bank to actually hold more equity, which will reduce leverage and thus decrease the likelihood of bankruptcy. The conclusion is that capital adequacy requirements of any sort only make sense if banks for some reason are not willing on their part to hold sufficient equity as a cushion.

Finding #3: Risk-weighted capital adequacy requirements do not work. Essentially, they just trigger fire sales, which spreads the crisis faster to other banks. In the end, systemic instability is exacerbated by such regulation.[7]

Finding #4: An unweighted leverage ratio restriction performs better in our simulations than a risk-adjusted equity requirement. Even though this regulation does not seem to be very effective, at least it does not exacerbate the crises in our simulations. A few caveats are in order here, however. First, one might expect an optimizing bank to aim for more risk exposure if the leverage ratio constraint is binding, while at the same time the risk-weighted constraint is not. Therefore, whenever the leverage ratio constraint binds, we should expect bank balance sheets to accumulate risk, thereby undermining the intended effect of making banks more secure. As we completely disregard this effect in our simulations, we probably overestimate the beneficial effects of the leverage ratio regulation. Second, we assume that banks that fall under the leverage ratio restriction simply shrink their balance sheets by paying off debt holders with cash. This deleveraging appears unproblematic in our simulations even if many banks attempt to do this simultaneously. The reason is that we have not modeled the interaction of banks through the debt market. If some banks deleverage in this fashion on a large scale, this would probably lower interest rates, which would then incite other banks to pick up more leverage, so that in the aggregate, debt would just be passed on from one bank to another. We have no interest rate in our model and we do not model the debt market. In our simulations, debt is reduced industry-wide when the leverage ratio restriction is binding for one bank. Both omissions — the neglect of banks' incentives to make their asset side more risky as well as the lack of a debt market in our model — is likely to make the leverage ratio restriction appear more beneficial than it actually is.

Finding #5: Regulating shadow banks in the same fashion as commercial banks is a recipe for disaster. If shadow banks are subject to the same rules as commercial banks, they obviously behave similarly. Regulating shadow banks makes it difficult for them to adopt the role of counter-party to the commercial banks' fire sales that are induced by their misfortunes and by the regulation that is imposed upon them. Our simulations reveal that investment funds cannot fill this gap. Mutual insurance breaks down. The homogeneity of behavior enhances the positive feedback of the system and the externality that banks exercise on each other through the order book. The implication is that small movements in the market price are able to trigger widespread fire sales and result in crisis and bank collapse on a massive scale. In the end, regulating shadow banks makes them, as well as commercial banks, much more likely to fail.

[7] This finding is in line with Daníelsson and Zigrand (2003).

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