The Leverage Ratio, Risk-Taking and Bank Stability

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Abstract

Under the new Basel III banking regulations, a non-risk based leverage ratio will be introduced alongside the risk-based capital requirement. This move away from a solely risk-based capital framework however, has raised some concern of increased bank risk-taking; potentially offsetting any benefits from requiring highly leveraged banks to hold more capital. We address exactly this trade-off between additional loss-absorbing capacity and higher bank risk-taking associated with a leverage ratio requirement in both a theoretical and empirical setting. Using a theoretical micro model, we show that a leverage ratio requirement indeed incentivises bound banks to slightly increase their risk-taking, but this increase in risk-taking is more than outweighed by the increase in loss-absorbing capacity from higher capital, thus leading to more stable banks. These theoretical predictions are then tested and confirmed in an empirical analysis on a large sample of EU banks. Our baseline empirical model suggests that a leverage ratio requirement would lead to a significant decline in the failure probability of highly leveraged banks.

Keywords: Bank capital; Risk-taking; Leverage ratio; Basel III

JEL classification: G01; G21; G28

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Non-Technical Summary

As a response to the global financial crisis, the Basel Committee on Banking Supervision (BCBS) decided to undertake a major reform to the regulatory framework of the banking system. Under the new Basel III banking regulations, a non-risk based Leverage Ratio (LR) requirement will be introduced alongside the risk-based capital framework with the aim to "restrict the build-up of excessive leverage in the banking sector to avoid destabilising deleveraging processes that can damage the broader financial system and the economy".[1] The LR is a non-risk based capital measure and is defined as Tier 1 capital over a bank's total exposure measure, which consists of on-balance sheet items as well as off-balance sheet items. It is widely expected that the LR will become a Pillar I requirement for banks under Basel III, ever since the BCBS issued a consultative document[2] that outlined a baseline proposal for the design of the LR in December 2009.

However, the LR has been subject to various criticism raised by market participants and other stakeholders. The main concern relates to the risk-insensitivity of the LR: assets with the same nominal value but of different riskiness are treated equally and face the same capital requirement under the non-risk based LR.[3] Given that an LR requirement has a skewed impact, binding only for those banks with a large share of low risk-weighted assets on their balance sheets, the move away from a solely risk-based capital requirement may thus induce these banks to increase their risk-taking; potentially offsetting any benefits from requiring them to hold more capital. This paper addresses exactly this trade-off between additional loss-absorbing capacity and higher bank risk-taking associated with an LR requirement in both a theoretical and empirical setting.

First, we build a simple theoretical model that is able to capture the trade-off between risk-taking and higher loss-absorption associated with an LR requirement. The model yields two key results. First, imposing an LR constraint indeed incentivises banks that are bound by it to modestly increase risk-taking. This occurs because the non-risk based nature of the LR effectively reduces the marginal cost of risk-taking. Under an LR requirement bound banks are no longer forced to hold additional capital when they take greater risk, and greater risk is associated with a greater expected return. Given that capital is expensive, under a risk-based frame-

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[1]See BCBS (2014a). The Basel III regulations also include a strengthened risk-based capital framework and two new liquidity requirements, i.e. the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR).

[2]See BCBS (2009).

[3]See for example ESRB (2015).

work this incentivises banks to reduce their risk-taking as adding capital contributes to marginal costs. Under a binding LR requirement, this marginal cost disappears and hence banks increase their risk-taking since they can now increase risk and return without the penalty of having to hold greater capital.

Nevertheless, this increase in risk-taking is not unbounded. On the one hand, the risk-based capital framework underlies the LR constraint, such that if the bank takes too much additional risk it will simply move back into the risk-based capital framework. On the other hand, there exists an offsetting effect on risk-taking incentives from the fact that banks are required to hold greater capital, as this to some extent makes them more cautious (banks have more "skin in the game"). Consequently, the second key result from the model suggests that imposing an LR requirement should be beneficial for bank stability as the additional loss-absorbing capacity of banks dominates the increase in risk-taking. In particular, the model suggests that if the LR requirement is not set at an excessive level, adding an LR constraint to the risk-based capital framework will both weakly decrease banks' probability of failure, and if the distribution of banks is not such that the majority of banks are concentrated around the LR minimum requirement, which is arguably the case in reality, will strictly decrease expected losses.

The theoretical banking model that we develop therefore yields two testable hypotheses. First, the introduction of an LR requirement should incentivise banks for which it is a binding constraint to modestly increase risk-taking. Second, the negative impact of increased risk-taking induced by an LR requirement should be outweighed by the beneficial impact of increased loss-absorbing capacity, resulting in more stable banks. We take these two hypotheses and test them empirically on a large dataset of EU banks that encompasses a unique collection of bank distress events.

The empirical analysis follows in three steps. We first test whether banks with low LRs started to increase their risk-taking and capital positions after the announcement of the Basel III LR regime at the end of 2009 using a difference-in-difference type approach. We then estimate the joint effects of the LR and risk-taking on bank distress probabilities in a logit model framework, in order to quantify the risk-stability trade-off associated with an LR requirement. Finally, we combine the first and second stage empirical results into a counterfactual simulation to test whether the negative impact of the estimated increase in risk-taking is outweighed by the benefits of increasing loss-absorbing capacity, i.e. whether an LR requirement is beneficial for bank stability.

The empirical evidence provided in the paper lends support to both hypotheses. Our estimates suggest that banks bound by the LR constraint increase their risk-weighted assets to total assets ratio by around 1.5 - 2 percentage points more than they otherwise would without an LR requirement. Importantly, this small increase in risk-taking is more than compensated for by the substantial increase in capital positions for highly leveraged banks, which results in significantly lower estimated distress probabilities for banks bound by the LR.

The theoretical and empirical results of our paper therefore support the introduction of an LR requirement alongside the risk-based capital framework for banks. The analysis further suggests that the LR and the risk-based capital framework reinforce each other by covering risks which the other is less able to capture; making sure banks do not operate with excessive leverage and at the same time, have sufficient incentives for keeping risk-taking in check.

1   Introduction

Excessive leverage has been identified as a key driver of the recent financial crisis and of many past crises.[4] Moreover, in the recent crisis a significant number of banks were found to have built up excessive leverage while apparently maintaining strong risk-based capital ratios (BCBS, 2014a). As a response, the Basel Committee on Banking Supervision (BCBS) decided to introduce into the Basel III regulatory framework, a non-risk based Leverage Ratio (LR) requirement alongside the risk-based capital requirement. This was done to help contain the build-up of excessive leverage and to increase the stability of the banking system.[5] The LR is a non-risk based capital measure and is defined as Tier 1 capital over a bank's total exposure measure, which consists of on-balance sheet items as well as off-balance sheet items. The main idea is that imposing a cap on leverage will improve the loss absorbing capacity of highly leveraged banks and therefore reduce their failure probability, ultimately reducing the likelihood of a repeat crisis.

Nevertheless, the LR has been subject to various criticism raised by market participants and other stakeholders.[6] The main concern relates to its risk-insensitivity: as a non-risk based measure, assets of the same nominal value but of different riskiness are treated equally and face the same capital requirement. This has raised some anxiety that a move away from a solely risk-based capital framework will simply lead banks constrained by the LR requirement to increase their risk-taking; potentially offsetting any benefits from holding higher capital.[7]

This paper addresses exactly this trade-off between additional loss-absorbing capacity and higher bank risk-taking associated with an LR requirement. This is done in both a theoretical and empirical model. We first build a simple micro

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[4]Using a historical dataset for 14 developed countries over almost 140 years, Schularick and Taylor (2012) provide ample evidence that excessive leverage contributed to recurrent episodes of financial instability.

[5]See BCBS (2009) and BCBS (2014a). The Basel III banking regulations also include a strengthened risk-based capital framework and two new liquidity requirements, i.e. the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR).

[6]For example the ex-CEO of Barclays Antony Jenkins expressed concern about the LR saying it needed "to be interpreted with care to avoid unintended consequences such as credit restriction and asset quality dilution" (see Treanor (2013)). Other examples include the Financial Supervisory Authority in Sweden (Finansinspektionen (2015)) which noted that "if non-risk-sensitive capital requirements - such as a leverage ratio requirement or standardised floor - are set at a level that makes them the binding capital restriction, Sweden may end up with a smaller, but riskier banking system. [...] A high leverage ratio requirement could consequently result in less financial stability".

[7]When considering the potential disadvantages of the LR, the ESRB (2015) Handbook chapter on the LR states on page 14 that "Most importantly, the leverage ratio is insensitive to assessments of the riskiness of different assets. Used on its own, it can incentivise banks to regulatory arbitrage by taking on riskier assets."

model that suggests indeed there is an increased incentive to take higher risk once banks become constrained by the LR requirement. Nonetheless, our theoretical analysis suggests this increase in risk-taking should be limited and outweighed by the beneficial impact of the concurrent increase in loss-absorbing capacity arising from a higher capital requirement; so banks should become more stable with an LR requirement.

These theoretical results are then tested and confirmed within a three-stage empirical analysis on a large sample of EU banks for the period 2005 - 2014. First, we provide evidence of moderate increases in bank risk-taking using a difference-in-difference type approach taking the Basel III LR announcement in 2009 as a treatment that only affects a subset of banks that are highly leveraged. Second, we show in a logit model framework that the marginal beneficial impact of increasing a bank's LR is much bigger than the marginal negative impact of increased bank risk-taking, especially if highly leverage banks are forced to increase their LRs to levels that are close to the currently discussed minimum standards in the range of 3 - 5%. Third, we combine the first and second stage empirical results into a counterfactual simulation to show that the negative impact of the estimated increase in risk-taking is outweighed by the benefits of increasing loss-absorbing capacity, i.e. that an LR requirement should be beneficial for financial stability by significantly reducing the failure probability of highly leveraged banks.

For our theoretical analysis, we develop a bank micro model along the lines of Dell'Ariccia et al. (2014) that is able to capture the trade-off between risk-taking and higher loss-absorption associated with an LR requirement. In line with the Basel III regulatory framework, we consider a setting in which the risk-based capital framework is complemented with a non-risk based LR requirement. Banks thus face the maximum of two capital charges. The LR requires banks to hold capital against its assets independent of the riskiness of its portfolio, whereas the capital requirement of the risk-based framework depends on the risk choice of the bank. Banks can choose between two types of assets: a (relatively) safe asset and a risky asset. We then introduce the key friction of our model, a correlated system-wide shock that has a small probability of occurring, but hits both the safe and the risky asset. In our setting, the risk-weighted framework is not able to perfectly cover this correlated shock, therefore providing an opportunity for the LR to improve upon a situation with only a risk-based framework. This friction relates directly to one of the Basel Committee's key reasons for the imposition of an LR: the build-up of leverage in low-risk assets and the imperfect coverage of rare shocks to these assets under the risk-based capital framework (BCBS, 2014b).

In a first step, we show that if equity is costly, imposing an LR requirement incentivises banks bound by it to take on more risk. This occurs because under an LR requirement, constrained banks are no longer forced to hold additional capital when they take greater risk, and greater risk is associated with a greater expected return. Given that capital is expensive, under a risk-based framework this incentivises banks to reduce their risk-taking as adding capital contributes to marginal costs. Under a binding LR requirement, this marginal cost disappears and hence banks increase their risk-taking since they can now increase risk without the penalty of having to hold greater capital.

Despite this however, we then show that imposing an LR requirement should decrease both banks' probability of failure and expected losses to depositors. In other words, the benefit of increased loss absorbing capacity brought about by the LR requirement outweighs any negative impact from additional risk-taking. This is due to two reasons. First, and most importantly, there is a limit to how much additional risk a bank can take. If it takes too much additional risk, it will simply move back into the risk-based capital framework. Hence, as long as the risk-based requirement applies alongside the LR, it acts to constrain this risk-taking incentive. Second, there exists a skin-in-the-game effect that somewhat offsets the incentive to increase risk-taking once a bank is bound by the LR. Forcing banks to hold greater capital means they survive larger shocks. As a result, banks internalise returns which they otherwise would have ignored due to limited liability and this slightly decreases their incentive to take further risk.

Our model therefore illustrates both how incentives adjust under a combined LR and risk-based capital framework, and how the trade-off between higher loss absorbing capacity and increased risk-taking looks like once banks become constrained by the LR. The results add to the literature in a similar vain to Blum (2008) and Kiema and Jokivuolle (2014) who also look at the effects of imposing an LR requirement in addition to the risk-based capital framework, but with a different focus of the analysis.[8] Using an adverse selection model, Blum (2008) argues that a risk-independent capital ratio can improve bank stability through its disincentivising effect to con-

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[8]Prior to Blum (2008), the literature had not considered a combined LR, risk-based capital framework, thus we are one of the first to address the benefits and costs of imposing an LR alongside the risk-based capital framework. The literature on the nexus between capital and risk-taking has been remarkably inconclusive. Theoretical predictions have ranged from suggesting higher requirements lead to riskier asset profiles (e.g. Kahane (1977), Michael Koehn (1980) and Kim and Santomero (1988)) to either suggesting the effect can be ambiguous (Gennotte and Pyle (1991); Calem and Rob (1999); Blum (1999)) or lead to lower risk-taking incentives (Keeley and Furlong (1990); Flannery (1989); Hellmann et al. (2000); Repullo (2004); Repullo and Suarez (2004)).

ceal true risk-levels. Kiema and Jokivuolle (2014) consider a similar question but through a model risk perspective. They show that the introduction of an LR requirement can induce formerly low risk banks to increase risk-taking, however in the presence of model risk, which arises if some loans get incorrectly rated, an LR requirement can improve stability due to the presence of a greater capital buffer should these mispriced loans become toxic. We move away from these papers by abstracting from this gaming and model risk perspective and instead show that the LR (combined with a risk-based capital requirement) is beneficial for bank stability not just because banks wish to game the system, but also due to its additional loss absorbing capacity.[9]

Our theoretical model allows us to derive two main hypotheses, which we test empirically. To our knowledge, we are thus the first paper to combine a theoretical and empirical analysis of the imposition of an LR requirement. In particular, our two hypotheses suggest that: 1) Introducing an LR requirement incentivises those banks bound by it to modestly increase risk-taking; 2) Forcing banks to hold greater capital via an LR requirement is beneficial for bank stability. Using a sample of around 500 EU banks over the period 2005-2014, we find evidence in support of both our hypotheses.

First, we investigate risk-taking incentives via a difference-in-difference type approach. The announcement of the Basel III LR at the end of 2009 is taken as a treatment that only affects banks below the LR requirement, which allows us to carve out treatment and control groups. Banks with LRs below the minimum requirement of 3% currently tested by the BCBS are treated, while banks with LRs above the threshold are the control group.[10] We use changes in the risk-weighted asset (RWA) to total assets ratio as a proxy for risk-taking, which directly relates to our theoretical model. The results confirm our first hypothesis: an LR requirement leads banks to increase risk-taking, but this increase is relatively contained (in the region of a 1.5 to 2 p.p. increase in the RWA ratio), and small relative to the required capital increase from an LR requirement. This finding is also in line with the previous empirical literature that has suggested a positive relationship between capital and bank risk-taking (see e.g. Shrieves and Dahl (1992); Aggarwal and Jacques (2001); Rime (2001); Jokipii and Milne (2011)).[11] Yet this literature has been plagued by endogeneity issues since capital and risk are inextricably linked.

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[9]We take as given that banks truthfully report both their risk and capital levels. The model could easily be extended to include both gaming and model risk. All results would continue to hold.

[10]We also test for different threshold levels to classify banks into treatment and control groups.

[11]Other studies have also suggested a negative relationship (see e.g. Jacques and Nigro (1997)).

Since we focus on a regime change of moving from a fully risk-based capital framework to one in which there also exists an LR requirement, we are better able to identify any risk-taking effect without concern for reverse causality.

Second, we estimate the joint effects of the LR and risk-taking on bank distress probabilities in a logit model framework. We build on the early warning literature along the lines of Betz et al. (2014) and Estrella et al. (2000) who use logit models to analyse out-of-sample forecasting properties of specific variables. Both papers emphasise the benefits of higher capital levels for financial stability, while Berger and Bouwman (2013) have shown that banks with higher capital levels are more likely to survive a financial crisis. We refine this analysis within the context of the LR. We use our unique dataset of EU bank distress events between 2005 - 2014 and build a logit model to analyse the relationship between higher LRs, risk-taking and bank distress probabilities, in order to quantify the risk-stability trade-off associated with an LR requirement. We show that the LR is a very important determinant for bank distress probabilities, both economically and statistically. Importantly, the marginal benefit of increasing a bank's LR from low levels is an order of magnitude larger than the marginal negative impact from taking on greater risk.

Third, we use the results from the first two empirical exercises to analyse whether given our estimated increase in risk-taking, bank distress probabilities would decline following the imposition of an LR requirement. In particular, the results from the logit model are combined with the estimated increase in risk-taking from the difference-in-difference model in a counterfactual simulation. We ask whether bank distress probabilities significantly decline if an LR requirement forces banks to increase their LRs to the minimum or target level, but at the same time this has the side effect of increased risk-taking (represented via higher RWA ratios). We perform the exercise with a 3%, 4% and 5% LR minimum and in all cases bank distress probabilities significantly decline, even for our most conservative exercise where banks are assumed to increase their risk-taking by triple our estimated amount. The results therefore support the second hypothesis derived from the theoretical model, that banks should become more stable with the imposition of an LR requirement despite the slight increases in bank risk-taking.

The remainder of the paper is organised as follows. Section 2 presents a brief overview of the Basel III LR framework. Section 3 develops the bank micro model and derives the testable hypotheses regarding the effect of an LR requirement on risk-taking and bank stability. Section 4 tests the hypotheses empirically, and section 5 concludes.

2 The Basel III Leverage Ratio

As a response to the global financial crisis, the BCBS decided to undertake a major reform to the regulatory framework of the banking system. Under the new Basel III banking regulations, a non-risk based LR requirement will be introduced alongside the risk-based capital framework with the aim to "restrict the build-up of excessive leverage in the banking sector to avoid destabilising deleveraging processes that can damage the broader financial system and the economy".[12] The LR is a non-risk based capital measure and is defined as Tier 1 capital over a bank's total exposure measure, which consists of on-balance sheet items as well as off-balance sheet items.

It is widely expected that the LR will become a Pillar I requirement for banks under Basel III, ever since the BCBS issued a consultative document[13] that outlined a baseline proposal for the design of the LR in December 2009. Following further public consultations and revisions to the design, the BCBS issued the (almost) final LR framework in January 2014 and is currently testing a minimum Tier 1 leverage ratio of 3% until 1 January 2017 with a view to migrating to a Pillar 1 treatment on 1 January 2018. The BCBS will review the calibration of a minimum required leverage ratio framework and make any final adjustment to the definition by 2017.[14] Figure 1 summarises the key regulatory milestones related to the LR which will be used in the empirical analysis in section 4.2 to motivate the econometric set-up to identify the impact of an LR requirement on bank risk-taking.

3 Theoretical model

The following section presents a simple microeconomic model that captures the trade-off between risk-taking incentives and higher loss-absorbing capacity associated with the introduction of an LR requirement.

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[12]See BCBS (2014a). The Basel III regulations also include a strengthened risk-based capital framework and two new liquidity requirements, i.e. the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR).

[13]See BCBS (2009).

[14]In Europe, the EBA is currently preparing a report on the impact and the potential calibration of the Leverage Ratio. Based on the results of the report, the European Commission shall submit by the end of 2016 a report on the impact and effectiveness of the leverage ratio to the European Parliament and the Council.

Figure 1: Key dates regarding the introduction of the Basel III Leverage Ratio
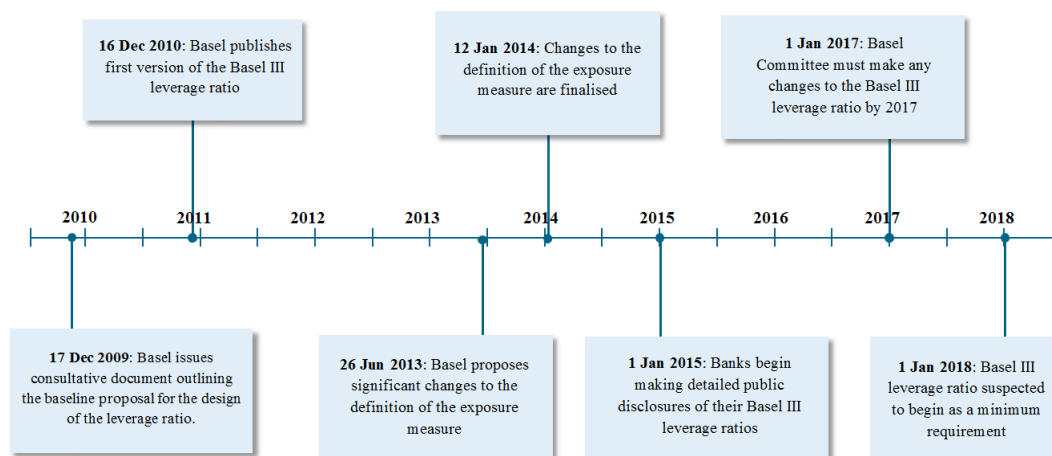
3.1 The set-up of the model environment

Consider a one-period economy with three types of agent: banks, investors and depositors. There are $n > 1$ banks, run by risk-neutral penniless bankers. The size of the bank's balance sheet is normalised to one. The bank finances itself with equity/capital k and deposits $(1 - k)$ subject to two capital requirements (a risk-based capital requirement and a leverage ratio requirement). There exists a continuum of identical, risk-neutral depositors. These depositors are negligible in size relative to banks. Depositors have two options: they either invest their endowment in bank deposits which yield a gross return of i, or alternatively deposit their endowment in a storage asset, which yields 1. Banks are covered by limited liability, they therefore repay depositors only in the case of survival. Nevertheless, there exists full deposit insurance.[15] This implies deposits are insensitive to risk-taking and will receive a deposit rate equal to the expected return on the safe asset $i = 1$.[16]

In addition to deposits, given bankers are wealth constrained (and must satisfy capital requirements), they can also raise funds by issuing equity. Investors have an outside option yielding ρ per unit of capital. As a result, given investors are risk-neutral, banks must ensure the return on equity they offer is at least as large

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[15]For simplicity, as in Hellman et al. (2000), we assume the insurance premium is zero. Nonetheless, our results hold for any fixed insurance premium

[16]Deposits will be insensitive to risk-taking since whether banks fail or survive, depositors will be fully compensated. As a result, as long as $i \geq 1$, depositors will prefer bank deposits (where at equality, depositors will be indifferent). Knowing this, banks will offer the lowest rate possible and thus set $i = 1$. Keeley and Furlong (1990) formally shows that when there exists deposit insurance, deposit supply will not be a function of bank risk.

as ρ in expected terms to satisfy their participation constraint. This setup offers a fair interpretation of the banking sector. There are many cases of banks announcing high targets for return on equity (ROE), often justifying this by the fact shareholders require them to achieve these high ROEs. Bankers often argue if they offered lower ROEs, this would make their shares unattractive, so they must target larger ROEs in order to attract funds. This narrative fits the current setup.[17]

Each bank may invest their funds in two assets: a risky asset and a (relatively) safe asset. Denote by ω investment in the safe asset and by $(1 - \omega)$ investment in the risky asset. As in Allen and Gale (2000), there exists a convex non-pecuniary investment cost to risky investment $c(\omega)$, where $c'(\omega) < 0$ and $c''(\omega) \leq 0$, so investing in the risky asset becomes increasingly expensive. Banks face two types of capital regulation: a risk-based requirement and a non-risk based leverage ratio requirement.

Since assets differ in their riskiness, the risk-based capital requirement is increasing in holdings of the risky asset. Specifically, under the Basel risk-based capital structure, on each asset banks are required to hold sufficient capital such that they cover expected and unexpected losses with some probability α, where in the Basel requirements $\alpha = 0.001$. Hence there exists a capital requirement k_{safe} on the safer asset, and k_{risky} on the risky asset. Given asset holdings of ω, the risk-based capital requirement can be written as $k_{rw} = k(\omega) = \omega k_{safe} + (1 - \omega)k_{risky}$.

In addition, banks are subject to an LR requirement which states that banks must hold a minimum level of capital k_{lev} independent of risk. The combined capital framework will be such that the bank must hold a capital level k greater than or equal to the higher of the two requirements, namely $k \geq \max\{k_{rw}, k_{lev}\}$. Which constraint requires the higher capital level depends on the riskiness of the bank's balance sheet. Figure 2 illustrates this. Since the risk-based requirement increases in holdings of the riskier asset, at low-risk holdings, the risk-based requirement (see the dotted diagonal line) lies below the LR requirement. As holdings of the riskier asset increase, the requirement also increases until beyond some level, denoted $(1 - \omega_{crit})$ in Figure 2, it starts to exceed the LR requirement. As a result, the combined capital framework exhibits a kinked structure.

There exist two possible states of nature, state 1, denoted s_1, which can be

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[17]This assumption can also be seen as a conservative assumption. If the outside option for investors were lower, the incentive to increase risk following the imposition of an LR would also be lower, since capital raising is no longer as expensive. The arguments against the LR crucially hinge on capital being a more expensive source of funds. Hence by making this assumption, we make it harder for the LR to produce a beneficial outcome. Consequently, reducing this assumption would merely make our results more favourable in terms of imposing an LR requirement.

Figure 2: Capital requirements under a combined leverage ratio and risk-based framework
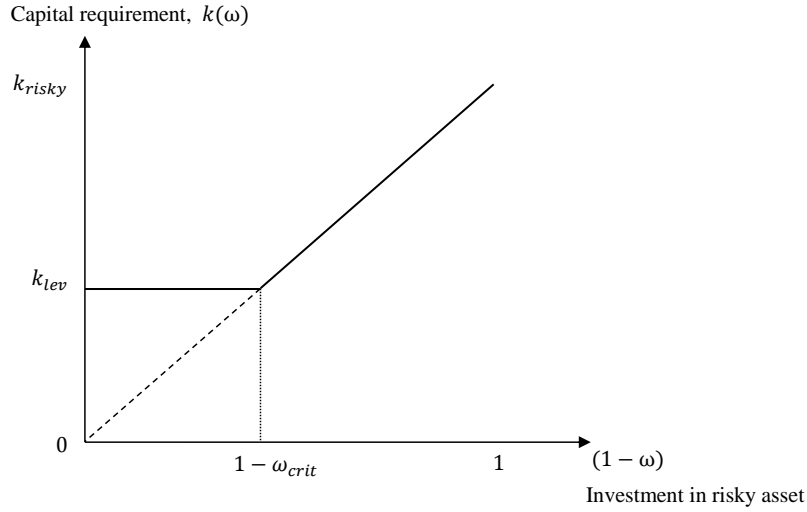

Notes: The graph shows the interaction between a leverage ratio requirement (k_{lev}) and the risk-based requirement which is increasing in $(1 - \omega)$. $(1 - \omega_{crit})$ is the point at which the capital requirement under both the risk-based and the leverage ratio requirement are equalised.

thought of as a good state, and state 2, denoted s_2, which can be thought of as a bad state. These states occur with probability μ and $(1 - \mu)$ respectively. Each asset's return is a function of the state of the world. The safe asset returns $R_1 \geq 1$ if state s_1 occurs, and $(1 - \lambda_1) \in (0, 1)$ if state s_2 occurs. On the other hand, in state s_1, the risky asset returns $R_2^h > R_1$ with probability π and $(1 - \lambda_2) \in (0, 1)$ with probability $(1 - \pi)$, while in state s_2, it returns $(1 - \lambda_3) \in (0, 1)$ with probability π, and 0 otherwise. The expected return on the risky asset is assumed to be greater than the expected return on the safe asset. The setup can be seen in Figure 3, where $\lambda_1 < \lambda_2 < \lambda_3$, and $\rho > [\mu R_1 + (1 - \mu)(1 - \lambda_1)]$. The risk of the bank's portfolio is thus determined by the investment proportion devoted to the risky asset relative to the safe asset.[18]

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[18]As discussed above, under the risk-based framework, the exact capital requirement will be a function of the probabilities: μ and π and how they relate to α. Let us consider the different possibilities. First, $(1 - \mu) = \alpha$, if this is the case, the risk-based capital requirement will require the bank to hold enough capital to survive state s_1, so $k_{safe} = 0$ and $k_{risky} = \lambda_2$. If $(1 - \mu) < \alpha$, again $k_{safe} = 0$, but k_{risky} will depend on π. If $(1 - \mu) + \mu(1 - \pi) > \alpha$, then $k_{risky} = \lambda_2$, else $k_{risky} = 0$. Since the case where $(1 - \mu) + \mu(1 - \pi) < \alpha$ entails a zero capital requirement under both assets and hence there is no risk-based nature to it, we ignore this case. So, ignoring the zero capital case, we can conclude that if $(1 - \mu) \leq \alpha$, $k_{safe} = 0$ and $k_{risky} = \lambda_2$. Suppose $(1 - \mu) > \alpha$, then it is immediately clear that $k_{safe} = \lambda_1$. For the risky asset, if $(1 - \mu)(1 - \pi) \leq \alpha$, then $k_{risky} = \lambda_3$, otherwise $k_{risky} = 1$. Since the case where $k_{risky} = 1$ implies a zero default probability for the bank, we ignore this case for the more realistic and interesting case of a positive default probability. Thus, if $(1 - \mu) > \alpha$, we can state that $k_{safe} = \lambda_1$ and $k_{risky} = \lambda_3$.

Figure 3: Payoff of the risky and safe asset

Safe asset: ω
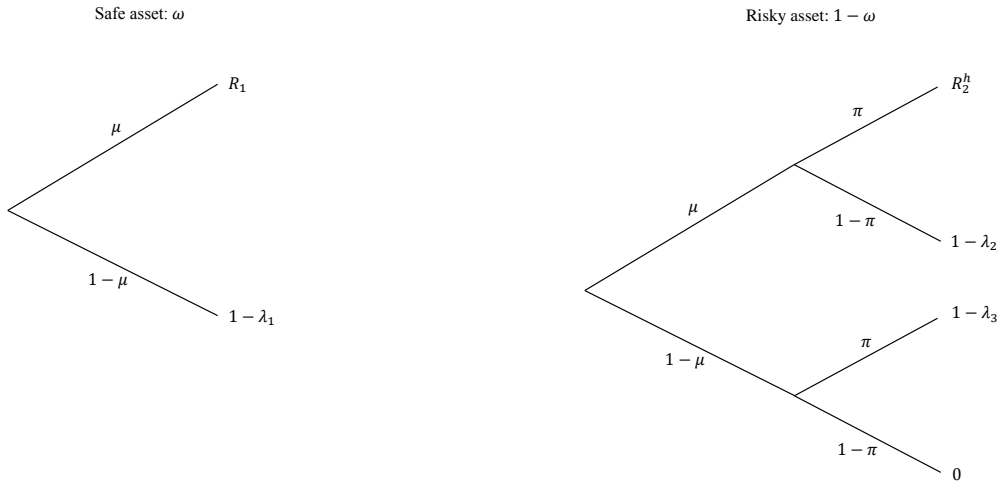
Risky asset: $1 - \omega$

Notes: Figure shows the payoff function dependent on the state of the world for the safe and risky asset.

The setup attempts to capture one of Basel's key reasons for the imposition of an LR: the inability of the risk-based framework to cover correlated shocks that also impact lower risk assets. We envisage state s_2 as a low probability event, but it is an event that hits both the safe and the risky asset. Hence it may be that the risk-weighted framework is not able to perfectly cover this correlated shock, thereby providing an opportunity for the LR to potentially improve upon a situation with only a risk-based framework.

3.2 The bank's decision problem

The objective for the bank is to maximise expected profits (conditional on survival). In order to achieve this, each bank must determine the structure of its portfolio in terms of both its asset and liability side. Each bank must optimally choose the amount of capital and deposits to hold (subject to both a risk-adjusted capital requirement and a leverage ratio constraint), how much to pay depositors and equity holders, and their investment $(\omega, 1 - \omega)$ in each asset. In order to raise funds, banks must satisfy both depositors and equity holders' participation constraints. As noted above, for depositors this implies banks must satisfy $i \geq 1$ since their outside option is to store their assets with a gross return of 1. In optimum, since banks wish to minimise costs, the bank will set $i = 1$. Investors on the other hand have an outside option ρ. Unlike depositors, they are not covered by deposit insurance, so banks must ensure they earn an expected gross return of at least their opportunity cost.

Suppose $(1-\theta)$ is the share of profits given to equity holders as compensation, then it must be that the bank ensures the following participation constraint is satisfied:

$$(1-\theta)[\mu\pi[\omega R_1 + (1-\omega)R_2^h - id] + \mu(1-\pi)\max\{[\omega R_1 + (1-\omega)(1-\lambda_2) - id], 0\}$$

$$+(1-\mu)\pi\max\{[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3) - id], 0\} + (1-\mu)(1-\pi)\max\{[\omega(1-\lambda_1) - id], 0\}] \geq \rho k$$

As with deposits, since banks treat this like a cost, in optimum this constraint must hold with equality.

Considering the entire setup together, we can write each bank's problem formally as:

$$\max_{\omega,\theta,i,k} \Pi = \theta[\mu\pi[\omega R_1 + (1-\omega)R_h^2 - id] + \mu(1-\pi)\max\{[\omega R_1 + (1-\omega)(1-\lambda_2) - id], 0\}$$

$$+(1-\mu)\pi\max\{[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3) - id], 0\} + (1-\mu)(1-\pi)\max\{[\omega(1-\lambda_1) - id], 0\}] - c(\omega)$$

subject to

$$(1-\theta)[\mu\pi[\omega R_1 + (1-\omega)R_2^h - id] + \mu(1-\pi)\max\{[\omega R_1 + (1-\omega)(1-\lambda_2) - id], 0\}$$

$$+(1-\mu)\pi\max\{[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3) - id], 0\} + (1-\mu)(1-\pi)\max\{[\omega(1-\lambda_1) - id], 0\}] \geq \rho k$$

$$d + k = 1$$

$$i \geq 1$$

$$k \geq \max\{k_{lev}, k(\omega)\}$$

where d is deposits, and following Dell'Ariccia et al. (2014), we parameterise the cost function as $c(\omega) = (c/2)(1-\omega)^2$.

It is worth noting that the above problem illustrates how bankers and equity holders are covered by limited liability. Whenever returns are negative, payoffs become zero. Furthermore, the problem illustrates how banks can adjust their probability of survival in two ways. First, banks can choose to directly decrease risk-taking, i.e. increase ω. Second, banks can increase their probability of survival by choosing to hold more capital. Should losses then occur, the bank is able to withstand them.

3.3 Main theoretical results

3.3.1 Risk-taking under a risk-based capital requirement

Let us first analyse the solution to the model when there exists only a risk-based capital requirement. The problem will be identical except since there does not exist an LR, the capital constraint will reduce to $k \geq k(\omega)$. As outlined in the previous paragraph, if desired, banks could choose to hold enough capital such they survive all potential losses. This has two effects. First, holding additional capital is costly since equity holders require an expected return of at least $\rho > 1$. Second, if the bank increases capital enough, it will be able to survive state s_2 which decreases the bank's probability of default and generates additional return. Yet this is a loss state in which the assets are yielding a gross return of less than 1. As Lemma 1 shows, the bank does not find it optimal to increase capital to survive these states. The cost of holding greater capital outweighs the benefit of obtaining the residual value in these states. Capital must return on average ρ to satisfy shareholders, yet depositors will accept $i = 1$. Since ρ is larger, ceteris paribus, banks will prefer to fund themselves with cheaper deposits. Banks will therefore never wish to hold more than the required capital amount. Indeed, banks would prefer to be 100% deposit financed, but due to the capital requirement, banks are forced to hold at least the minimum. As a result, the capital constraint binds. Lemma 1 formalises this.

Lemma 1 *Banks always wish to hold as little capital as possible; therefore the capital requirement will bind.*

Proof. See the appendix. ∎

Since the risk-weighted capital requirement will bind, it will impact risk-taking decisions. Holding more of the risky asset entails holding greater capital and as we have noted, this is expensive. Hence, there exists a trade-off between holding more of the risky asset, which in expected terms yields more, and the costs from doing so. The bank will choose the point at which the marginal revenue from greater investment in the risky asset equals the marginal cost. The first order condition (FOC) depicts this:[19]

$$\mu[\pi R_2^h + (1 - \pi)(1 - \lambda_2) - R_1] = -\rho k'(\omega) - k'(\omega)\mu - c'(\omega)$$

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[19]For illustrative purposes, in the text we consider the case where $(1 - \mu) \leq \alpha$, however the results are based on the more general case where $(1 - \mu)$ can be less than or equal to *alpha* or greater than α.

The left hand side (LHS) of this expression shows the marginal benefit from increasing holdings of the risky asset $(1 - \omega)$, while the right hand side (RHS) illustrates the marginal cost. The marginal benefit comprises the increased potential payoff the risky asset offers, while the marginal cost takes into account both the cost of investing in the risky asset, $c'(\omega) < 0$, and the fact that holding greater quantities of the risky asset require higher capital levels, shown in the $k'(\omega)$ terms. In the risk-based framework there is a trade-off the bank can exploit in terms of capital and risk; by choosing to hold less risk, the bank somewhat offsets the lower return by its ability to lower expensive capital. Banks trade off this potential loss of profits with the cost of risky investment, and hence choose a risk level such that the marginal benefit from increasing $(1 - \omega)$ is zero.

The condition illustrates the trade-off banks possess when risk-taking under a risk-based framework. Increasing the weight on the risky asset increases potential returns, but at the same time entails costs related to investment and capital raising. A risk-weighted capital requirement thus disincentivises risk-taking, as it forces banks to hold more capital if they wish to take on more risk.

3.3.2   Risk-taking with a leverage ratio requirement

Suppose that now banks are subject to an additional constraint, namely, a constraint on leverage such that $k \geq k_{lev}$ regardless of ω. Given the leverage ratio exists alongside the risk-based capital framework, any LR below the risk-weighted requirement will have no effect (since it does not bind) and the results of the previous paragraph still hold. In order to make the LR bite, the LR must be set such that it is above the risk-weighted capital requirement of a bank. Suppose the LR is set to $k_{lev} > k(\omega_{rw}^*)$ such that it is the binding constraint, where ω_{rw}^* denotes the optimal risk level under the risk-based framework. Although banks can now potentially survive larger losses (since they hold greater capital), it may be that as a result of the LR, bound banks shift so much of their portfolio into the risky asset that even with this higher level of capital, they cannot withstand these now more probable, larger losses. Whether this increase in capital is beneficial depends on how much (if at all) the bank is incentivised to shift its portfolio into the risky asset (which is more likely to fail and its residual value is lower).

The change in risk incentives can be clearly seen by comparing the FOC with respect to ω under a risk-based framework to the FOC if the LR is binding. Suppose the LR is set just above the risk-based capital requirement, then the FOC will be

characterised by:

$$\mu[\pi R_2^h + (1 - \pi)(1 - \lambda_2) - R_1] = -c'(\omega)$$

As can be seen, all terms related to the risk-weighted capital requirement have disappeared due to the binding LR. Removing this dependence on risk means banks can now increase risk without having to hold additional capital. In other words, the marginal cost of risk-taking declines as there is no longer a requirement to increase expensive capital if the bank increases $(1 - \omega)$. By removing the link between capital and risk-taking, the bank will be incentivised to take more risk. At the same time however, depending on the LR level, the benefit from increasing risk-taking can also slightly decrease since banks now survive slightly larger shocks with higher capital and thus they are forced to internalise these returns they otherwise would have ignored - so called "skin-in-the-game". Due to the discrete nature of the asset setup, this effect first appears when the LR is set high enough that the bank can survive state s_2 when the risky asset pays off $(1 - \lambda_3)$. The FOC becomes:

$$\mu[\pi R_2^h + (1 - \pi)(1 - \lambda_2) - R_1] - (1 - \mu)\pi(\lambda_3 - \lambda_1) = -c'(\omega)$$

Compared to the previous FOC, one can clearly see the presence of a "skin-in-the-game" effect, $(1 - \mu)\pi(\lambda_3 - \lambda_1)$, which brings down the chosen level of risk slightly. As capital holdings rise, banks survive larger and larger shocks.[20] Since banks then attach value to these returns, this decreases the benefit of higher risk-taking. There are thus two opposing effects. The first effect (i.e. removing the link between risk and capital) - the loss of the $k'(\omega)$ terms in the FOC - incentivises greater risk-taking, whereas the second effect - the skin-in-the-game effect - incentivises less risk-taking. Yet this "skin-in-the-game" effect is small; state s_2 is a low probability state and thus $(1 - \mu)$ is small. Proposition 2 formalises this and shows that when equity is costly, in particular when $\rho > \max\left\{1 + \alpha\left[\frac{1 - \lambda_1}{(\lambda_3 - \lambda_1)}\right], (1 - \alpha) + \alpha\frac{[\pi\lambda_3 + (1 - \pi) - \lambda_1]}{\lambda_2}\right\}$ (where remember $\alpha = 0.001$, so ρ does not need to be very large to satisfy this condition), the first effect always dominates and banks increase risk-taking with an LR requirement.[21]

Proposition 2 *If equity is costly, imposing a leverage ratio requirement incentivises banks to take on more risk.*

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[20]Due to the discrete nature of the model this occurs with jumps.

[21]As will be discussed in further detail later, for larger values of ρ and k, the optimal level of risk as given by the FOCs, may not be sufficient to satisfy the shareholders' participation constraint, since $\rho > \mu R_1 + (1 - \mu)(1 - \lambda_1)$. This means banks must choose a higher risk level than desired. This however does not alter any of the results in this section since by definition this would require a higher risk level than that optimally chosen by the bank.

Proof. See the appendix. ∎

We can conclude therefore that once the LR binds, risk-taking will increase. The LR in effect allows banks to engage in greater risk-shifting. Removing the binding risk-weighted capital requirement allows banks to increase risk while imposing most of that risk onto depositors (ultimately taxpayers) - since they are not forced to raise any further capital. Since there exists full deposit insurance, depositors are not sensitive to this risk-taking; hence banks increase risk without incurring higher funding costs. With a risk-weighted capital requirement, this ability to risk-shift is somewhat offset since taking on further risk implies increasing capital, which is expensive. Once the risk-weighted capital requirement ceases to bind, banks can increase risk-taking without needing further additions of capital. This was a major inhibitor to risk-taking, hence under a leverage ratio, banks have a greater incentive to risk-shift.

3.3.3 Risk-taking vs. loss absorbing capacity

Proposition 2 showed that imposing an LR can incentivise banks to increase risk-taking. Nonetheless, this does not imply that an LR is detrimental. Quite the contrary, whether the LR improves a bank's default probability or expected losses depends on the extent of this risk-taking compared to increased loss absorbing capacity. With an LR, banks may potentially survive a state s_2 shock, but in order to generate a benefit, it must be that any additional risk is outweighed by this loss-absorbing capacity. At the same time, even if the probability of default remains the same, the LR may induce a benefit via its effect on expected losses - since any losses that do occur, bear more onto the bank rather than depositors. Proposition 3 formalises this discussion.

Proposition 3 *If the LR is not set too high, so $k_{lev} < \overline{k}$, imposing a leverage ratio requirement will both:*

1. *Weakly decrease failure probabilities*

2. *And strictly decrease expected losses if $k_{lev} > \underline{k}$*

where $\underline{k}$ and $\overline{k}$ are defined in the appendix.

Proof. See the appendix. ∎

Proposition 3 illustrates that an LR can improve default probabilities and reduce expected losses. In other words, risk-taking is not sufficiently large to outweigh the loss-absorbing benefit. This is due to two reasons. First, as we noted before, the skin-in-the-game effect somewhat offsets this incentive to increase risk-taking. This to an extent subdues the risk-taking incentive. Second, and more importantly, there is a limit to how much additional risk a bank can take, since if it takes too much risk, it will simply move back into the risk-based framework. Since this acts as a backstop to risk-taking, banks are limited in the extent to which they can increase risk-taking. These two effects combine to prevent excessive risk-taking and thus the LR has a beneficial effect.

The lower bound on the expected losses condition is related to the amount of loss absorbing capacity available. For example, if the LR is set to an epsilon above the risk-weighted capital requirement for a bank, the LR adds barely any additional loss absorbing capacity, yet, the bank will take on more risk; this therefore leads to an increase in expected losses relative to the solely risk-based framework. At higher levels of capital, the additional loss absorption is sufficient to outweigh any additional risk-taking. The result suggests therefore that if we consider a distribution of banks with different risk-based capital requirements, which is arguably the case in reality, as long as the distribution is not concentrated around the LR minimum, an LR requirement will lead to a strict decline in expected losses.

Lastly, Proposition 3 shows there is a potential risk to setting the leverage ratio too high. This is because since $\rho > [\mu R_1 + (1 - \mu)(1 - \lambda_1)]$, as the LR rises beyond some point, the optimal choice of risk that the bank would like to take no longer meets the shareholders' participation constraint. As a result, banks can be forced to increase risk-taking further just to meet their required return on equity. The point at which this arises depends on the size of ρ, with higher levels of ρ reducing this point. At these higher levels of capital, the increase in risk-taking is not sufficiently constrained and thus a leverage ratio can be detrimental.

4   Empirical analysis

The model presented in the previous section suggests two testable hypotheses. First, the introduction of an LR requirement should incentivise banks for which it is a binding constraint to modestly increase risk-taking. Second, the negative impact of increased risk-taking induced by a leverage ratio constraint should be outweighed by the beneficial impact of increased loss-absorbing capacity, resulting in more stable

banks. We take these two hypotheses and test them empirically on a large dataset of EU banks that encompasses a unique collection of bank distress events. The empirical analysis follows in three steps. We first test whether banks with low leverage ratios started to increase their risk-taking and capital positions after the announcement of the Basel III LR regime using a difference-in-difference type approach. We then estimate the joint effects of the LR and risk-taking on bank distress probabilities in a logit model framework, in order to quantify the risk-stability trade-off associated with an LR requirement. Finally, we combine the first and second stage empirical results into a counterfactual simulation to test whether the negative impact of the estimated increase in risk-taking is outweighed by the benefits of increasing loss-absorbing capacity, i.e. whether a leverage ratio requirement is beneficial for bank stability.

The empirical evidence provided in the following sections lends support to both hypotheses. Our estimates suggest that banks bound by the leverage ratio requirement increase their risk-weighted assets to total assets ratio by around 1.5 - 2 percentage points more than they otherwise would without a leverage ratio requirement. Importantly, this small increase in risk-taking is more than compensated for by the substantial increase in capital positions for highly leveraged banks, which results in significantly lower estimated distress probabilities for banks constrained by the LR. The remainder of this section describes the underlying dataset and detailed results of the three stages of the empirical analysis.

4.1   Dataset

The dataset consists of a large unbalanced panel of around 500 EU banks covering the years 2005 - 2014, and is based on publicly available data only. There are three main building blocks of the dataset: i) a large set of bank-specific variables based on publicly available annual financial statements from SNL; ii) a unique collection of bank distress events that covers bankruptcies, defaults, liquidations, state-aid cases and distressed mergers from various data sources and; iii) various country-level macro-financial variables from the ECB's Statistical Data Warehouse. The dataset builds upon and expands the dataset described in Betz et al. (2014) and Lang et al. (2015).

4.2 Effect of a leverage ratio constraint on bank risk-taking

To identify how the risk-taking behaviour of a bank changes after the imposition of an LR requirement, we exploit the panel structure of our dataset in combination with the timing of the Basel III LR announcement, as described in section 2. We attempt to achieve identification by borrowing from the programme evaluation literature and treating the announcement of the Basel III LR as a treatment that only affects a subset of banks, i.e. only banks below the LR requirement.[22] Since our dataset includes time periods where a leverage ratio was not part of the regulatory regime (only the risk-based framework was in existence), we use a difference-in-difference type analysis in which the effect of an LR requirement on risk-taking is estimated through a treatment dummy, while controlling for a large set of bank-specific and country-level variables that capture systematic differences in bank behaviour pre- and post-treatment. Our econometric strategy therefore is to compare the periods before the existence of an LR requirement with the periods after and then to analyse whether those who were affected by the imposition of an LR requirement (i.e. those treated) increased their risk-taking behaviour.

Our identification strategy is somewhat complicated by the fact that the LR will not become a binding Pillar I regulatory requirement until 2018. Nevertheless, we rely on the assumption that banks already started to adjust their behaviour in response to the Basel III LR announcement, for which there seems to be ample anecdotal evidence.[23] The assumption that banks started to react already to the Basel III LR announcement can also be justified by the fact that large banks were already required to start reporting their leverage ratios to supervisors from the beginning of 2015 onwards. Moreover, adjusting balance sheet structures takes time, so that it is reasonable to assume that banks already started to react well in advance of the LR becoming a binding regulatory requirement. Indeed, economic reasoning suggests that in order to properly identify the effect of the Basel III LR, it is necessary to take into account anticipatory effects, since by 2018 all banks must already satisfy the leverage ratio requirement and thus any effects on risk-taking will probably already have occurred before that date. Formally, our empirical strategy

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[22]This classification of banks into treatment and control groups can be justified with the kinked structure of capital requirements under a combined leverage ratio and risk-based capital framework, which was illustrated in figure 2. The leverage ratio requirement will only bind for those banks with leverage ratios below the minimum requirement, or in other words for banks with low risk-weighted asset ratios. For all other banks, the risk-based capital framework will remain the binding constraint, so their behaviour should not be different in the pre-treatment and post-treatment periods, i.e. they can be seen as the control group.

[23]Next to anecdotal evidence, the empirical evidence provided in this paper shows that banks with low leverage ratios started to bolster them after the Basel III LR announcement.

consists of estimating various versions of the following general panel model, where the left-hand-side variable is a risk-taking proxy (either in levels or first differences) for bank i, located in country j, in year t:

$$y_{i,j,t} = \alpha + \beta T_{i,j,t} + \theta' X_{i,j,t} + \varphi' Y_{j,t} + \mu_i + \lambda_t + \epsilon_{i,j,t} \tag{1}$$

The terms μ_i and λ_t are bank and time fixed-effects respectively, $X_{i,j,t}$ and $Y_{j,t}$ are vectors of bank-specific and country-specific control variables that may also include lags and differences, and $\epsilon_{i,j,t}$ is an i.i.d error term. In the risk-taking model above, $T_{i,j,t}$ is the treatment dummy of interest. It is set equal to 1 for a given bank and year if its leverage ratio in the previous year was below the (planned) regulatory minimum, but only for years following the first announcement of the Basel III LR. The treatment dummy is set to 0 otherwise. Thus, the coefficient of interest for the first stage of the empirical analysis is β, which measures how the announcement of the Basel III LR requirement has affected the risk-taking behaviour of banks. 2010 is set as the treatment start date in reference to the December 2009 BCBS consultative document that outlined the baseline proposal for the LR (see timeline presented in Figure 1). Moreover, 3% is taken as the relevant LR threshold since the BCBS is currently testing a minimum leverage ratio of 3% until 1 January 2017.[24] As our measure of bank risk-taking, we use the ratio of risk-weighted assets to total assets. While the ratio of risk-weighted assets to total assets is an imperfect measure of true bank risk-taking, it is the most direct measure of risk-taking, and it is the measure that should be affected by the introduction of a leverage ratio requirement.[25] Since data for the Basel III definition of the LR is unavailable, as our LR proxy, the ratio of Tier 1 equity to total assets is used, which has been shown to correlate highly with the Basel III regulatory definition of the LR.

Table 1 presents the baseline estimation results for the effect of the Basel III LR announcement on the risk-taking behaviour of EU banks. In line with the first hypothesis that was derived from the theoretical model in section 2, the results suggest that since the Basel III LR framework was announced at the end of 2009, EU

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[24]For robustness purposes we also test different threshold levels to classify treatment and control groups.

[25]While the risk-weighted assets ratio is potentially imprecise for comparing the level of risk-taking across banks, changes in this measure for a given bank should in principle be highly correlated with actual changes in risk-taking. This should be true as long as internal risk models for a given bank do not change abruptly and risk-weight levels under the standardised approach and for a given set of internal models are positively correlated with true risk. In addition, control variables for the calculation method of risk weights are included in the panel regressions, which should partly account for the fact that risk-weight levels appear to differ systematically between the standardised approach and the internal ratings based approach for determining risk-weights.

banks with low leverage ratios have slightly increased their risk-taking, as measured by their risk-weighted assets to total assets ratio. This conclusion is robust to whether the model is specified in first differences (columns 1 - 3) or levels (columns 4 - 7) and whether the estimation method is fixed-effects regression (columns 1 - 5) or dynamic panel GMM (columns 6 - 7) as in Arellano and Bond (1991).[26] The estimated coefficients for the treatment effect are always positive and highly significant for virtually all model specifications. In terms of the quantitative impact, the point estimates for the treatment effect of a 3% leverage ratio requirement suggest that banks bound by it increase their risk-weighted assets ratio by around 1.2 to 2 percentage points more than they otherwise would, which appears rather muted.

What is more, while the Basel III LR announcement seems to have incentivised slightly higher risk-taking, the concurrent strengthening of the risk-based capital framework under Basel III seems to have had the opposite effect.[27] Specifically, the range of point estimates presented in Table 1 suggests that banks with Tier 1 ratios below 10% reduced their risk-weighted asset ratios by 0.36 to 2.3 percentage points more than they otherwise would have, after the strengthening of the risk-based capital framework under Basel III was announced. Hence, the small estimated effects on bank risk-taking of the Basel III leverage ratio announcement are not a result of the concurrent strengthening of the risk-based capital framework since this effect is controlled for.

The small estimated increase in risk-taking for banks bound by the Basel III LR remains robust to various other tests, both quantitatively and in terms of statistical significance. First, columns 1 - 3 in Table 2 show that the result is robust to using different bank and country samples. Second, the results in columns 4 - 6 tackle potential concerns that banks with vastly different leverage ratios are fundamentally different through a Regression Discontinuity Design (RDD).[28] By restricting

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[26]Fixed effects (FE) regression and GMM are both estimated since a lagged dependent variable is introduced in the model. In the FE regressions all variables are lagged by one period to avoid endogeneity issues. In the GMM estimation, contemporaneous variables are used but those that are considered as endogenous are instrumented. In particular, the GMM estimation takes macro-financial variables and the Basel regime indicators as exogenous; all other variables are instrumented using lags of the variable in question.

[27]The Tier 1 treatment dummy in the risk-taking regressions is constructed in a similar way to the leverage ratio treatment dummy. It is set equal to 1 for a given bank and year if its Tier 1 ratio in the previous year was below 10%, but only for years after 2009 in reference to the Basel III regulatory overhaul. The treatment dummy is set to 0 otherwise.

[28]Without controls, the validity of difference-in-difference crucially relies on the identical ex-ante behaviour of banks in the control and treatment groups, so that it is only the treatment that generates differing behaviour, not differences among group participants.

Table 1: Estimated effect of the Basel III leverage ratio on bank risk-taking

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Leverage ratio treatment	1.748***	1.713**	1.225*	1.340**	0.638	1.657*	1.973**
Tier 1 ratio treatment	-2.335***	-2.212***	-1.458***	-1.023**	-0.653	-0.687	-0.363
RWA / Total assets, lag		-0.127***	-0.154***	0.464***	0.447***	0.351***	0.320***
RWA / Total assets, lag 2			-0.193***		-0.095***	-0.070	-0.068
Total assets, log	1.663**	0.893	0.553	-7.164***	-8.382***	-11.68***	-11.02***
Total loans / Total assets	-0.012	0.029	0.015	0.257***	0.255***	0.332***	0.325***
Pre-tax ROA	0.173	0.291	0.351	0.147	0.079	0.340*	0.305*
Net interest margin	-1.257***	-1.182**	-0.755	1.425***	1.864***	1.706*	2.136**
NPLs / Total assets				0.096*	0.084	0.013	0.003
Basel II dummy	-2.364**	-2.306**	3.242*	-0.773	-0.539	-2.607	-3.004*
Basel II.5 dummy	-2.369**	-2.180*	3.211*	-0.714	-0.806	-2.824*	-3.162*
Basel III dummy	-0.096	0.200	3.933	-0.025	-0.322	-2.907	-3.610
Advanced IRB dummy	0.754	-0.062	-2.339	-1.263	-2.466*	-1.278	0.666
Foundations IRB dummy	-0.632	-0.573	-1.836	-1.894**	-3.837***	-4.809**	-5.744***
Mix IRB / SA dummy	-1.012	-1.234	-2.809***	-4.518***	-4.913***	-2.215	-1.023
GDP growth, y-on-y	-0.235**	-0.241**	-0.239*	-0.165	-0.131	-0.070	-0.039
Inflation, y-on-y	0.297*	0.232	0.472***	-0.290*	-0.427**	-0.770***	-0.827***
Unempl. rate change, y-on-y	0.673***	0.578**	0.633*				
MIP financial sector debt	0.068**	0.065**	0.053				
Total credit / GDP	-0.020	-0.019	-0.028	0.053***	0.059***	0.052*	0.043*
Stock price growth, y-on-y	0.054***	0.063***	0.037**				
Bund-spread	-0.088	-0.076	-0.106	0.083	0.004	0.265*	0.274**
House price growth, y-on-y				0.040	0.032	-0.004	0.0002
Government Debt / GDP				-0.012	-0.024	-0.060	-0.058
Intercept	2.793	2.591	0.676	28.01***	42.69***		
Observations	2,711	2,550	2,038	2,795	2,343	1,801	1,801
R-squared	0.076	0.092	0.124	0.535	0.500		
Number of banks	617	583	528	571	537	474	474
AR1-p						2.80e-05	2.45e-05
AR2-p						0.785	0.790
Hansen-p						0.495	0.192
Dependent variable	Differenced	Differenced	Differenced	Level	Level	Level	Level
Lagged dependent	No	Lag 1	Lag 2	Lag 1	Lag 2	Lag 2	Lag 2
Estimation method	FE	FE	FE	FE	FE	GMM	GMM
Bank sample	All EU	All EU	All EU	All EU	All EU	All EU	All EU

Notes: The dependent variable is the risk-weighted assets to total assets ratio (expressed as a percentage) either in differences (columns 1-3) or levels (columns 4-7). For the models in differences all explanatory variables are lagged by one period to avoid endogeneity issues. For the models in levels contemporaneous explanatory variables are used, but those that are considered as potentially endogenous are instrumented by their own lags in the GMM estimations. The models in columns 1-5 are estimated with bank and time fixed-effects (FE). Columns 6-7 are estimated using GMM, where in column 6 all valid lags of the dependent variable and bank-specific variables are used as GMM-style instruments, while in column 7 all valid lags up to lag 5 are used as GMM-style instruments. Macro variables and Basel regime variables are treated as exogenous and are therefore used as IV-style instruments in columns 6-7. AR1-p, AR2-p and Hansen-p refer to the p-values of the tests for first- and second-order autocorrelation of the differenced residuals and exogeneity of the instruments using the Hansen J statistic respectively. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. Significance is based on clustered robust standard errors. For the models in first differences (columns 1-3), the following explanatory variables are also transformed into first differences: the lags of risk-weighted assets / total assets, the logarithm of total assets, the ratio of total loans to total assets, and the bund-spread.

Table 2: Robustness of the estimated effect on bank risk-taking

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Leverage ratio treatment, 3%	1.678***	1.025*	2.217***	1.238*	1.305*	1.566**	2.284**			
Leverage ratio treatment 2, 3%								-2.072**		
Leverage ratio treatment, 4%									1.571***	
Leverage ratio treatment, 5%										1.834***
Tier 1 ratio treatment	-2.394***	-1.904***	-2.556***	-1.755***	-2.383**	-2.585***	-2.398***	-2.213***	-2.186***	-2.244***
Observations	2,325	1,476	646	1,010	545	1,767	1,754	2,550	2,550	2,550
R-squared	0.086	0.074	0.111	0.161	0.254	0.126	0.105	0.092	0.093	0.096
Number of banks	529	324	107	274	185	433	506	583	583	583
Estimation method	FE	FE	FE	FE RDD, optimal	FE RDD, half	FE RDD, double	FE	FE	FE	FE
Bank sample	Western Europe	W. Europe excl. GIIPS	SSM SIs	All EU	All EU	All EU	All EU 3 > LR > 5	All EU	All EU	All EU

Notes: The dependent variable is the first difference of the risk-weighted assets to total assets ratio (expressed in percentage points). The same set of control variables as in the second column of Table 1 are included in all of the regressions, including bank and time fixed-effects. All explanatory variables are lagged by one period to avoid endogeneity issues. All EU sample means estimation is based on all of the EU banks contained in the dataset. Western Europe represents the bank subsample encompassing Austria, Belgium, Germany, Denmark, Spain, Finland, France, the UK, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Sweden. The Western Europe excl. GIIPS sample represents the Western Europe sample excluding banks from Greece, Italy, Ireland, Portugal and Spain. The SSM SI sample includes only significant institutions (SIs) which are directly supervised by the ECB's Single Supervisory Mechanism (SSM). All EU $3 > LR > 5$ excludes all observations where a given bank had a leverage ratio greater or equal than 3% and smaller or equal than 5%. RDD refers to a Regression Discontinuity Design that restricts the estimation sample to banks that are close to the leverage ratio threshold on either side. The optimal band-width is plus / minus 1.805 around the baseline 3% leverage ratio threshold. The leverage ratio treatment variables are dummy variables that indicate whether a given bank had a leverage ratio below the threshold level in the previous year, for years after 2009. The leverage ratio treatment 2 variable measures the one-sided distance from the required minimum level. Formally: treatment variable $2 = $ treatment dummy $\cdot (LR - LR_{min})$. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. Significance is based on clustered robust standard errors.

the estimation sample to banks that are close to either side of the LR threshold it is more likely that these banks exhibit similar ex-ante behaviour. This allows us to estimate a local average treatment effect (LATE). The optimal bandwidth around the LR threshold is determined via the procedure proposed by Imbens and Kalyanaraman (2012). As can be seen from columns 4 - 6, our core result is left unchanged. The treatment dummy remains significant at all different bandwidth levels (we experiment with different bandwidth levels for robustness) and the coefficient remains within a similar region of magnitude, namely between 1.24 and 1.57 percentage points.

Columns 7 - 10 of Table 2 tackle concerns related to potential misclassifications of the treatment and control groups, given that uncertainty remains over the final level of the LR threshold. Column 7 shows that the significant small increase in risk-taking remains when the model is re-estimated excluding all banks with LRs between 3% and 5%.[29] In addition, column 8 in Table 2 suggests that the induced increase in risk-taking due to the LR requirement is smaller, the closer a bank is to the 3% LR threshold.[30] The coefficient estimate suggests that banks with LRs of 1.5%, 2% and 2.5% adjusted their risk-weighted asset ratios upward by 3.1, 2.1 and 1.0 percentage points respectively. This fits well with intuition, since the incentive for additional risk-taking should be smaller if a bank is required to increase capital

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[29]Since the leverage ratio minimum is widely expected to be between 3% - 5%, excluding all bank observations with leverage ratios in this range should alleviate potential misclassification problems of treatment and control groups.

[30]The 3% leverage ratio treatment 2 variable measures the one-sided distance from the required minimum level. Hence, if the leverage ratio of a bank was 1%, the treatment variable would be -2%. Formally: treatment variable $2 = $ treatment dummy $\cdot (LR - LR_{min})$.

only slightly, say from a 2.9% to a 3% LR, compared to if a bank is required to increase capital by a lot, for instance from a 1% to a 3% LR. Finally, columns 9 - 10 in Table 2 show that significant coefficient estimates with similar magnitudes as before are obtained if the LR treatment dummy is based on a 4% and 5% minimum leverage ratio requirement. In summary, the results from the first stage empirical exercise suggest that an LR requirement appears to incentivise additional risk-taking for banks bound by it, but this additional risk-taking appears limited, as suggested by our theoretical model of section 3.

To shed more light on banks' reactions to the Basel III LR announcement, the risk-taking regressions are also re-estimated with the change in a bank's LR as the dependent variable, to see if treated banks were increasing their LRs at the same time as taking on further risk. This indeed seems to have been the case, as can be seen from Table 3, with estimates of around a 0.44 - 1.1 percentage point greater increases in a bank's LR than would have otherwise happened. This result is again robust to different country and bank samples, running various RDD specifications, and assuming different treatment thresholds. This finding also provides support for the assumption that banks already started to react to the Basel III LR upon announcement in 2009, well before it is planned to migrate to a binding Pillar I regulatory requirement in 2018. To summarise, while treated banks may have increased their risk-weighted assets ratios by around 1.5 to 2 p.p. more, they also increased their leverage ratios by up to 1 p.p. more over the period of consideration. This is a considerably higher increase in a bank's capital position than what would be required under the risk-based capital framework to cover the estimated increase in risk-weighted assets.

4.3   Trade-off between loss-absorption and risk-taking

For the second part of the empirical analysis, we use our unique dataset of EU bank distress events in a discrete choice modelling framework, to analyse the joint effects of the LR and risk-taking on bank distress probabilities. This analysis is crucial in order to quantify the net impact of the risk-stability trade-off associated with an LR requirement. As discussed in van den Berg et al. (2008), a logit model is preferred over a probit model, because the fatter tailed error distribution matches better to the empirical frequency of bank distress events. While the early-warning literature has commonly used a pooled logit approach (see e.g. Lo Duca and Peltonen (2013)) we control for both time and country fixed-effects, since in-sample fit and unbiased coefficient estimates are more important for our analysis than optimising out-of-

Table 3: Estimated effect on banks' leverage ratios

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Leverage ratio treatment, 3%	0.831***	0.795***	1.146***	0.439***	0.518***	0.718***	1.081***			
Leverage ratio treatment 2, 3%								-0.999***		
Leverage ratio treatment, 4%									0.652***	
Leverage ratio treatment, 5%										0.492***
Tier 1 ratio treatment	0.400***	0.354***	0.662***	0.142	-0.132	0.169	0.473***	0.400***	0.419***	0.420***
Observations	2,631	2,393	648	1,021	544	1,807	1,826	2,631	2,631	2,631
R-squared	0.102	0.095	0.164	0.152	0.215	0.137	0.110	0.102	0.103	0.098
Number of banks	602	538	107	280	186	451	524	602	602	602
Estimation method	FE	FE	FE	FE RDD, optimal	FE RDD, half	FE RDD, double	FE	FE	FE	FE
Bank sample	Western Europe	W. Europe excl. GIIPS	SSM SIs	All EU	All EU	All EU	All EU $3 > LR > 5$	All EU	All EU	All EU

Notes: The dependent variable is the first difference of the leverage ratio (expressed in percentage points). The same set of control variables as in the second column of Table 1 are included in all of the regressions, including bank and time fixed-effects. All explanatory variables are lagged by one period to avoid endogeneity issues. All EU sample means estimation is based on all of the EU banks contained in the dataset. Western Europe excl. GIIPS represents the bank subsample encompassing Austria, Belgium, Germany, Denmark, Finland, France, the UK, Luxembourg, the Netherlands, and Sweden. The SSM SI sample includes only significant institutions (SIs) which are directly supervised by the ECB's Single Supervisory Mechanism (SSM). All EU $3 > LR > 5$ excludes all observations where a given bank had a leverage ratio greater or equal than 3% and smaller or equal than 5%. RDD refers to a Regression Discontinuity Design that restricts the estimation sample to banks that are close to the leverage ratio threshold on either side. The optimal band-width is plus / minus 1.805 around the baseline 3% leverage ratio threshold. The leverage ratio treatment variables are dummy variables that indicate whether a given bank had a leverage ratio below the threshold level in the previous year, for years after 2009. The leverage ratio treatment 2 variable measures the one-sided distance from the required minimum level. Formally: treatment variable 2 = treatment dummy $\cdot$ $(LR - LR_{min})$. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. Significance is based on clustered robust standard errors.

sample predictive performance.[31] Specifically, various versions of the following logit model are estimated, where the left-hand-side variable is the binary distress indicator for bank i, located in country j, in year $t + 1$, γ_j and λ_{t+1} are country and time fixed-effects respectively, and $X_{i,j,t}$ and $Y_{j,t}$ are vectors of bank-specific and country-specific control variables that may also include lags and differences:

$$P(I_{i,j,t+1} = 1) = \frac{\exp(\alpha + \theta'X_{i,j,t} + \varphi'Y_{j,t} + \gamma_j + \lambda_{t+1})}{1 + \exp(\alpha + \theta'X_{i,j,t} + \varphi'Y_{j,t} + \gamma_j + \lambda_{t+1})} \qquad (2)$$

Table 4 presents the main results from our bank distress analysis, where the LR is proxied by the ratio of Tier 1 equity to total assets and risk-taking is proxied by the ratio of risk-weighted assets to total assets, as in the first stage empirical exercise above. Columns 1 - 2 present the baseline estimation results excluding and including country and time fixed-effects. In line with economic intuition, the LR has a negative impact and risk-taking a positive impact on bank distress probabilities. Most importantly, in comparison to risk-taking, the LR seems to be much more important for determining a bank's distress probability, both statistically and economically. For example, models (1) and (2) suggest that a 1 p.p. increase in a bank's LR is associated with around a 35-39% decline in the relative probability of distress to non-distress (the odds ratio).[32] This is much larger than the marginal impact from taking on greater risk. The coefficient estimates suggest that increasing

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[31]Controlling for time and country fixed-effects should lead to better in-sample fit, as shown by Fuertes and Kalotychou (2006).

[32]For a detailed discussion on the interpretation of logit coefficients, see Cameron and Trivedi (2005).

Table 4: Estimated effect of the leverage ratio and risk-taking on bank distress probabilities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Leverage ratio proxy	-0.510***	-0.427***	-1.046***	-3.206***	-2.865***	-3.957***	-5.188**	-1.748
Leverage ratio proxy, squared			0.054***	0.463***	0.420***	0.580***	0.465	0.168
Leverage ratio proxy, cubed				-0.023***	-0.021**	-0.028***	-0.014	-0.010
RWA / Total assets	0.035***	0.011	0.166***	0.202***	0.188***	0.251***	0.406**	0.262**
RWA / Total assets, squared			-0.001***	-0.002***	-0.002***	-0.002***	-0.002	-0.002*
NPLs / Total assets	0.072**	0.055	0.090***	0.101***	0.098***	0.097**	0.117	0.092
Coverage ratio	-0.014**	-0.011**	-0.012**	-0.012***	-0.012	-0.013**	-0.026***	-0.003
Pre-tax ROA	-0.013	-0.082	-0.018	-0.001	-0.031	-0.001	-0.402	-0.053
Interest expenses / Total liabilities	0.203***	0.152**	0.125**	0.140**	0.152**	0.147**	0.149	0.094
Loan-to-Deposit ratio	0.002***	0.002***	0.003***	0.003***	0.003***	0.003***	0.005***	0.004***
Total assets, log	0.314***	0.345***	0.323***	0.334***	0.330***	0.341***	0.438**	0.212
Basel II dummy	0.698*	0.175	-0.001	0.018	0.171	-0.104	-1.206	-0.298
Basel II.5 dummy	-1.180	-1.256	-1.492	-1.632	-1.214	-1.660	-2.539	-2.238
Advanced IRB dummy	-1.967**	-1.751**	-1.593**	-1.733**	-1.844**	-1.702**	-0.496	-1.025
Foundations IRB dummy	0.627	0.612	0.527	0.537	0.625	0.564	1.125*	-2.783***
Mix IRB / SA dummy	0.222	0.116	0.088	0.127	0.126	0.135	1.771***	0.854
Bund-spread, y-on-y change	0.284***	0.495*	0.515**	0.485*	0.553*	0.354*	1.882	1.393***
Government Debt / GDP	0.009*	-0.067**	-0.070***	-0.073***	-0.096***	-0.090***	0.050	-0.191***
MIP unemployment rate	0.105***	0.218**	0.185**	0.182**	0.262***	-0.002	-0.725*	0.660***
GDP growth, y-on-y	-0.009	-0.211	-0.156	-0.163	-0.209	-0.222	-0.470	-0.307
Inflation, y-on-y	-0.099	-0.807**	-0.859***	-0.886***	-0.910**	-0.735***	-1.074*	-1.709***
MIP private sector credit flow	0.066***	0.096***	0.103***	0.108***	0.137***	-0.034	-0.027	0.180***
Total credit / GDP	0.001	0.047**	0.057***	0.056***	0.089***	0.046*	-0.044	0.095***
Issued debt / Liabilities, y-on-y change	-0.095	-0.200*	-0.205	-0.227*	-0.387***	-0.159	0.163	-0.470**
Stock price growth, y-on-y	-0.011	0.038*	0.039*	0.041**	0.044*	0.043	0.115	0.098**
Intercept term	-6.157***	-26.26***	-29.96***	-26.80***	-34.80***	-22.84***	-10.76	-54.52***
Observations	1,661	1,661	1,661	1,661	1,234	1,334	674	556
Pseudo R2	0.284	0.410	0.430	0.437	0.431	0.408	0.559	0.555
AUROC	0.870	0.926	0.929	0.930	0.926	0.918	0.961	0.946
Country and time fixed-effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Non-linear effects	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Bank sample	All EU	All EU	All EU	All EU	Euro Area	Western Europe	W. Europe excl. GIIPS	SSM SIs

Notes: Logit model estimates are obtained on a binary bank distress variable (See Betz et al. (2014) and Lang et al. (2015) for details on the bank distress event definitions). The numbers in the table are logit model coefficients. All right hand side variables are lagged by one year. All EU sample means estimation is based on all of the EU banks contained in the dataset. The Euro Area sample only includes banks from the 19 Auro Area countries. Western Europe represents the bank subsample encompassing Austria, Belgium, Germany, Denmark, Spain, Finland, France, the UK, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Sweden. The Western Europe excl. GIIPS sample represents the Western Europe sample excluding banks from Greece, Italy, Ireland, Portugal and Spain. The SSM SI sample includes only significant institutions (SIs) which are directly supervised by the ECB's Single Supervisory Mechanism (SSM). *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. Significance is based on clustered robust standard errors. AUROC refers to the Area Under the Receiver Operating Characteristics Curve, which is a global measure of how well the model can classify observations into distress and non-distress periods. An uninformative model has an AUROC of 0.5, while a perfect model has an AUROC of 1.

a bank's risk-weighted assets ratio by 1 p.p. is associated with an increase in its relative distress probability of only around 1-3.5%. This demonstrates the relative importance of the LR in determining bank distress probabilities.

The other models in Table 4 show that the results are robust to introducing non-linear effects in the LR and risk-weighted assets ratio (columns 3 - 4) and to considering different country and bank samples (columns 5 - 8). Adding squared terms for both variables of interest and a cubic term for the LR indeed improves the fit of the model, as measures by the Pseudo R-squared and the Area Under the Receiver Operating Characteristics Curve (AUROC), as well as the statistical significance of the estimated effect of risk-taking on bank distress probabilities. Fig-

Figure 4: Non-linear effects of the Leverage Ratio and risk-taking on bank distress
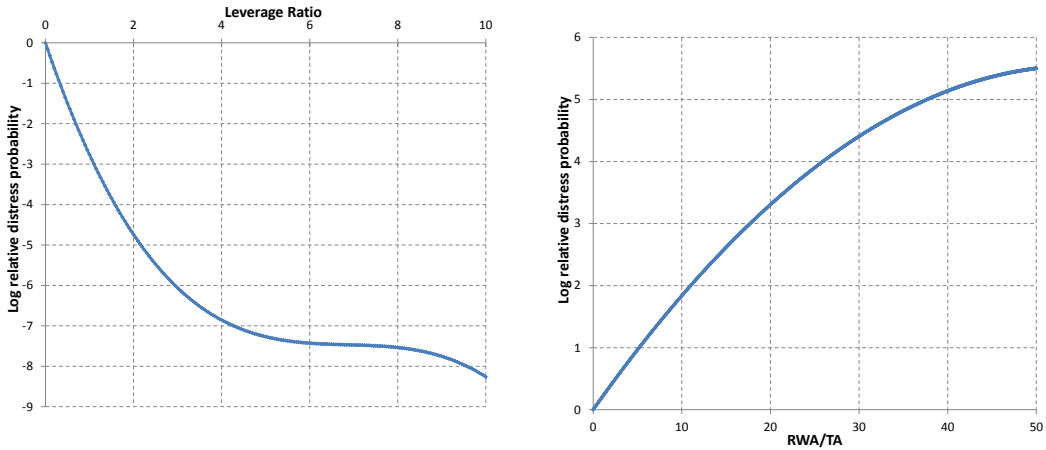
Notes: The log relative distress probability is equal to the log of the probability of distress divided by the probability of non-distress. Specifically, if the probability of distress is given by p, then it is equal to $\log(p/(1-p))$. For illustrative purposes, in generating these charts, all variables except the specified variable are set to zero. Results are based on the coefficient estimates of model (4) in Table 4.

ure 4 illustrates graphically the estimated non-linear effects of the leverage ratio and risk-taking on bank distress probabilities obtained from model (4), which is the most complete specification. There seems to be considerable benefit for bank stability from increasing the leverage ratio from low levels, but as a bank's LR gets to around 5% the benefits from increasing it further start to diminish slightly. Moreover, the marginal beneficial impact for bank stability of increasing the LR from low levels is much stronger than the marginal negative impact of increasing a bank's risk-weighted assets. Columns 5 - 8 confirm that this result remains qualitatively and quantitatively if we restrict the estimation sample to banks from the Euro Area, Western Europe, Western Europe excluding former crisis countries, or to banks directly supervised by the Single Supervisory Mechanism (SSM).

4.4 Net effect of a leverage ratio constraint on bank stability

The two previous empirical exercises suggest that while constrained banks slightly increase risk-taking with an LR requirement, the concurrent increase in their Tier 1 to asset ratio appears more important for bank stability considerations. To analyse this more formally, the results from the bank distress model are combined with the estimated increase in risk-taking in a counterfactual simulation. The experiment proceeds as follows. We first take all bank-year observations in our sample where the bank had an LR below the relevant minimum (or target level), and compute the associated distress probabilities using the true data. We then compute counterfac-

Table 5: Simulated reduction in average bank distress probabilities

LR threshold:	3%	4%	5%	4%	5%	5%
Banks with an LR of:	Less than 3%			Between 3-4%		Between 4-5%
$\Delta(RWA/TA) = 2$	-0.077***	-0.105***	-0.107***	-0.033***	-0.062***	-0.030***
$\Delta(RWA/TA) = 4$	-0.066**	-0.105***	-0.107***	-0.022*	-0.062***	-0.019*
$\Delta(RWA/TA) = 6$	-0.052*	-0.103***	-0.107***	-0.008	-0.060***	-0.004

Notes: The numbers represent the average simulated change in the distress probability for the relevant bank sample between 2005 - 2014, expressed as decimal numbers (i.e. 0.1 represents 10 percentage points). Changes in distress probabilities are derived by increasing a bank's leverage ratio to the stated percentage while at the same time increasing its risk-weighted assets ratio by the stated amount. Average changes are reported separately for the sample of banks with an LR less than 3%, between 3-4% and between 4-5%. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. Significance is based on bootstrapped standard errors on 10000 replications.

tual distress probabilities for the same set of bank-year observations, assuming that banks increase their LRs up to the required minimum (or target level), but at the same time also increase their risk-weighted assets by the estimated amount. Finally, we look at the average change in distress probabilities across all the relevant bank-year observations in the sample to see whether on average bank distress probabilities decline and whether any decline is statistically significant. In this way, we attempt to assess quantitatively the net effect of the potential trade-off between greater loss-absorbing capacity and higher bank risk-taking associated with an LR requirement. To allow for a conservative assessment, the upper range of the estimated increase in risk-taking is assumed, i.e. a 2 p.p. increase in the risk-weighted assets ratio. For robustness purposes, a 4 and 6 p.p. increase in the risk-weighted assets ratio is also tested. The simulation is performed for a 3%, 4% and 5% leverage ratio minimum (or target level).

Table 5 reports mean estimated figures from the various simulations. The numbers can be interpreted as the average percentage point change in distress probability for the relevant banks in our sample between 2005 and 2014. Since increasing the leverage ratio minimum (or target level) increases the sample of banks below this minimum (or target level), to ensure comparability across simulations, results are reported separately for the sample of banks with an LR less than 3%, between 3-4% and between 4-5%. The results demonstrate that bank distress probabilities should significantly decline with an LR requirement, even when taking into account much higher increases in risk-taking than were estimated. For example, Table 5 shows that assuming a 3% LR target and an increase in the risk-weighted assets ratio of 2 p.p., the average distress probability declines by 7.7 p.p. for the given sample of bank-years. If the increase in the risk-weighted assets ratio is assumed to be 6 p.p., the average decline in distress probabilities would still be 5.2 p.p. The simulation

results therefore lend support to the second hypothesis that was derived from our theoretical model, namely that the beneficial impact of higher capital holdings from an LR requirement should more than outweigh the negative impact of increased risk-taking, thus leading to more stable banks.

5 Conclusion

Theoretical considerations and empirical evidence for EU banks provided in this paper suggest that the introduction of an LR requirement into the Basel III regulatory framework should lead to more stable banks. This paper has shown that although there indeed exists an increased incentive to take risk once banks become bound by the LR, this increase is more than outweighed by the synchronous increase in loss-absorbing capacity due to higher capital. The analysis therefore supports the introduction of an LR requirement alongside the risk-based capital framework. The analysis further suggests that the LR and the risk-based capital framework reinforce each other by covering risks which the other is less able to capture; making sure banks do not operate with excessive leverage and at the same time, have sufficient incentives for keeping risk-taking in check.

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Appendix A: Mathematical proofs

Proof of Lemma 1

The proof proceeds as follows. We first work under the assumption that $(1 - \mu) \leq \alpha$ so that $k(\omega) = (1 - \omega)\lambda_2$. We show that for any ω a bank will prefer to hold the minimum capital requirement. We then repeat the same steps under the assumption that $(1 - \mu) > \alpha$ so that $k(\omega) = \omega\lambda_1 + (1 - \omega)\lambda_3$.

Taking the first assumption, let us first show that for any ω, if the capital requirement is binding, the bank will not be able to survive a state s_2 shock, thus it will always enter bankruptcy in state s_2.

In state s_2, the safe asset returns $(1 - \lambda_1)$, while the risky asset returns a maximum of $(1 - \lambda_3)$. Suppose the bank holds the minimum capital requirement, i.e. $k(\omega) = (1 - \omega)\lambda_2$

To survive a shock in state s_2, it must be that:

$$\omega(1 - \lambda_1) + (1 - \omega)(1 - \lambda_3) \geq (1 - k_{rw})$$

otherwise the return on the two assets are not sufficient to repay depositors even when the risky asset pays off its highest state s_2 return. Imposing the assumption that banks hold the minimum capital requirement and rearranging, this becomes:

$$\omega\lambda_1 + (1 - \omega)(\lambda_3 - \lambda_2) \leq 0$$

which is a contradiction, since $\lambda_3 > \lambda_2$. So for any $\omega \in [0, 1]$, this condition cannot hold. Hence if banks hold the minimum capital requirement, they can never survive state s_2.

Given this is the case, we show that for any ω, banks will not find it optimal to hold excess capital.

The profit from holding the minimum capital requirement is:

$$\mu[\omega R_1 + (1 - \omega)\pi R_2^h + (1 - \omega)(1 - \lambda_2)(1 - \pi)] - (1 - k(\omega))\mu - \rho k(\omega) - c(\omega)$$

If the bank decides to hold excess capital, where k_{ex} denotes a capital level above

the minimum, then profit will be either:

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] + (1-\mu)[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)]\pi$$

$$-(1-k_{ex})\left[\mu + (1-\mu)\pi\right] - \rho k_{ex} - c(\omega)$$

if the bank holds only enough excess capital to survive when the risky asset returns $(1-\lambda_3)$, or:

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] + (1-\mu)[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)\pi] - (1-k_{ex}) - \rho k_{ex} - c(\omega)$$

if the bank can hold enough excess capital to survive all shocks.

We show that holding the minimum capital requirement is preferred to both these alternatives, namely:

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] - (1-k(\omega))\mu - \rho k(\omega) - c(\omega) >$$

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] + (1-\mu)[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)]\pi$$

$$-(1-k_{ex})\left[\mu + (1-\mu)\pi\right] - \rho k_{ex} - c(\omega)$$

and

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] - (1-k(\omega))\mu - \rho k(\omega) - c(\omega) >$$

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] + (1-\mu)[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)\pi] - (1-k_{ex}) - \rho k_{ex} - c(\omega)$$

Let us proceed with the first condition. Plugging in the minimum capital requirement and simplifying, we find this is true if and only if:

$$\rho > \mu + (1-\mu)\pi \frac{[k_{ex} - \omega\lambda_1 - (1-\omega)\lambda_3]}{[k_{ex} - (1-\omega)\lambda_2]}$$

which is true by definition, since $\rho > 1$, and $\mu + (1-\mu)\pi \frac{[k_{ex} - \omega\lambda_1 - (1-\omega)\lambda_3]}{[k_{ex} - (1-\omega)\lambda_2]} < 1$, since $[k_{ex} - (1-\omega)\lambda_2] > [k_{ex} - \omega\lambda_1 - (1-\omega)\lambda_3]$ for any ω.

Performing the same exercise with the second condition, we find a similar condition stating that banks will prefer to hold the minimum capital requirement if and only if:

$$\rho > \mu + (1-\mu)\frac{[k_{ex} - \omega\lambda_1 - (1-\omega)\left[\lambda_3\pi + (1-\pi)\right]]}{[k_{ex} - (1-\omega)\lambda_2]}$$

which again is true by definition since $\rho > 1$, and $\mu + (1-\mu)\frac{[k_{ex} - \omega\lambda_1 - (1-\omega)[\lambda_3\pi + (1-\pi)]]}{[k_{ex} - (1-\omega)\lambda_2]} <$

1, since $[k_{ex}-\omega\lambda_1-(1-\omega)\left[\lambda_3\pi + (1 - \pi)\right]] < [k_{ex}-\omega\lambda_1-(1-\omega)\lambda_3] < [k_{ex} - (1 - \omega)\lambda_2]$.

Let us now consider the alternative assumption: $(1 - \mu) > \alpha$

We proceed as before and show that a bank will never wish to hold excess capital such that the capital constraint will bind.

First, suppose the capital requirement binds. Suppose $\omega \in [0, 1)$.[33] The bank will not be able to survive a state s_2 shock where the risky asset returns zero. This is the case if and only if:

$$\omega(1 - \lambda_1) \leq (1 - k(\omega))$$

$$0 \leq (1 - \omega)(1 - \lambda_3)$$

which is true since $\omega \in [0, 1)$ and $\lambda_3 \in (0, 1)$. So if the capital requirement binds, the bank can only survive if the risky asset pays off its residual value $(1 - \lambda_3)$ in state s_2.

The bank will prefer the capital requirement to bind if and only if profits under a binding capital requirement are higher than holding excess capital, namely:

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] + (1-\mu)[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)]\pi$$

$$-(1 - k(\omega))\left[\mu + (1 - \mu)\pi\right] - \rho k(\omega) - c(\omega)$$

$$>$$

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)(1-\pi)] + (1-\mu)[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)\pi]$$

$$-(1 - k_{ex}) - \rho k_{ex} - c(\omega)$$

Rearranging, this is true if and only if:

$$\rho > \mu + (1 - \mu)\frac{[k_{ex} - (1 - \omega)\left[(1 - \pi) + \lambda_3\pi\right] - \omega\lambda_1(1 - \pi)]}{[k_{ex} - (1 - \omega)\lambda_3]}$$

which holds since $\rho > 1$ and $\mu + (1 - \mu)\frac{[k_{ex}-(1-\omega)[(1-\pi)+\lambda_3\pi]-\omega\lambda_1(1-\pi)]}{[k_{ex}-(1-\omega)\lambda_3]} < 1$ since $\mu \in [0, 1]$ and $\frac{[k_{ex}-(1-\omega)[(1-\pi)+\lambda_3\pi]-\omega\lambda_1(1-\pi)]}{[k_{ex}-(1-\omega)\lambda_3]} < 1$ since $[k_{ex} - (1 - \omega)\left[(1 - \pi) + \lambda_3\pi\right] - \omega\lambda_1(1 - \pi)] < [k_{ex} - (1 - \omega)\lambda_3 - \omega\lambda_1(1 - \pi)] < [k_{ex} - (1 - \omega)\lambda_3]$.

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[33]If $\omega = 1$, then profits are given by $\mu R_1 + (1 - \mu)(1 - \lambda_1) - (1 - k) - \rho k - c(1)$. Clearly since $\rho > 1$, this is maximised at $k = 0$, so banks will choose the minimum capital level.

Proof of Proposition 2

From lemma 1, we know that the capital requirement will bind. We now show that when equity is expensive, and indeed we formalise what expensive means, banks will increase risk-taking following the imposition of an LR.

The proof proceeds in two stages. First, we show the optimal solution under a solely risk-based framework. Second, we show that under a binding LR, a bank's optimal risk level will be higher than this. We perform the analysis first assuming $(1 - \mu) \leq \alpha$ and then repeat assuming $(1 - \mu) > \alpha$.

- If $(1 - \mu) \leq \alpha$, the capital requirement is $k(\omega) = (1 - \omega)\lambda_2$

We know from the proof of lemma 1 that the bank cannot survive state s_2. So, the bank will choose an ω that maximises:

$$\mu[\omega R_1 + (1 - \omega)\pi R_2^h + (1 - \omega)(1 - \lambda_2)\pi] - (1 - k(\omega))\mu - \rho k(\omega) - c(\omega)$$

The optimal choice can be written as:

$$(1 - \omega) = \frac{\mu \left[\pi R_2^h + (1 - \lambda_2)\pi - R_1\right] - \lambda_2 (\rho - \mu)}{c}$$

This illustrates the trade-off between risk and capital. The numerator shows the expected increase in return from increasing holdings of the risky asset $\mu \left[\pi R_2^h + (1 - \lambda_2)\pi - R_1\right]$, which is offset in terms of the cost of having to hold more capital $(\rho - \mu)\lambda_2$. Optimality holds at the point where these opposing effects balance (also taking into account the risky investment cost, c).

Imposing a binding LR into the framework, the bank will maximise profits, $\Pi(\omega)$, where the exact profit will be a function of the leverage ratio level. As discussed in the text, for large ρ, there will be a point at which the shareholders' participation constraint forces banks to take on further risk. By definition this risk level is higher than the optimal risk the bank would otherwise choose. As a result, it is sufficient to show that if the optimal level of risk is higher than the risk-based choice, then this level of risk will be also.

Let us suppose therefore that ρ is low enough that even at $k_{lev} = 1$, banks could choose their optimal risk level and they would still satisfy the shareholders' participation constraint. This puts a lower bound on the bank's chosen level of risk,

which we can show is larger than the risk-based choice. Under this assumption, the profit function will be:

$$\Pi(\omega) =$$

$$
\begin{cases}
\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)\pi] - (1-k)\mu - \rho k - c(\omega) & \text{if } k_{lev} < k_1 \\
\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)\pi] + (1-\mu)\pi[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)] - (1-k)[\mu + (1-\mu)\pi] - \rho k - c(\omega) & \text{if } k_{lev} \in [k_1, k_2) \\
\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)\pi] + (1-\mu)\pi[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)] + (1-\mu)(1-\pi)\omega(1-\lambda_1) - (1-k) - \rho k - c(\omega) & \text{if } k_{lev} \geq k_2
\end{cases}
$$

where k_1 denotes the LR where banks break even in state s_2 when the risky asset pays off $(1-\lambda_3)$, and k_2 denotes the LR where banks break even in state s_2 when the risky asset pays off 0.

The optimal $(1-\omega)$ can be characterised by:

$$
(1-\omega) = \begin{cases}
\mu[\pi R_2^h + (1-\lambda_2)\pi - R_1]/c & \text{if } k_{lev} < k_1 \\
\mu[\pi R_2^h + (1-\lambda_2)\pi - R_1]/c - (1-\mu)\pi(\lambda_3 - \lambda_1)/c & \text{if } k_{lev} \in (k_1, k_2) \\
\mu[\pi R_2^h + (1-\lambda_2)\pi - R_1]/c - (1-\mu)\pi(\lambda_3 - \lambda_1)/c - (1-\mu)(1-\pi)(1-\lambda_1)/c & \text{if } k_{lev} > k_2
\end{cases}
$$

The first row is clearly larger than the risk-based requirement. The smallest of these is the bottom row. We derive a condition on ρ and show that this will be larger than the risk-based choice. Thus, given this is a lower bound, all will be larger. Comparing this risk choice (in the bottom row) with the risk-based choice, we find that it will be larger if and only if: $(1-\mu)[\pi(\lambda_3 - \lambda_1) + (1-\pi)(1-\lambda_1)] < \lambda_2(\rho - \mu)$. Rearranging this, we find:

$$\rho > \mu + (1-\mu)\frac{[\pi(\lambda_3 - \lambda_1) + (1-\pi)(1-\lambda_1)]}{\lambda_2}$$

If $\pi(\lambda_3 - \lambda_1) + (1-\pi)(1-\lambda_1) \leq \lambda_2$, this definitely holds, since $\rho > 1$ and $\mu \in [0,1]$. Otherwise, since $(1-\mu) \leq \alpha$, we can state that it will definitely hold if:

$$\rho > (1-\alpha) + \alpha\left[\frac{\pi\lambda_3 + (1-\pi) - \lambda_1}{\lambda_2}\right]$$

- $(1-\mu) > \alpha$ such that the capital requirement is $k(\omega) = \omega\lambda_1 + (1-\omega)\lambda_3$

Repeating the same steps as above. Under a solely risk-based requirement, the bank will maximise:

$$\mu[\omega R_1 + (1-\omega)\pi R_2^h + (1-\omega)(1-\lambda_2)\pi] + (1-\mu)\pi[\omega(1-\lambda_1) + (1-\omega)(1-\lambda_3)]$$

$$-(1-k(\omega))[\mu + (1-\mu)\pi] - \rho k(\omega) - c(\omega)$$

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The optimal risk level will thus be:

$$(1-\omega) = \frac{\mu[\pi R_2^h + (1 - \lambda_2)\pi - R_1] - (1 - \mu)\pi[\lambda_3 - \lambda_1] - (\lambda_3 - \lambda_1)\left[\rho - [\mu + (1 - \mu)\pi]\right]}{c}$$

With a binding LR requirement, ignoring the concerns about the shareholders' participation constraint as before, the maximisation becomes:

$$\Pi(\omega) =$$

$$\begin{cases} \mu[\omega R_1 + (1 - \omega)\pi R_2^h + (1 - \omega)(1 - \lambda_2)\pi] + (1 - \mu)\pi[\omega(1 - \lambda_1) + (1 - \omega)(1 - \lambda_3)] - (1 - k) - \rho k - c(\omega) & \text{if } k_{lev} < k_2 \\ \mu[\omega R_1 + (1 - \omega)\pi R_2^h + (1 - \omega)(1 - \lambda_2)\pi] + (1 - \mu)\pi[\omega(1 - \lambda_1) + (1 - \omega)(1 - \lambda_3)] + (1 - \mu)(1 - \pi)\omega(1 - \lambda_1) - (1 - k) - \rho k - c(\omega) & \text{if } k_{lev} > k_2 \end{cases}$$

where k_2 is defined as before.

The optimal $(1 - \omega)$ can be characterised by:

$$(1 - \omega) = \begin{cases} \mu[\pi R_2^h + (1 - \lambda_2)\pi - R_1]/c - (1 - \mu)\pi[\lambda_3 - \lambda_1]/c & \text{if } k_{lev} < k_2 \\ \mu[\pi R_2^h + (1 - \lambda_2)\pi - R_1]/c - (1 - \mu)\pi\,(\lambda_3 - \lambda_1)\,/c - (1 - \mu)(1 - \pi)(1 - \lambda_1)/c & \text{if } k_{lev} > k_2 \end{cases}$$

Again, the first row is clearly larger, so we show that the bottom row (the lowest it can possibly be for all parameter values) is also larger. This is true iff:

$$(\lambda_3 - \lambda_1)\left[\rho - [\mu + (1 - \mu)\pi]\right] > (1 - \mu)(1 - \pi)(1 - \lambda_1)$$

Namely:

$$\rho > \mu + (1 - \mu)\left[\pi + (1 - \pi)\frac{(1 - \lambda_1)}{(\lambda_3 - \lambda_1)}\right]$$

As before, we can write a similar condition on ρ in terms of α. So we can state that risk will increase if:

$$\rho > 1 + \alpha\left[\frac{1 - \lambda_1}{\lambda_3 - \lambda_1}\right]$$

where this is obtained by substituting $(1 - \mu)(1 - \pi) = \alpha$ into the prior condition, since as discussed in the text, when we consider the case $(1 - \mu) > \alpha$, we only consider the realistic case: $(1 - \mu)(1 - \pi) \leq \alpha$.

So, irrespective of the parameter values, we can state, if:

$$\rho > \max\left\{1 + \alpha\left[\frac{1 - \lambda_1}{(\lambda_3 - \lambda_1)}\right], (1 - \alpha) + \frac{\alpha[\pi\lambda_3 + (1 - \pi) - \lambda_1]}{\lambda_2}\right\}$$

banks will always take more risk under a leverage ratio.

Proof of Proposition 3

The proof proceeds in two steps. First, we look at failure probabilities, looking at the two cases: $(1 - \mu) > \alpha$ and $(1 - \mu) \leq \alpha$. Then we consider expected losses, again under the two cases.

- $(1 - \mu) \leq \alpha$, so the capital requirement is $k(\omega) = (1 - \omega)\lambda_2$

Under the risk-based framework, by definition, the probability of default is $(1 - \mu)$. When the leverage ratio binds, the bank will have more capital, but at the same time will take more risk. This level of risk however is capped at the maximum possible level of risk before the bank moves back into the risk-based framework. We show that even if the bank takes this level of risk, default probabilities will not rise, and for some leverage ratio levels, will decline relative to the risk-based probability.

The maximum risk level occurs at the point where the risk-based capital requirement equals the leverage ratio requirement: i.e. $k(\omega) = (1 - \omega_{\max})\lambda_2 = k_{lev}$. In other words, the maximum the bank can increase risk to is: $(1 - \omega_{\max}) = \frac{k_{lev}}{\lambda_2}$. Suppose this is the case and the bank increases risk to the maximum, so $(1 - \omega_{lev}) = (1 - \omega_{\max}) = \frac{k_{lev}}{\lambda_2}$:

We show that even at this level, the bank will survive the shock in state s_1 and thus its probability of default will not be less than $(1 - \mu)$. This is true if and only if $\omega R_1 + (1 - \omega)(1 - \lambda_2) \geq (1 - k_{lev})$

Plugging the maximum risk level into the above:

$$\left(1 - \frac{k_{lev}}{\lambda_2}\right) R_1 + \frac{k_{lev}}{\lambda_2}(1 - \lambda_2) \geq (1 - k_{lev})$$

Rearranging:

$$(R_1 - 1)\left(1 - \frac{k_{lev}}{\lambda_2}\right) \geq 0$$

which is true for all $k_{lev} \leq \lambda_2$.

So, for all $k_{lev} \leq \lambda_2$, the bank can take the maximum risk and it will still survive the state s_1 shock. This is because, with the risk-based framework underlying the leverage ratio, it cannot be that the leverage ratio allows failure in this state, otherwise the risk-based capital requirement would have been higher. If $k_{lev} > \lambda_2$, the bank can still never enter bankruptcy in state s_1. To see this, denote $k_{lev} = \lambda_2 + \varepsilon$, $(\varepsilon > 0)$ as any leverage ratio above λ_2. For any $\omega \in [0, 1]$,

$\omega R_1 + (1 - \omega)(1 - \lambda_2) > (1 - k_{lev}) = (1 - \lambda_2 - \varepsilon)$, so for any k_{lev}, the probability of default will not fall below $(1 - \mu)$.

We now show that the probability of default can be strictly lower under a leverage ratio. The probability of default will be strictly lower if under an LR the bank can survive a shock in state s_2. Suppose the parameters are such that the optimal solution lies below the maximum risk level discussed above. A bank will survive a λ_3 shock in state s_2 iff:

$$\omega(1 - \lambda_1) + (1 - \omega)(1 - \lambda_3) \geq (1 - k_{lev})$$

Plugging in the optimal ω

$$k_{lev} \geq 1 - \omega^*_{lev}(1 - \lambda_1) - (1 - \omega^*_{lev})(1 - \lambda_3)$$

As seen in proposition 2, ω^*_{lev} is not a function of k_{lev}, so for k_{lev} greater than this, probability of default can be strictly lower.

- $(1 - \mu) > \alpha$, so the capital requirement is $k(\omega) = \omega\lambda_1 + (1 - \omega)\lambda_3$

Under the risk-based framework, the probability of default is $(1 - \mu)(1 - \pi)$ since it defaults only if the risky asset pays off 0 in state s_2. Repeating the steps above, suppose the bank takes the maximum possible risk: $k(\omega) = \omega_{\max}\lambda_1 + (1 - \omega_{\max})\lambda_3 = k_{lev}$, so $\omega_{\max} = \frac{k_{lev} - \lambda_3}{(\lambda_1 - \lambda_3)}$

The probability of default will be at least as low as under a solely risk-based framework iff it can survive when the risky asset pays off $(1 - \lambda_3)$ in state s_2, i.e.:

$$\omega(1 - \lambda_1) + (1 - \omega)(1 - \lambda_3) \geq (1 - k_{lev})$$

Rearranging,

$$\frac{k_{lev} - \lambda_3}{(\lambda_1 - \lambda_3)}(1 - \lambda_1) + (1 - \frac{k_{lev} - \lambda_3}{(\lambda_1 - \lambda_3)})(1 - \lambda_3) \geq (1 - k_{lev})$$

$$(1 - k_{lev}) \geq (1 - k_{lev})$$

Both sides are equalised, so the bank will survive a λ_3 state s_2 shock even if it takes the maximum risk.[34]

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[34]ω_{max} as defined above only applies for $k_{lev} \leq \lambda_3$, nevertheless for levels above λ_3, banks will still survive a λ_3 shock by definition that they hold more capital than λ_3.

Let's now consider when an LR leads to a strict decline in the probability of default. This will be true iff:

$$\omega(1 - \lambda_1) \geq (1 - k_{lev})$$

$$k_{lev} \geq 1 - \omega_{lev}^*(1 - \lambda_1)$$

Again, as seen in proposition 2, ω_{lev}^* is not a function of k_{lev}, so there can be region where the probability of default is strictly lower.

Overall therefore, imposing an LR requirement weakly decreases the probability of default.

Now, consider expected losses, again for the two cases: $(1 - \mu) \leq \alpha$ and $(1 - \mu) > \alpha$. The proof proceeds to show that there exists a region $(\underline{k}, \overline{k})$ where expected losses are strictly lower for any ρ.

- $(1 - \mu) > \alpha$, so the capital requirement is $k(\omega) = \omega\lambda_1 + (1 - \omega)\lambda_3$

Under the risk-based framework, expected losses will be:

$$(1 - \mu)(1 - \pi)\left[(1 - k(\omega)) - \omega_{rw}(1 - \lambda_1)\right]$$

Under an LR, expected losses will be:[35]

$$(1 - \mu)(1 - \pi)\left[(1 - k_{lev}) - \omega_{lev}(1 - \lambda_1)\right]$$

We first show that unlike distress probabilities, if the bank takes the maximal risk, expected losses will be larger under an LR. Taking the maximal risk under this case implies: $\omega_{lev} = \omega_{\max} = \frac{k_{lev} - \lambda_3}{(\lambda_1 - \lambda_3)}$. Plugging this into the expected losses functions above and rearranging, we find that expected losses will be lower under an LR iff:

$$k_{lev} > k(\omega) + \left[\omega_{rw} - \frac{k_{lev} - \lambda_3}{(\lambda_1 - \lambda_3)}\right](1 - \lambda_1)]$$

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[35]There also potentially exists another region for larger k in which for the chosen ω banks can survive all shocks. This however requires a low ρ such that the shareholders' participation constraint does not force banks to take too much risk. Since we look for a condition for all ρ, indeed we are particularly interested for larger ρ (the more realistic case), we need not consider this case, as if we find a condition such that it holds for large ρ, it will definitely hold for smaller ρ.

This simplifies to

$$k_{lev} [\lambda_3 - 1] > k(\omega) [\lambda_3 - 1]$$

but since $\lambda_3 < 1$, this is a contradiction as $k_{lev} > k(\omega)$. So if the bank takes maximal risk, expected losses will be larger under an LR.

As can be readily seen from $\omega_{\max} = \frac{\lambda_3 - k_{lev}}{(\lambda_3 - \lambda_1)}$, this function is decreasing in k_{lev}.[36] So, at low k_{lev} the bank's interior solution may be larger than this maximal possible risk level, whereas at higher k_{lev}, the interior solution is possible. To be beneficial in terms of expected losses therefore, as can be seen from above, the solution must be an interior one. In other words $\omega_{lev} > \frac{\lambda_3 - k_{lev}}{\lambda_3 - \lambda_1}$ or, $k_{lev} > \omega_{lev}^* \lambda_1 + (1 - \omega_{lev}^*)\lambda_3$ where ω_{lev}^* is given in proposition 2.

If this is the case, expected losses will be smaller under an LR iff:

$$(1-\mu)(1-\pi)\left[(1 - k_{lev}) - \omega_{lev}(1 - \lambda_1)\right] < (1 - \mu)(1 - \pi)\left[(1 - k(\omega)) - \omega_{rw}(1 - \lambda_1)\right]$$

Plugging in the optimal solution and rearranging, we find:

$$k_{lev} - k(\omega) > [\omega_{rw} - \omega_{lev}](1 - \lambda_1)$$

$$k_{lev} > k(\omega) + (\lambda_3 - \lambda_1)[\rho - [\mu + (1 - \mu)\pi]](1 - \lambda_1)$$

k_{lev} can be set at any level greater than $k(\omega)$, so there exists a region just above $k(\omega)$ in which expected losses are greater under an LR - there is risk-shifting but little loss absorption.

From the above, we can conclude that an LR leads to a benefit in terms of expected losses when there is an interior solution and k_{lev} is above this level, i.e. $k_{lev} > \max\{\omega_{lev}\lambda_1 + (1-\omega_{lev})\lambda_3, k(\omega_{rw}) + (\lambda_3 - \lambda_1)[\rho - [\mu + (1 - \mu)\pi]](1 - \lambda_1)\} \equiv \underline{k_1}$

We now show that for too high levels of k, expected losses can be higher under an LR. As discussed earlier, for some parameter values, it can be that for large k, the shareholders' participation constraint ceases to be satisfied at the optimal risk level. As a result, the bank's risk level will be entirely pinned down by the shareholders' participation constraint, and we know from above that taking the maximum risk (or close to it) will lead to an increase in expected losses.

For large k and ρ therefore, the chosen ω will be pinned down by:

$$\omega E[safe] + (1 - \omega) E[risky] - (1 - k) \Pr(survive) = \rho k$$

---

[36]Remember, ω is investment in the safe asset.

Rearranging, we find:

$$\omega = \frac{\left[\mu \pi R_2^h + \mu (1 - \pi)(1 - \lambda_2) + (1 - \mu) \pi (1 - \lambda_3)\right] - (\rho - [\mu + (1 - \mu) \pi]) k - [\mu + (1 - \mu) \pi]}{\left[\mu \pi R_2^h + \mu (1 - \pi)(1 - \lambda_2) + (1 - \mu) \pi (1 - \lambda_3) - [\mu R_1 + (1 - \mu)\pi(1 - \lambda_1))]\right]}$$

This is decreasing in k, so raising capital further increases risk-taking in this region. We show that for large ρ there exists a k_{lev} such that above this level, expected losses will be below the risk-based level. We know from above that expected losses will be lower under an LR iff:

$$k_{lev} - k(\omega) > [\omega_{rw} - \omega_{lev}](1 - \lambda_1)$$

Plugging in what we know to be the solution for ω_{lev} and rearranging, we find that if $\rho > [\mu + (1 - \mu) \pi] + \frac{\mu \pi R_2^h + \mu(1 - \pi)(1 - \lambda_2) + (1 - \mu)\pi(1 - \lambda_3) - [\mu R_1 + (1 - \mu \pi(1 - \lambda_1))]}{1 - \lambda_1}$ and the participation constraint pins down the risk chosen by the bank, then expected losses will be lower under an LR if:

$$k_{lev} < \overline{k_1}$$
$$\equiv \frac{[k(\omega_{rw}) + \omega_{rw}(1 - \lambda_1)] \left[\mu \pi R_2^h + \mu (1 - \pi)(1 - \lambda_2) + (1 - \mu) \pi (1 - \lambda_3) - [\mu R_1 + (1 - \mu \pi(1 - \lambda_1))]\right]}{\left[\mu \pi R_2^h + \mu (1 - \pi)(1 - \lambda_2) + (1 - \mu) \pi (1 - \lambda_3) - [\mu R_1 + (1 - \mu \pi(1 - \lambda_1))]\right] - (\rho - [\mu + (1 - \mu) \pi])(1 - \lambda_1)}$$
$$- \frac{\left[\mu \pi R_2^h + \mu(1 - \pi)(1 - \lambda_2) + (1 - \mu)\pi(1 - \lambda_3)\right] - [\mu + (1 - \mu)\pi]}{\left[\mu \pi R_2^h + \mu (1 - \pi)(1 - \lambda_2) + (1 - \mu) \pi (1 - \lambda_3) - [\mu R_1 + (1 - \mu)\pi(1 - \lambda_1))]\right] - (\rho - [\mu + (1 - \mu) \pi])(1 - \lambda_1)} (1 - \lambda_1)$$

Lastly, we show that this upper bound level is strictly greater than the lower bound level. The lower bound level was defined at the point where $k_{lev} = k(\omega_{rw}^*) + \omega_{rw}^*(1 - \lambda_1) - \omega_{lev}^*(1 - \lambda_1)$ where $*$ denotes optimal levels. The upper bound level was defined at the point where $k_{lev} = k(\omega_{rw}^*) + \omega_{rw}^*(1 - \lambda_1) - \omega_{lev}^{pc}(1 - \lambda_1)$ where pc denotes the level determined by the shareholders' participation constraint. Since $\omega_{lev}^{pc} < \omega_{lev}^*$, it must be that the upper bound is strictly greater than the lower bound. The upper bound is also larger than the level required for an interior solution. We can see this by comparing the two conditions. The upper bound will be larger iff $\omega_{lev}^* \lambda_1 + (1 - \omega_{lev}^*)\lambda_3 < \omega_{rw}^* \lambda_1 + (1 - \omega_{rw}^*)\lambda_3 + (1 - \lambda_1)(\omega_{rw}^* - \omega_{lev}^{pc})$. Rearranging, we find: $(1 - \lambda_1)(\omega_{rw}^* - \omega_{lev}^{pc}) - (\omega_{rw}^* - \omega_{lev}^*)(\lambda_3 - \lambda_1) > 0$, which is true since $\omega_{lev}^{pc} < \omega_{lev}^*$ and $\lambda_3 < 1$.

We can conclude therefore that for $k_{lev} \in \left(\underline{k_1}, \overline{k_1}\right)$ expected losses will be lower.

- $(1 - \mu) \leq \alpha$, so the capital requirement is $k(\omega) = (1 - \omega)\lambda_2$

Under a risk-based framework, expected losses will be:

$$(1 - \mu) \left[(1 - k(\omega)) - \omega_{rw} (1 - \lambda_1) - (1 - \omega_{rw}) (1 - \lambda_3) \pi \right]$$

Under an LR, expected losses will be a maximum of:

$$(1 - \mu) \left[(1 - k_{lev}) - \omega_{lev} (1 - \lambda_1) - (1 - \omega_{lev}) (1 - \lambda_3) \pi \right]$$

This is a maximum since as discussed before, the bank will always survive state s_1, but at higher leverage ratios, it can be possible that if there exists an interior solution such that the shareholders' participation constraint has not forced the risk level to increase too much that it offsets the increase in capital, the bank also survives a λ_3 shock in state s_2 or potentially more. If this is the case, then by definition these cases would have a lower expected loss than the LR expected loss shown above, since the bank would have more capital, a lower probability of default, and a lower investment in the risky asset (as shown in proposition 2). Hence obtaining a lower bound condition on k such that it holds for the above is sufficient, since it will also hold for the other parameter values.

Let us follow the same procedure as previously. The maximum risk the bank can take is: $(1 - \omega_{\max}) = \frac{k_{lev}}{\lambda_2}$. We show that if the bank takes this level of risk, expected losses can be larger under an LR. Suppose not, then it must be that:

$$\left[(1 - \lambda_1) - (1 - \lambda_3) \pi \right] \left(\omega_{rw} - 1 + \frac{k_{lev}}{\lambda_2} \right) < k_{lev} - k(\omega)$$

$$\left[(1 - \lambda_1) - (1 - \lambda_3) \pi - \lambda_2 \right] k_{lev} < k(\omega) \left[(1 - \lambda_1) - (1 - \lambda_3) \pi - \lambda_2 \right]$$

If $\left[(1 - \lambda_1) - (1 - \lambda_3) \pi - \lambda_2 \right] > 0$,[37]

$$k_{lev} < k(\omega)$$

which is a contradiction. So if the bank takes the maximal risk, expected losses are larger under an LR.

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[37] For the alternative assumption, clearly expected losses will be lower since $k_{lev} > k(\omega)$, hence we do not need to consider this case.

Suppose then that there exists an interior solution. Comparing the expected losses with and without an LR, expected losses will be lower under an LR iff:

$$(1 - \mu) \left[(1 - k_{lev}) - \omega_{lev} (1 - \lambda_1) - (1 - \omega_{lev}) (1 - \lambda_3) \pi \right]$$

$$< (1 - \mu) \left[(1 - k(\omega)) - \omega_{rw} (1 - \lambda_1) - (1 - \omega_{rw}) (1 - \lambda_3) \pi \right]$$

$$k(\omega_{rw}) + \left[(1 - \lambda_1) - (1 - \lambda_3) \pi \right] \frac{\lambda_2 (\rho - \mu)}{c} < k_{lev}$$

So as before, there exists a region just above $k(\omega_{rw}^*)$ in which expected losses will be higher. A sufficient condition to reduce expected losses therefore is for an interior solution and the leverage ratio to be set above this level. This gives a lower bound since if the parameters are such that the bank can indeed also survive a λ_3 shock, expected losses will be lower by definition that we have an interior solution and investment in the risky asset will be slightly lower with more capital (as shown in proposition 2). This thus gives us a lower bound on the LR to be beneficial:
$k_{lev} > \max\{(1 - \omega_{lev})\lambda_2, k(\omega_{rw}^*) + \left[(1 - \lambda_1) - (1 - \lambda_3) \pi \right] \frac{\lambda_2 (\rho - \mu)}{c}\} \equiv \underline{k_2}$

As before, we now consider large k. For some parameter values, specifically for large ρ, the shareholders' participation constraint will cease to be satisfied at the chosen risk levels. Hence the level of risk will be pinned down entirely by the participation constraint, i.e.:

$$\omega_{lev} E[safe] + (1 - \omega_{lev}) E[risky] - (1 - k) \Pr(survive) < \rho k$$

So ω must satisfy:

$$\frac{E[risky] - \rho k - (1 - k) \Pr(survive)}{E[risky] - E[safe]} = \omega$$

This is decreasing in k, so risk-taking is increasing in k. We obtain a condition on k such that it is valid for all ρ. To obtain the upper bound, we must consider both when $k_{lev} < \lambda_3$ and when $k_{lev} \geq \lambda_3$, since when $k_{lev} \geq \lambda_3$, by definition the bank must be able to survive a λ_3 shock in state s_2. Let us first consider $k_{lev} < \lambda_3$. We can again obtain a lower bound such that the condition holds for all ρ by considering a ρ high enough such that the participation constraint begins to pin down the risk-level in the first region where the bank can only survive state s_1. If expected losses are lower below this LR, then they will also be for lower values of ρ as $(1 - \omega)$ would

increase slower, while k would increase at the same pace. Plugging the solution into the expected losses functions, expected losses will be larger under an LR iff:

$$(1-\mu)\left[(1-k_{lev})-\frac{\mu(R_2^h\pi+(1-\pi)(1-\lambda_2))-\rho k-(1-k)\mu}{\mu(R_2^h\pi+(1-\pi)(1-\lambda_2))-\mu R_1}(1-\lambda_1)-(1-\frac{\mu(R_2^h\pi+(1-\pi)(1-\lambda_2))-\rho k-(1-k)\mu}{\mu(R_2^h\pi+(1-\pi)(1-\lambda_2))-\mu R_1})(1-\lambda_3)\pi\right]$$

$$> (1-\mu)\left[(1-k(\omega))-\omega_{rw}(1-\lambda_1)-(1-\omega_{rw})(1-\lambda_3)\pi\right]$$

Rearranging, we find that if $\rho > \mu+\frac{\mu[R_2^h\pi+(1-\pi)(1-\lambda_2)-R_1]}{(1-\lambda_1)-(1-\lambda_3)\pi}$, we can write a condition on k_{lev} such that above this, expected losses are larger under an LR. So to be beneficial, it must be that:

$$k_{lev} < \tilde{k_1}$$

$$\equiv \frac{[k(\omega_{rw})+\omega_{rw}(1-\lambda_1)+(1-\omega_{rw})(1-\lambda_3)\pi]\,\mu\left[R_2^h\pi+(1-\pi)(1-\lambda_2)-R_1\right]-\mu\left[R_2^h\pi+(1-\pi)(1-\lambda_2)-1\right](1-\lambda_1)+\mu(R_1-1)(1-\lambda_3)\pi}{\mu\left[R_2^h\pi+(1-\pi)(1-\lambda_2)-R_1\right]-(\rho-\mu)\left[(1-\lambda_1)-(1-\lambda_3)\pi\right]}$$

Let us now consider $k_{lev} \geq \lambda_3$. Finding a similar condition, expected losses will be larger under an LR if the participation constraint pins down the risk choice and

$$(1-\mu)\left[(1-k(\omega))-\omega_{rw}(1-\lambda_1)-(1-\omega_{rw})(1-\lambda_3)\pi\right] < (1-\mu)(1-\pi)\left[(1-k_{lev})-\omega_{lev}(1-\lambda_1)\right]$$

If $\rho > \frac{\mu[\pi R_2^h+(1-\pi)(1-\lambda_2)]+(1-\mu)(1-\lambda_3)\pi-[\mu R_1+(1-\mu)(1-\lambda_1)\pi]}{1-\lambda_1} + \mu + (1-\mu)\pi$, this simplifies to:

$$k_{lev} > \tilde{k_2} \equiv \frac{\mu[\pi R_2^h+(1-\pi)(1-\lambda_2)]+(1-\mu)(1-\lambda_3)\pi-\mu R_1-(1-\mu)(1-\lambda_1)\pi}{\mu[\pi R_2^h+(1-\pi)(1-\lambda_2)]+(1-\mu)(1-\lambda_3)\pi-\mu R_1-(1-\mu)\pi(1-\lambda_1)-[\rho-\mu-(1-\mu)\pi](1-\lambda_1)}$$

$$\cdot\left[1-\frac{(1-k(\omega_{rw}))-\omega_{rw}(1-\lambda_1)-(1-\omega_{rw})(1-\lambda_3)\pi]}{(1-\pi)}\right]$$

$$-\frac{\pi R_2^h+(1-\pi)(1-\lambda_2)]+(1-\mu)(1-\lambda_3)\pi-[\mu+(1-\mu)\pi]}{\mu[\pi R_2^h+(1-\pi)(1-\lambda_2)]+(1-\mu)(1-\lambda_3)\pi-\mu R_1-(1-\mu)\pi(1-\lambda_1)-[\rho-\mu-(1-\mu)\pi](1-\lambda_1)}(1-\lambda_1)$$

Lastly, we show that these upper bound levels are strictly greater than the lower bound level derived earlier. The lower bound level was defined at the point where $k_{lev} = k(\omega_{rw}^*) + \omega_{rw}^*(1-\lambda_1) - \omega_{lev}^*(1-\lambda_1)$ where $*$ denotes optimal levels. The upper bound level was defined at the point where $k_{lev} = k(\omega_{rw}^*) + \omega_{rw}^*(1-\lambda_1) - \omega_{lev}^{pc}(1-\lambda_1)$ where pc denotes the level determined by the shareholders' participation constraint. Since $\omega_{lev}^{pc} < \omega_{lev}^*$, it must be that the upper bound is strictly greater than the lower bound. Equally, the upper bound is also strictly greater than the k required for an interior solution, i.e. $k = (1-\omega_{lev}^*)\lambda_2$. This will be true if and only if: $k(\omega_{rw}^*) + \omega_{rw}^*(1-\lambda_1) - \omega_{lev}^{pc}(1-\lambda_1) > (1-\omega_{lev}^*)\lambda_2$. Rearranging, we find $(\omega_{lev}^* - \omega_{rw}^*)\lambda_2 + (\omega_{rw}^* - \omega_{lev}^{pc}-)[(1-\lambda_1)-(1-\lambda_3)\pi] > 0$, which must be true since

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$\omega_{rw}^* > \omega_{lev}^* > \omega_{lev}^{pc}$ and $[(1 - \lambda_1) - (1 - \lambda_3)\pi] > \lambda_2$.

Taking the two conditions, which are a function of the underlying parameters, we can state that as long as $k_{lev} < \overline{k_2} \equiv \min\left\{\tilde{k}_1, \tilde{k}_2\right\}$, expected losses will decline. Hence, there exists a region $(\underline{k_2}, \overline{k_2})$ in which expected losses will be lower.

Overall therefore, in both of the cases $(1 - \mu) \leq \alpha$ and $(1 - \mu) > \alpha$, there exists a region $(\underline{k}, \overline{k})$ (where $(\underline{k}, \overline{k}) = (\underline{k_1}, \overline{k_1})$ if $(1 - \mu) > \alpha$, and $(\underline{k}, \overline{k}) = (\underline{k_2}, \overline{k_2})$ if $(1 - \mu) \leq \alpha$) where expected losses will be strictly lower than under a solely risk-based capital requirement.