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Leverage and Risk Weighted Capital Requirements*

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Abstract

The global financial crisis has highlighted the limitations of risk-sensitive bank capital ratios. To tackle this problem, the Basel III regulatory framework has introduced a minimum leverage ratio, defined as a banks Tier 1 capital over an exposure measure, which is independent of risk assessment. Using a medium sized DSGE model that features a banking sector, financial frictions and various economic agents with differing degrees of creditworthiness, we seek to answer three questions: 1) How does the leverage ratio behave over the cycle compared with the risk-weighted asset ratio? 2) What are the costs and the benefits of introducing a leverage ratio, in terms of the levels and volatilities of some key macro variables of interest? 3) What can we learn about the interaction of the two regulatory ratios in the long run? The main answers are the following: 1) The leverage ratio acts as a backstop to the risk-sensitive capital requirement: it is a tight constraint during a boom and a soft constraint in a bust; 2) the net benefits of introducing the leverage ratio could be substantial; 3) the steady state value of the regulatory minima for the two ratios strongly depends on the riskiness and the composition of bank lending portfolios.

JEL Codes: G21, G28, G32
Key words: Bank Capital Buffers, Regulation, Risk-Weighted Assets, Leverage

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1 Introduction

The global financial crisis has highlighted the limitations of risk-weighted bank capital ratios (regulatory capital divided by risk-weighted assets). Despite numerous refinements and revisions over the last two decades, the weights applied to asset categories seem to have failed to fully reflect banks' portfolio risk causing an increase in systemic risk (Acharya and Richardson (2009), Hellwig (2010), and Vallascas and Hagendorff (2013)). To tackle this problem the new regulatory framework of Basel III has introduced a minimum leverage ratio, defined as a bank's Tier 1 capital over an exposure measure, which is independent of risk assessment (Ingves (2014)).

The aim of the leverage ratio is to act as a complement and a backstop to risk-based capital requirements. It should counterbalance the build-up of systemic risk by limiting the effects of risk weight compression during booms. The leverage ratio is therefore expected to act counter-cyclically, being tighter in booms and looser in busts. If bank capital behaved in this way over the cycle, both the probability of a crisis and also the amplitude of output fluctuations would be reduced.

The Basel III framework requires that the leverage ratio and the more complex risk-based requirements work together. The leverage ratio indicates the maximum loss that can be absorbed by equity, while the risk-based requirement refers to a bank's capacity to absorb potential losses. The use of a leverage ratio is not new. A similar measure has been in force in Canada and the United States since the early 1980s (Crawford et al. (2009) and D'Hulster (2009)). Canada introduced the leverage ratio in 1982 after a period of rapid leveraging-up by its banks, and tightened the requirements in 1991. In the United States, the leverage ratio was introduced in 1981 amid concerns over bank safety due to falling bank capitalization and a number of bank failures (Wall and Peterson (1987) and Wall (1989)). The introduction of a leverage ratio requirement for large banking groups was announced in Switzerland in 2009 (FINMA, 2009). Similar requirements have been proposed, more recently, in other jurisdictions as well, with a view to implementing them by 2018 (BCBS, 2014b).

Motivated by these considerations this paper addresses the following questions:

1. How does the leverage ratio evolve over the cycle compared with the risk-weighted asset ratio?

2. What are the costs and the benefits of introducing a leverage ratio (in terms of level and volatility of some key variables)?

3. What can we learn about the interaction of the two regulatory ratios in the long run?

To address these questions we embed the regulator's problem within a macroeconomic model. Specifically we build on the DSGE model developed by Angelini et al. (2014) to examine the functioning and shortcomings of risk-based capital regulation and the role of the leverage ratio in mitigating the procyclicality problem. This model features a simplified banking sector and heterogeneity in the creditworthiness of the various economic agents. The model also features risk-sensitive capital requirements and a stylized countercyclical capital buffer. We contribute by augmenting this model in two ways. First, we introduce a leverage ratio, independent of risk assessment, whose deviation from the minimum requirements produces additional capital adjustment costs. Second, we allow the risk weights on lending to households and non-financial firms to be different in the steady state. This modification allows us to mimic the real world setting and generates different interest rates for the two classes of loans.

However, this framework has a few limitations. This setup does not allow for bank defaults in equilibrium and does not allow for credit risk materialization. In other words, the models belonging to this class do not explicitly feature inefficiencies that regulation aims to correct, rather than assumes it to be exogenously given. It is for these reasons that we will conduct a strictly positive analysis. We do not address normative questions such as the optimality of the leverage ratio. Our contribution to the literature lies in the fact that, in contrast to earlier papers, we model the financial intermediaries such that they are subject to a minimum leverage requirement in addition to the risk-based capital requirement, in line with one of the main tenets of the Basel III guidelines. The aim is to study how these ratios interact over the business cycle. The costs and benefits analyzed are in terms of levels and standard deviations of some key variables of interest. Our study does not assess the benefits of the leverage ratio in terms of reducing the frequency and severity of financial crises.

Our main results are as follows: (i) The leverage ratio is more counter-cyclical than the risk-weighted capital ratio: it is a tight constraint during a boom and a soft constraint in a bust; (ii) The benefits of introducing the leverage requirement appear to be substantially higher than the associated costs; and (iii) the steady state values of the two ratios strongly depend on the riskiness and the composition of lending portfolios. The remainder of the paper is organized as follows. The next section discusses the issue of procyclicality and why bank capital regulation is important in making the financial system more resilient. Section 3 describes Basel III regulation and presents some stylized facts on bank capital ratios. Section 4 describes the model, Section 5 presents the calibration while Section 6 discusses the results.

2 Why is bank capital important?

Bank capital is the part of the bank's funds that is contributed by the owners or shareholders, as opposed to external sources of funding which include deposits, inter-bank funding and obligations. Minimum capital requirements are intended to reduce bank insolvency risk. The main objective is to make sure that banks have sufficient internal resources to withstand adverse economic shocks and to improve incentive distortions that are created by a number of market imperfections in the banking sector.

2.1 Basel regimes

Over time, bank regulators have developed a sophisticated system of solvency regulations that are intended to increase the safety of individual institutions and the stability of the financial system. The first Basel Accord (Basel I) was adopted in 1988 by the G-10 with the aim of harmonizing capital regulation across countries and strengthening the stability of the international banking system (BCBS, 1988). The framework was designed to encourage banks to increase their capital positions and to make regulatory capital more sensitive to banks' perceived credit risks. Accordingly, assets and off-balance sheet activities were assigned risk weights between 0 and 100% according to their perceived risks, and banks were obliged to hold a minimal amount of capital relative to total risk-weighted assets and off-balance sheet activities.

The second Basel Accord (Basel II), which was first published in 2004 and implemented in most industrial countries in 2007, can be seen as a refinement of Basel I that introduces a complementary three pillar concept of bank regulation - minimum capital requirements, supervisory review (Internal Capital Adequacy Assessment Process) and market discipline (disclosure requirements). Amongst other things, it enforced the existing standards by introducing additional capital requirements for market risks, in particular interest rate and exchange risks (BCBS, 2005). Basel II also allowed banks to use their own internal models to evaluate risk, once the models were validated by the supervisory authority.

With the onset of the global financial crisis in 2008 and the perception of a number of weaknesses in the existing regulatory framework, the Basel Committee on Banking Supervision developed the third Basel Accord (Basel III) with the aim of implementing it in 2018 (BCBS, 2014b). It address the perception that the risk weights applied to asset categories have failed to fully reflect banks' portfolio risk causing an increase in systemic risk. To tackle this problem, among other things, Basel III has introduced a minimum leverage ratio that is independent of risk assessment and treats all exposures equally. As a result, the new capital regulation consists of three complementary components: (i) the risk-weighted capital regulation in which capital adequacy is set in relation to a historical assessment of risks augmented by countercyclical buffers (Drehmann et al. (2010)); (ii) the stress-testing framework which assesses banks' resilience to tail risks (BCBS, 2009b); and (iii) the leverage regulation that is independent of risk assessment.

It is important to note that the Basel III regulation requires the three components to be in place concomitantly, since each of them addresses a particular vulnerability. For instance, if the leverage ratio were used in isolation, then the information on individual asset risks would not be taken into account when assessing capital adequacy. Banks might then be incentivized to shift their investments from low-risk to high-risk assets. On the other hand, if there were only stress tests and risk-weighted capital requirements, banks would remain prone to model risk when classifying of particular assets into risk categories and in estimating future tail risks. Moreover, the problem that banks may leverage up their balance sheet by investing in assets that appear in the low-risk category would remain unaddressed.

To sum up, the leverage ratio is intended to act as a complement and a backstop to risk-based capital requirements. It should counterbalance the build-up of systemic risk by limiting the effects of risk weight compression during booms. The leverage ratio is therefore expected to act (more) countercyclically than the risk-weighted asset ratio, being tighter in booms and looser in busts.

2.2 What are the long term net benefits of bank capital regulation?

There is an intense debate between policymakers, industry lobbying groups and academics about the costs and benefits of bank capital requirements. Earlier contributions by Harrison (2004) and Brealey (2006) analyze the Basel II package and conclude that no compelling arguments support the claim that bank equity has a social cost. Focusing on the current crisis, Turner (2010) and Goodhart

(2010) argue that a significant increase in equity requirements is the most important step regulators should take to achieve the broader macroprudential goal of protecting the banking sector from period of excess aggregate credit growth. Acharya et al. (2011), Acharya et al. (2016) and Goodhart et al. (2010) suggest - in line with the actual implementation of the capital conservation buffer - that regulators should impose restrictions on dividends and equity pay-outs as part of prudential capital regulation. Admati et al. (2013) make a clear assessment of the applicability of standard corporate financial analysis and of the Modigliani-Miller propositions to understanding the economic impact of the new bank capital regulation and conclude that the benefits are larger than the costs. However, the authors do not provide any empirical quantification of the net benefits.

There are other papers that try to assess the costs and benefits of higher capital requirements. One example is Miles et al. (2011) who derive the optimal capital ratio for UK banks. They calculate costs using a two-step approach (first, estimate the impact of higher capital on lending spreads; next, estimate the impact of higher lending spreads on output). The key result is that a 1 percentage point increase in capital requirements causes output to fall by 0.02% (compared with 0.09 in Angelini et al. (2014) who use a similar set up). In the long term, the increase in lending spreads caused by a 1 percentage point in the capital requirement is equal to 0.8 basis points, smaller by a factor of 16 than the estimate by King (2010) of 13 basis points. Given these costs and taking into account that higher capital also reduces the probability of a banking crisis, their welfare analysis suggests that the optimal bank capital should be around 20% of risk-weighted assets. Benes and Kumhof (2015) use a theoretical model to analyze the impact of prudential rules and a countercyclical capital buffer requirement, similar to the reform proposed in Basel III, and find that theoretically a buffer requirement has the ability to increase overall welfare by reducing the volatility of output. More recently, Karmakar (2016) uses a DSGE model with a non-linear and occasionally binding capital requirement constraint and shows that higher capital requirements reduce business cycle volatility and raises welfare. He also derives an optimal capital requirement of 16%, in line with the Basel guidelines.

The Institute of International Finance, (IIF 2011) argues that the economic cost of Basel III - in terms of foregone real GDP - will be significant, about 0.7% per year over the five years following the implementation of Basel III. The difference with respect to Miles et al. (2011) depends on several factors, the most important one being the short time horizon and the lack of any assessments of the benefits in the long run.

Corbae and D'Erasmo (2013) develop a dynamic model of banking industry dynamics to investigate banking regulations, and specifically Basel III, and their effect on industry dynamics. They find that a rise in capital requirements from 4 to 6% leads to a rise in loan interest rates by about 50 basis points as well as a lower level of GDP, while the cost of deposit insurance falls substantially. Generally similar results are obtained in the DSGE model presented by Aliaga-Diaz and Olivero (2012). When the capital requirement is raised by 2 percentage points in their model, loan rates rise by about 15 basis points, while output falls by slightly less than 1%. Consistently with these results, Drehmann and Gambacorta (2012) find that the introduction of a countercyclical capital buffer helps to reduce credit growth during booms and attenuate the credit contraction once it is released.

An overall assessment of the net benefits (benefits minus costs) of Basel III are reported in the Long-term Economic Impact study (the so-called LEI report, see BCBS, 2010b). In particular, this study indicates that the economic costs associated with tighter capital and liquidity standards are considerably lower than the estimated positive benefit that the reform should have by reducing the probability of banking crises and their associated banking losses. However, none of the DSGE models used in this study feature credit risk and the possibility of default, so that the main benefits of the reform are calculated by considering the reduction in output volatility (see Angelini et al. (2014)). This is a limitation of our study as too.[1]

3 Stylized facts about the risk-weighted capital and leverage requirements

One aspect that remains to be assessed is if the side-by-side application of risk-weighted capital and leverage requirements could be of help in preventing the occurrence of a fragile boom and smoothing the cycle. One of the lessons from the recent financial crisis is that the banks built up a substantial amount of leverage while apparently maintaining strong risk-based capital ratios. When the financial markets forced the banks to deleverage rapidly, this put a strong downward pressure on asset prices. This in turn brought about a decline in bank capital and eventually a credit squeeze that exacerbated the problem.

[1]Most models used in the LEIs exercise are of the dynamic stochastic general equilibrium (DSGE) family. However, following a 'diversification' approach, a limited number of alternative models (example: semi-structural and vector error correction models (VECM)) were also used (see Angelini et al., 2015).

Typically, during booms, risk materialization is low and hence banks have an incentive to engage in profit-making opportunities. It is precisely at this time, that risk weights are low, giving the impression that banks are sufficiently capitalized and in sound financial health. Overoptimistic assessment of risk weights lead to large-scale extension of credit and hence decline in lending standards. The reduction of risk weights could be particularly strong in a period in which interest rates are low. This is the so-called the risk-taking channel (Borio and Zhu (2008), Adrian and Shin (2014), Altunbas et al. (2014)) and works not only through a "search for yield" mechanism but also through the impact of low interest rates on valuations, incomes and cash flows. A reduction in the policy rate boosts asset and collateral values, which in turn can modify bank estimates of probabilities of default, loss given default and volatilities. For example, low interest rates by increasing asset prices tend to reduce asset price volatility and thus risk perceptions. Since higher stock prices increases the value of equity relative to corporate debt, a sharp increase in stock prices reduces corporate leverage and could thus lessen the risk of holding stocks. All this has a direct impact on value-at-risk methodologies for economic and regulatory capital purposes (Danielsson et al. (2004)). As volatility tends to decline in rising markets, it releases the risk budgets of financial firms and encourages leveraged position-taking. A similar argument is provided in the model by Adrian and Shin (2014), who stress that changes in measured risk determine adjustments in bank balance sheets and leverage conditions and that this, in turn, amplifies business cycle movements.

While the procyclical features of risk-weights have been widely discussed, we still lack a precise quantification of their effects. Brei and Gambacorta (2016) test whether the cyclical sensitivity of the capital ratios increased from Basel I to Basel II, with the introduction of internal ratings-based (IRB) models and tailored risk-weights. In particular, they find that the level of the risk-weighted capital ratios decreased in response to its introduction in 2007, just before the beginning of the global financial crisis. In a recent paper, Behn, Haselmann and Wachtel (2016) analyze the effects of changes in risk-weights after the default of Lehman brothers and find that increases in capital charges caused by procyclical regulation had a strong and economically meaningful impact on the adjustment of loans over the credit risk shock. In particular, their estimates indicate that, in response to the shock, IRB banks reduced loans to the same firm by 2.1 to 3.9 percentage points more when capital charges for the loan were based on internal ratings than when they were based on fixed risk weights (standardized approach).

When loan quality starts to deteriorate, capital is used to absorb the losses. It is mainly for this reason that we need a non risk based measure that will complement the risk based capital requirements. The leverage ratio indicates the maximum loss that can be absorbed by equity. The opposite happens during economic downturns. During such times, risk weights are high and hence the capital requirement constraint tightens but the leverage requirement is unaffected by the changes in risk weighting and it will be satisfied. The main point is that the two capital requirements need to work together to limit a boom-bust cycle.

It must be noted that a necessary condition for the minimum LR requirement to act as a cyclical backstop to the RWRs is that the banks' exposure expands more strongly during a financial boom than the corresponding increase in its' risk-weighted assets. This should make the LR work counter-cyclically. Indeed, using a large data set covering international banks headquartered in 14 advanced economies, Brei and Gambacorta (2016) find that the Basel III leverage ratio is significantly more countercyclical than the risk-weighted regulatory capital ratio: it is a tighter constraint for banks in booms and a looser constraint in recessions. The main results of Brei and Gambacorta (2016) are summarized in Table (1). A 1% point increase in real GDP growth is associated with a reduction of the LR of 5 basis points, while the risk-weighted ratio does not react to GDP movements. Similar results are obtained using a financial measure of the cycle, the credit gap (the difference between the credit to GDP ratio and its trend).

The Basel Committee on Banking Supervision sets out that the leverage ratio is intended to:

1. Avoid excessive build-up of leverage so that rapid deleveraging, in the event of a crisis, does not destabilize both the financial and real sectors.

2. Complement the risk-based measures with a simple, non risk-based "backstop" measure.

The Basel III leverage ratio (LR) is defined as a capital measure over total exposure,[2]

$$\text{Leverage Ratio} = \frac{\text{Capital}}{\text{Exposure}}$$

In this paper, we will explore if the leverage requirement really acts as a backstop to the capital requirements. Despite the fact that the minimum leverage ratio has already been set at 3%, we cannot use this as a minimum requirement to calibrate the model because the composition of the

[2] The total exposure is given by total assets and other commitments. A detailed explanation of the definition of capital and total exposures can be found in BCBS (2014a).

credit portfolio of our banks is quite simplified: it does not include interbank loans and more importantly government bonds (our model does not feature a public sector).[3]

Following Fender and Lewrick (2015), a useful concept in calibrating the LR in a manner consistent with the existing RWRs (i.e. by taking possible interactions into account) is the "RWA density" or "density ratio" (DR), defined as the ratio of RWA to the LR exposure measure. The density ratio denotes the average risk weight per unit of exposure for any given bank or banking system. The relationship between the LR and the DR can be obtained by expanding the LR definition as follows:

$$LR = \frac{Capital}{RWA} * \frac{RWA}{Exposure} = RWR * DR \tag{1}$$

The LR can thus be expressed as the product of the risk-weighted capital ratio (RWR= Capital/Risk-weighted assets) and the DR. This relationship can help us calibrate a consistent minimum LR requirement.

Equation (1) shows how the LR and the RWRs complement each other from a cross-sectional point of view. If, all else equal, a bank's risk model underestimates its risk weights, this will bias the Tier 1 capital ratio upwards. Yet, at the same time, the DR is biased downwards, making a minimum LR requirement relatively more constraining. Conversely, for a given LR requirement, a bank with a relatively low DR will have an incentive to shift its balance sheet towards riskier assets to earn more income - a type of behavior that the RWRs would constrain. This suggests that banks' risk-weighted capital ratios and the LR provide complementary information when banks' resilience is assessed.

The coherence between the LR and the RWR requirement, set by the Basel III regulation at 8.5%, implies the calculation of a plausible value for the DR in the steady state.[4] In the context of our model, banks lend only to households and non-financial firms and we have to reconstruct a plausible density ratio taking into account: (a) the risk weights for loans to households and non-

[3]Refer the Group of Central Bank Governors and Heads of Supervision (GHOS) press release dated 11th January, 2016. (http://www.bis.org/press/p160111.htm). There is still an ongoing debate about the possibility of a leverage surcharge for global systemically important banks (G-SIBs). Most of the existing leverage ratio frameworks indicate an additional surcharge of 1-2% (Bank of England, Financial Stability Report, 2016). The additional surcharge for G-SIBs on the risk-weighted capital ratio has been already designed by the Basel III regulation following a bucket approach from 1-3.5% (http://www.bis.org/publ/bcbs255.pdf). For simplicity, we do not consider such buffers in our model.

[4]New Basel III regulation has tightened risk-weighted capital requirements. Banks have to meet a 6% Tier 1 capital ratio (comprising a more broadly defined Tier 1 capital element as numerator); and (ii) maintain an additional capital conservation buffer of 2.5% (in terms of CET1 capital to RWA). The new minimum could be considered to be 8.5%

financial firms and (b) the proportion of bank loans to these two sectors in the long run.

The first point can be solved using information in EBA (2011) that reports the average risk weights implied by the internal models of European banks. In particular, weights are 0.37 for household lending and 0.92 for lending to non-financial firms. These weights are very similar to those implied by the standardized approach in Basel I, which are, respectively, 0.35 and 1.00. As for the second point, we can simply rely on the long-term share of loans to the non-financial sector in the euro area that is approximately 60% to households and 40% to firms. Taking these values into account the density ratio is equal to 0.59 (0.37*0.6+0.92*0.4) and from equation (1) it is possible to derive a plausible value for the minimum LR approximately equal to 5% (8.5*0.59). In our numerical results, we will use this as a baseline case for the minimum LR requirement. It is worth stressing that this value is coherent with the calibration of our specific model and should not be interpreted as a benchmark for the calibration of the actual minimum requirement in the euro area.

4 The model

We build on the model by Gerali et al. (2010) and Angelini et al. (2014). There are some trade-offs to using this framework. The framework allows us to study a non-naive financial sector, besides incorporating credit frictions, borrowing constraints and a set of real and nominal rigidities. The borrowing constraints are modeled as Iacoviello (2005) while the real and nominal rigidities are similar to the ones developed in Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2003). The borrowing constraints and the bank regulatory constraints are always binding and not occasionally binding. In this section, we discuss the main features of the model. For further details, we would like to refer the reader to Angelini et al. (2014).

4.1 A brief overview

The flowchart in Figure 1 shows the interactions between the different agents in the economy. There are two types of households (patient and impatient) who consume, supply labor, accumulate housing (in fixed supply) and either borrow or lend. The two types of households differ in their respective discount factors ($\beta^P > \beta^I$). The difference in discount factors leads to positive financial flows in equilibrium. The patient households sell deposits to the banks while the impatient households borrow, subject to a collateral constraint. The entrepreneurs hire labor from the households, and buy capital from the capital goods producers, to produce a homogeneous intermediate good.

The banks accept deposit and supply business and mortgage loans. Similar to the impatient households, the entrepreneur also faces a collateral constraint while drawing a loan from the bank. Another useful feature of this model is that the banks are monopolistically competitive. In other words, they set lending and deposit rates to maximize profits. The banks can only accumulate capital through retained earnings i.e. we do not allow for equity issuance.

On the production side, there are also monopolistically competitive retailers and capital goods producers. The retailers buy intermediate goods from the entrepreneurs, differentiate and price them, subject to nominal rigidities. The capital goods producers help us introduce a price of capital to study asset price dynamics.

The model also features a monetary authority and a macroprudential authority. The monetary authority sets policy rates and follows a standard Taylor rule. The macroprudential authority sets the minimum risk based capital and leverage requirements. We now study the individual agents in greater detail.

4.2 The patient households

The representative patient household 'i' chooses $c_t^P(i)$, $l_t^P(i)$, $h_t^P(i)$ and $d_t^P(i)$ to maximize the expected utility,

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \left[(1-a^P)\epsilon_t^z log(c_t^P(i) - a^P c_{t-1}^P) + \epsilon_t^h log h_t^P(i) - \frac{l_t^P(i)^{1+\phi}}{1+\phi} \right]$$

subject to the following budget constraint (in real terms)

$$c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t^P(i) \leq w_t^P l_t^P(i) + \frac{(1+r_{t-1}^d) d_{t-1}^P(i)}{\pi_t} + t_t^P(i), \tag{2}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ is the rate of inflation. The expected utility depends on current and lagged consumption c_t^P, housing h_t^P and labor hours l_t^P. There are external habits in consumption. The household utility is subject to two preference shocks. The shock to consumption is ϵ_t^z and the shock to housing demand is ϵ_t^h. They follow independent AR(1) processes. Equation (2) is the budget constraint. The expenses include consumption, accumulation of housing and selling one period deposits to the banks. The receipts are in the form of labor income, gross return on last periods deposits and some lump-sum transfers t_t. The real house price is q_t^h and w_t^P is the real wage rate.

4.3 The impatient households

The representative patient household 'i' chooses $c_t^I(i)$, $l_t^I(i)$, $h_t^I(i)$ and $b_t^I(i)$ to maximize the expected utility

$$E_0 \sum_{t=0}^{\infty} \beta_I^t \left[(1-a^I)\epsilon_t^z log(c_t^I(i) - a^I c_{t-1}^I) + \epsilon_t^h log h_t^I(i) - \frac{l_t^I(i)^{1+\phi}}{1+\phi} \right]$$

subject to the following budget constraint (in real terms)

$$c_t^I(i) + q_t^h \Delta h_t^I(i) + \frac{(1+r_{t-1}^{bH}) b_{t-1}^I(i)}{\pi_t} \leq w_t^I l_t^I(i) + b_t^I(i) + t_t^I(i) \tag{3}$$

and the borrowing constraint,

$$(1+r_t^{bH}) b_t^I(i) \leq m_t^I E_t \left[q_{t+1}^h h_t^I(i) \pi_{t+1} \right] \tag{4}$$

Similar to the patient households, the expected utility of the impatient households depends on consumption c_t^I, housing h_t^I and hours worked l_t^I and are subject to the same preference shocks. The budget constraint in this case looks somewhat different from the earlier case. The expenses consists of consumption, accumulation of housing and servicing of debt b_{t-1}^I. The receipts comprise labor income, new loans and lump-sum transfers.

Equation (4) above represents the households borrowing constraint. This states that the household can borrow up to the expected value of their housing and m_t^I is the stochastic LTV ratio for mortgages.

4.4 The entrepreneurs

Each entrepreneur 'i' maximizes his expected utility that depends only on consumption $c_t^E(i)$.

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \left[log(c_t^E(i) - a^E c_{t-1}^E) \right]$$

The entrepreneurs choose consumption c_t^E, physical capital k_t^E, loans b_t^E, and the labor inputs

$l_t^{E,P}$ and $l_t^{E,I}$. The budget constraint for the entrepreneurs is given by:

$$c_t^E(i) + w_t^P l_t^{E,P}(i) + w_t^I l^{E,I}(i) + \frac{1 + r_{t-1}^{bE}}{\pi_t} b_{t-1}^E(i) + q_t^k k_t^E(i) = \frac{y_t^E(i)}{x_t} + b_t^E(i) + q_t^k(1-\delta)k_{t-1}^E(i), \quad (5)$$

where δ and q_t^k are the depreciation and price of physical capital, respectively. The competitive good is produced by the technology,

$$y_t^E(i) = a_t^E \left[k_{t-1}^E(i)\right]^\alpha \left[l_t^E(i)\right]^{1-\alpha}$$

The relative competitive price of the good is $1/x_t = P_t^W/p_t$, a_t^E is the stochastic TFP and $l_t^E = (l_t^{E,P})^\mu (l_t^{E,I})^{1-\mu}$, where μ is the share of patient households labor.[5]

Further, the entrepreneurs are also subject to borrowing constraints. They can also borrow up to the expected value of their undepreciated capital i.e.

$$(1 + r_t^{bE})b_t^E(i) \leq m_t^E E_t \left[q_{t+1}^k(1-\delta)k_t^E(i)\pi_{t+1}\right], \quad (6)$$

where m_t^E is the stochastic LTV on entrepreneurial loans. Following Iacoviello (2005) and Gerali et al. (2010), we choose the value of shocks such that the borrowing constraints always bind in the neighborhood of the steady state.

4.5 The banks

The banks have market power in setting lending and deposit rates. They adjust loans and deposits in response to cyclical conditions of the economy while satisfying the balance sheet identity and the regulatory requirements. Each bank consists of a wholesale unit that manages bank capital and two retail units that accept deposits and make loans.

4.5.1 The wholesale branch

The wholesale branch operates under perfect competition. On the liabilities side, it combines the bank capital, K_t^b, with the retail deposits, D_t, while on the asset side, it provides funds to the retail branch to extend differentiated loans, B_t^H and B_t^E. There is also a cost associated with the

[5] A detailed discussion can be found in Iacoviello and Neri (2010).

wholesale activity. We assume that the banks incurs quadratic costs whenever it deviates from a required leverage and a risk-weighted asset ratio. These requirements are fixed by the regulator and hence the bank takes these targets as exogenously given while solving the optimization problem. The exogenous target incorporates the accelerator mechanism as described by Adrian and Shin (2010). Essentially, the bank tries to stay close to a constant leverage and risk-weighted asset ratio and there are costs to deviating from these targets.

There is no equity issuance in the model and therefore bank capital is accumulated through retained earnings only. The law of motion for bank capital is as follows:

$$K^b_{t+1}(j) = (1 - \delta^b)K^b_t(j) + J^b_t,$$

where J^b_{t-1} represents the overall profits of the banking group. The wholesale branch chooses loans and deposits to maximize the discounted sum of cash flows:

$$E_0 \sum_{t=0}^{\infty} \Lambda^P_{0,t} \Big[(1 + R^{BH}_t)B^H_t(j) + (1 + R^{BE}_t)B^E_t(j) - (B^H_{t+1}(j) + B^E_{t+1}(j)) + D_{t+1}(j) - (1 + R^d_t)D_t(j)$$

$$+(K^b_{t+1}(j) - K^b_t(j)) - \frac{\kappa_{Kb}}{2}\left(\frac{K^b_t(j)}{\omega^H_t B^H_t(j) + \omega^E_t B^E_t(j)} - \nu_t\right)^2 K^b_t(j) - \frac{\kappa_{Lb}}{2}\left(\frac{K^b_t(j)}{B^H_t(j) + B^E_t(j)} - \phi^b\right)^2 K^b_t(j)\Big]$$

subject to the balance sheet identity, $B^H_t(j) + B^E_t(j) - D^b_t(j) = K^b_t(j)$

δ^b measures the resources used up in the activity of managing bank capital. It could also capture the idea that owing some exogenous reasons, aggregate bank capital depreciates. This could be because some borrowers do not payback their loans, fall in asset prices etc. This should not be interpreted in the same way as the depreciation of physical capital. The value was calibrated to obtain a steady state capital to total loans ratio of 8.5% and that corresponds to $\delta^b = 0.11$. The last two terms in the above expression show the quadratic costs incurred on deviating from the capital and leverage requirements, respectively. These costs are parametrized by κ_{Kb} and κ_{Lb}. The first-order conditions yield a relationship between the capital position of the bank and the spread between the wholesale lending and deposit rates. We can write the FOCs for any bank, j, as follows:

$$R_t^{BH} - R_t^d = -\kappa_{Kb}(\frac{K_t^b}{\omega_t^H B_t^H + \omega_t^E B_t^E} - \nu_t^b)(\frac{K_t^b}{\omega_t^H B_t^H + \omega_t^E B_t^E})^2 \omega_t^H -$$
$$\kappa_{Lb}(\frac{K_t^b}{B_t^H + B_t^E} - \phi^b)(\frac{K_t^b}{B_t^H + B_t^E})^2 \quad (7)$$

$$R_t^{BE} - R_t^d = -\kappa_{Kb}(\frac{K_t^b}{\omega_t^H B_t^H + \omega_t^E B_t^E} - \nu_t^b)(\frac{K_t^b}{\omega_t^H B_t^H + \omega_t^E B_t^E})^2 \omega_t^E -$$
$$\kappa_{Lb}(\frac{K_t^b}{B_t^H + B_t^E} - \phi^b)(\frac{K_t^b}{B_t^H + B_t^E})^2 \quad (8)$$

It can be seen that equations (7) and (8) are identical if the risk weights are same i.e. $R_t^{BH} = R_t^{BE}$, if $\omega_t^E = \omega_t^H$. The left-hand side shows the marginal profits from increasing lending (equal to the spread) while the right-hand side shows the costs of deviating from the minimum requirements. We also assume that the bank has access to unlimited finance from the central bank at the policy rate and thereby by arbitrage, the wholesale deposit rate is equal to the policy rate. Following Angelini et al. (2014), we model risk weights as follows:

$$\omega_t^i = (1 - \rho^i)\overline{\omega}^i + (1 - \rho^i)\chi^i(Y_t - Y_{t-4}) + \rho^i \omega_{t-1}^i, \qquad i = H, E$$

In the above equation, $\overline{\omega}^i$ corresponds to the steady-state risk weights on household and business lending. $\chi^i < 0$ which means the risk weights tend to be low during booms and high during recessions. The cyclicality of the risk weights is what differentiates a bank's regulatory capital ratio from its leverage ratio, following the discussion in Section 3. The law of motion for risk weights helps us capture the difference between the capital and leverage ratios over the business cycle. The law of motion for risk weights, though simple, captures one of the main ideas embedded in the Internal Risk Based (IRB) approach to computing risk weight functions. As we know, credit risk in a portfolio arises from two sources, systematic and idiosyncratic (BCBS 2006). Systematic risk represents the effect of unexpected changes in macroeconomic and financial market conditions on the performance of borrowers, while idiosyncratic risk represents the effects of risks that are particular to individual borrowers. As a borrower's portfolio becomes more granular, in the sense that the larger exposures account for smaller shares of total portfolio exposure, idiosyncratic risk can be completely diversified away. The more granular the portfolio, the less is the likelihood of risk weights responding to idiosyncratic risk. Note that the situation is completely different for systematic (aggregate) risk as very few firms are completely shielded from the macroeconomic environment in which they operate. Therefore this risk is undiversifiable and hence can cause the riskiness of the borrowers to move countercyclically. Our risk-weight function captures a similar idea and we proxy the undiversifiable systematic (aggregate) factor by output.

4.5.2 The retail branch

A Dixit-Stiglitz framework is assumed for the retail credit and deposit markets. The elasticities of loan and deposit demand coming from households and entrepreneurs is given by ε_t^{bs} and ε_t^{d}, where $s = H, E$. These terms will be a major determinant of spreads between bank rates and the policy rate. We maintain the assumption in Gerali et al. (2010) that each of these elasticity terms is stochastic. Innovations to interest rate elasticities of loans and deposits can be interpreted as innovations to bank spreads arising independently of monetary policy. The retail branch takes the loan and deposit demand schedules as given and then chooses the interest rates to maximize profits. The loan and deposit demand schedules, facing bank j, can be derived as follows:

$$b_t^s(j) = \left(\frac{r_t^{bs}(j)}{r_t^{bs}}\right)^{-\varepsilon_t^{bs}} b_t^s \qquad d_t^P(j) = \left(\frac{r_t^{d}(j)}{r_t^{d}}\right)^{-\varepsilon_t^{d}} d_t, \qquad s = H, E \tag{9}$$

We observe that the aggregate demand for loans at bank j by impatient households or entrepreneurs depends on the overall volume of loans to households or entrepreneurs and on the interest rate charged on loans relative to the rate index for that specific type of loan. We also note that the aggregate households demand for deposits at bank any bank, "j", depends on the aggregate amount of deposits in the whole economy, d_t.

The retail loan branch j chooses the interest rate on loans to maximize:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \Big[r_t^{BH}(j) b_t^H(j) + r_t^{BE}(j) b_t^E(j) - (R_t^{BH} B_t^H(j) + R_t^{BE} B_t^E(j))$$

$$-\frac{\kappa_{bH}}{2}(\frac{r_t^{bH}(j)}{r_{t-1}^{bH}(j)} - 1)^2 r_t^{bH} b_t^H - \frac{\kappa_{bE}}{2}(\frac{r_t^{bE}(j)}{r_{t-1}^{bE}(j)} - 1)^2 r_t^{bE} b_t^E], \tag{10}$$

subject to the loan demand forthcoming from households and entrepreneurs (Equation (9)). The first two terms are simply the returns from lending to households and entrepreneurs. The next term reflects the cost of remunerating funds received from the wholesale branch. The last two terms are the costs of adjusting the interest rates. After imposing a symmetric equilibrium, the first-order conditions for interest rates yield:

$$1-\varepsilon_t^{bs}+\varepsilon_t^{bs}\frac{R_t^{bs}}{r_t^{bs}}-\kappa_{bs}(\frac{r_t^{bs}}{r_{t-1}^{bs}}-1)\frac{r_t^{bs}}{r_{t-1}^{bs}}+E_t[\Lambda_{t+1}^p\kappa_{bs}(\frac{r_{t+1}^{bs}}{r_t^{bs}}-1)(\frac{r_{t+1}^{bs}}{r_t^{bs}})^2\frac{B_{t+1}^s}{B_t^s}]=0 \tag{11}$$

The discount factor is equal to the one of patient households because they own the bank. It can be seen that the retail rates depend on the markup and the wholesale rate (the marginal cost for the bank) which in turn depends on the banks capital position and the policy rate. A similar equation can be derived for the deposit retail branch:

$$-1+\varepsilon_t^{d}-\varepsilon_t^{d}\frac{R_t}{r_t^{d}}-\kappa_{d}(\frac{r_t^{d}}{r_{t-1}^{d}}-1)\frac{r_t^{d}}{r_{t-1}^{d}}+E_t[\Lambda_{t+1}^p\kappa_{d}(\frac{r_{t+1}^{d}}{r_t^{d}}-1)(\frac{r_{t+1}^{d}}{r_t^{d}})^2\frac{d_{t+1}}{d_t}]=0 \tag{12}$$

It can be seen from equations (11) and (12) that when prices are perfectly flexible, the lending rates are simply a markup over the policy rate while the deposit rate is a markdown on the policy rate, i.e.,

$$r_t^{bs}=\frac{\varepsilon_t^{bs}}{1-\varepsilon_t^{bs}}R_t^{bs} \qquad r_t^{d}=\frac{\varepsilon_t^{d}}{\varepsilon_t^{d}-1}R_t^{d}, \qquad s=H,E$$

Finally, the total profits of the banking group, j, can be written as follows:[6]

$$J_t^b=r_t^{BH}b_t^H+r_t^{BE}b_t^E-r_t^d d_t-\frac{\kappa_{Kb}}{2}(\frac{K_t^b}{\omega_t^H B_t^H+\omega_t^E B_t^E}-\nu_t^b)^2K_t^b$$
$$-\frac{\kappa_{Lb}}{2}(\frac{K_t^b}{B_t^H+B_t^E}-\phi^b)^2K_t^b-\frac{\kappa_{bH}}{2}(\frac{r_t^{bH}(j)}{r_{t-1}^{bH}(j)}-1)^2r_t^{bH}b_t^H-\frac{\kappa_{bE}}{2}(\frac{r_t^{bE}(j)}{r_{t-1}^{bE}(j)}-1)^2r_t^{bE}b_t^E \tag{13}$$

Thus total bank profits are total receipts from retail loans less deposit costs, costs of deviating from the leverage and capital requirement regulations, and interest rate adjustment costs.

4.6 Retailers and capital goods producers

Capital goods producers buy undepreciated capital from entrepreneurs and final goods from retailers to produce new capital which is sold back to entrepreneurs, at price Q_t^k. This process of

[6] Retail and wholesale branches taken together and ignoring within group transactions.

transforming the final goods into capital goods entails adjustment costs. Following Bernanke et al. (1999), the retail goods producers are assumed to be monopolistically competitive. They face nominal rigidities and their price is indexed to a combination of past and steady inflation. They face quadratic adjustment costs to change prices beyond what is allowed by indexation.

4.7 Monetary and macroprudential policy

There are a few more ingredients that warrant discussion, namely the monetary authority and the macroprudential authority.

The monetary authority sets policy rates according to a standard Taylor rule:

$$(1 + r_t) = (1 + r)^{1-\phi_R}(1 + r_{t-1})^{\phi_R} \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\phi_R)} \left(\frac{y_t}{y}\right)^{\phi_y(1-\phi_R)} \epsilon_t^r,$$

where ϕ_y and ϕ_π are the weights attached to output and inflation growth respectively and ϵ_t^r is a white noise monetary policy shock.

The macroprudential setup is different in this paper with respect to Angelini et al. (2014). The macroprudential authority sets a time-varying capital requirement and a fixed leverage requirement, that banks must comply with at all times. As discussed earlier, there are costs to deviating from these exogenously set targets. Time-varying capital requirements follow:

$$\nu_t = (1 - \rho_\nu)\overline{\nu} + (1 - \rho_\nu) \left[\chi_\nu \left(\frac{B_t}{Y_t} - \frac{\overline{B}}{\overline{Y}}\right)\right] + \rho_\nu \nu_{t-1},$$

where $\chi_\nu > 0$ would imply the presence of a countercyclical capital buffer. The objective of having such time-varying capital requirements is to increase bank capital when the loan to output ratio deviates away from its steady-state level (Drehmann and Gambacorta (2012)). The countercyclical capital buffer used in the model follows Basel III recommendations (BCBS, 2010). Credit-to-GDP gaps are valuable early warning indicators for systemic banking crises. As such, they are useful for identifying vulnerabilities and can help guide the deployment of macroprudential tools such as the build-up of countercyclical capital buffers (Drehmann et al. 2010).

Lastly, to close the model, we specify the main market clearing condition. The aggregate output in the economy is divided into consumption, accumulation of physical and bank capital, and the various adjustment costs.

$$Y_t = C_t + I_t + \delta^b \frac{K^b_{t+1}}{\pi_t} + Adj_t,$$

where $C_t = c^P_t + c^I_t + c^E_t$ is the aggregate consumption, I_t is aggregate investment undertaken, and K^b_{t+1} is the aggregate bank capital. The term Adj_t includes all adjustment costs. In the housing market, equilibrium is given by $\overline{h} = h^P_t(i) + h^I_t(i)$, where $\overline{h}$ is the fixed housing stock.

5 Calibration

Most of the parameters used are the ones estimated in Gerali et al. (2010). The main parameters are reported in Table 2. The discount factor is identical for the impatient households and the entrepreneurs. The steady-state risk-weighted capital requirement is set at 8.5% which includes a core Tier 1 requirement of 6% and a conservation buffer of 2.5%. As discussed earlier, the model calibration of the leverage ratio is sensitive to the steady-state risk weights. To illustrate this point a bit further, we use Figure 2 to plot equation (1). On the x and y axis, we alter the risk-weights on mortgage and firm lending while on the z axis we plot the leverage ratio. As is intuitive, the leverage ratio is increasing in either of the steady-state risk weights. In terms of equation (1), this is because an increase in either of the two risk weights increases the risk weight density, thereby increasing the minimum leverage requirement. Intuitively, when the overall economic scenario is more risky, it is prudent to hold more capital. Our baseline calibration corresponds to steady-state risk weights of 0.37 on household lending and 0.92 on entrepreneurial lending. Given that the steady-state risk-weighted capital ratio requirement and that the share of lending to households vs. firms is 60-40, we calibrate the leverage ratio to be 5%. We also report the results of using the standardized risk weights for the calibration i.e. 0.35 and 1.00 for mortgage to households and firm lending respectively.

The depreciation of physical capital (δ) is set to get an annual depreciation of 10%. The mark-ups in the goods and labor markets are assumed to be 25% and 20% yielding values of $\varepsilon^l = 5$ and $\varepsilon^y = 6$ respectively. The weight of housing in the utility function is taken from Iacoviello and Neri (2010) and is set at $\varepsilon^h = 0.2$. The LTV ratio on mortgage lending is set at 70% and this is in line with the average LTV ratio, for mortgages, in Europe and the USA, Calza et al. (2013).[7] The LTV

[7] Refer Table 1 of the working paper version here: https://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp1069.pdf

ratios for entrepreneurs is set at 35%. Christensen et al. (2007) estimate a value of 0.32 for Canada, in which firms can borrow against capital while Gerali et al. (2010) computed a number close to 0.40 for the euro area. Based on this evidence, we set the LTV for entrepreneurial lending at 0.35.[8] The calibration of the TFP shock is standard, as it is adopted from the business cycle literature.

Regarding the parameters of the law of motion for the risk weights, we use the estimated parameters from Angelini et al. (2011).[9] The parameters χ^H, χ^E, ρ^H, and ρ^E are set at, respectively, -10, -15, 0.94, and 0.92. Regarding the steady-state risk weights, we experiment with two sets of values. The first set corresponds to the European Banking Authority figures ($\omega^H = 0.37$ and $\omega^E = 0.92$) while the second set corresponds to the standardized risk weighting approach ($\omega^H = 0.35$ and $\omega^E = 1.00$). The costs of deviating from the regulatory capital and leverage ratio requirements i.e. κ_{Kb} and κ_{Lb} are set at 8.00 and 7.63 respectively. The former targets a steady state capital to risk weighted asset ratio of 8.5% while the latter targets a steady state leverage ratio of 5%.

6 Results

We will analyze the response of the economy to two shocks, namely a positive technology shock and a shock to the loan-to-value ratio for entrepreneurial lending. We will also conduct some exercises with alternative values of the leverage ratio to understand the costs and benefits of the same.

6.1 Response to a positive technology shock

We analyze the response of some key variables in response to a unit standard deviation shock to total factor productivity. Figure 3 illustrates the main mechanism of the model. The left-hand panel shows how the risk weights decline during booms. The decline in risk weights could encourage excessive risk taking during booms and this is precisely what the leverage ratio aims to correct. The right panel shows how the leverage ratio and the risk-sensitive capital ratio evolve after the incidence of the shock. The mechanism is the following. During booms, lending to households and

[8] This is also the number used in Gerali et al. (2010).

[9] They use data on delinquency rates on loans to households and non-financial corporations in the US as proxies for the probabilities of default on these loans (similar data for the euro area were not available). They input these time series into the Basel II capital requirements formula, and, using a series of assumptions concerning the other key variables of the formula, they back out the time series for the risk weights. Next they estimate the law of motion for the risk-weights equation to obtain the parameters. For more details, we refer the reader to Appendix 1 of Angelini et al. (2011).

firms increases, driving down the leverage and the capital ratio. However, risk weights also decline and therefore the decline in the leverage ratio (non-risk-sensitive) is larger than the capital-to-RWA ratio. This increases costs for the bank because it deviates more from the regulatory requirements. In the absence of the leverage requirement, the bank would continue to expand lending. It is in this way that the leverage ratio restricts a credit cycle boom. It is intuitive to see that the opposite would happen in an economic downturn. In that scenario, the capital ratio would be the more binding constraint as the risk weights also tend to increase. Thus the leverage ratio is intended to be the constraining ratio in booms and the milder constraint in a downturn. In Figure 4 we report the impulse response of some other key variables of the model. In the top panels, we show the IRFs of loan to output ratio and the total lending: precisely the variables the macroprudential instruments target. In the lower panel, we show the two most important real variables, namely, output and investment. These figures clearly highlight the benefits of introducing the leverage ratio requirement in addition to the risk weighted ratio requirement. Volatility in the credit cycle is reduced substantially, which also translates into a moderation of the real series.

Although there are clear gains from introducing the minimum leverage requirement for banks, there are also some associated costs. Table 3 addresses this question. Following the literature, we base our analysis on the impact on output (Gerali et al. (2010) and Angelini et al. (2014)). We show the leverage requirement's effect in reducing the steady-state level and volatility of output. For the sake of robustness, this analysis is done for two different sets of steady-state risk weights. The first set of values corresponds to the European Banking Authority figures ($\omega^H = 0.37$ and $\omega^E = 0.92$) while the second set corresponds to the standardized risk weighting approach ($\omega^H = 0.35$ and $\omega^E = 1.00$). The EBA risk weights would imply a minimum leverage requirement of approximately 5% while the standardized approach would imply 5.20%.[10] We observe that, conditional on the choice of steady-state risk weights, the leverage requirement generates a loss in steady-state output in the range of $0.7 - 1.7\%$. On the other hand, the reduction in output variability is quite substantial ($24 - 28\%$). To put these magnitudes in perspective, we make a comparison with other studies that have evaluated the impact of Basel III. Similar results are obtained in the DSGE model by Aliaga-Diaz and Olivero (2012). When the capital requirement is raised by two percentage points in their model, loan rates rise by about 15 basis points, while output falls by slightly less than 1

[10] Assuming that the minimum risk-weighted capital requirement is 8.5% and the share of mortgage lending to households is 0.6.

per cent. Simulation conducted in BCBS (2010) using a wide range of econometric tools, mostly DSGE models, finds that on average a 2% increase in risk-weighted capital requirements leads to a reduction in the steady-state output of 0.2% and output volatility of 2.6%. Our numbers indicate that introducing the leverage ratio produce somewhat larger costs on steady state output but the benefits in terms of reduction of output volatility are substantially larger.

6.2 A shock to the loan-to-value ratio

In this section, we conduct an alternative check by analyzing the response to a shock to the LTV ratio for entrepreneurial loans. More specifically, we analyze a one-time rise in the LTV ratio by 20 percentage points. This corresponds to the average increase in the LTV ratio experienced in the euro area in the pre-crisis period: from 60% in 2003 to 80% in 2007 (Mercer Oliver Wyman (2003) and ECB (2009)). We present results for the shock to the LTV on entrepreneurial lending but the shock to LTV on mortgage lending was also analyzed and the results are qualitatively similar. Figures 5 - 6 and Table 4 present the results. Figure 5 presents the impact on the risk weights and the regulatory ratios, after the incidence of the shock, with both the regulatory minima operating. Similar to the case of the TFP shock, we find that the leverage ratio declines much more than the risk-weighted capital ratio, causing the leverage requirement to bind earlier. This is once again driven by the decline in risk weights and because the bank accumulates capital relatively slowly. On impact, the lending responds first, leading to a decline in both ratios. This is the almost instantaneous volume effect. But with the higher LTV, interest rates are also higher. Once interest rates start increasing, the banks profits and capital also start increasing. This leads to a gradual recovery in the regulatory ratios. Figure 6 once again reports the impulse response of the main variables following the shock. Note that in contrast to the TFP shock, the risk weights in this case decline much less and this is partly due to the way the risk weights have been modeled: The productivity shock affects output and risk weights directly but this is not the case in the present scenario. Table 4 represents the cost-benefit analysis in this scenario. The main insights are similar to the ones presented in Table 3. We represent the theoretical moments from the simulation of the model, with the LTV shock operative. The last column highlights the fact that the reduction in the volatility is substantially higher than the reduction in levels. This is all the more evident in the lending variables. This is intuitive as the principal aim of imposing the minimum leverage requirement is to reduce the volatility of the credit cycle. It should be mentioned here that we are not analyzing a shock to house prices separately, as the dynamics of a house price shock are qualitatively similar to the LTV shock, in the model. A rise in house prices would relax borrowing constraints, which would lead to higher credit growth. The benefits of introducing the leverage ratio in such a situation will be identical.

6.3 Altering the sensitivity of risk weights to output

The main reason for introducing the leverage ratio requirement is that risk weights tend to be cyclical and that, during booms, the risk-weighted capital ratio may not be a good indicator of a bank's capital situation. Therefore, a natural question to ask is: how does the role of the leverage ratio change as the cyclicality of risk weights is altered? Table 5 reports the standard deviations of the loan-to-output ratio, total loans, output, and consumption. The baseline case corresponds to the calibration by Angelini et al. (2014). The second case is a thought experiment where we increase the sensitivity by a factor of ten.[11] We report the theoretical second moment from a 1000 period simulation conditional on the occurrence of the productivity shock. We find that, when risk weights tend to be highly countercyclical, the introduction of the leverage ratio is much more effective in controlling the volatilities in the system. The decline in standard deviations is quite large and more so for the lending variables, which is precisely what the leverage ratio aims to control.

7 Conclusion

The main benefit of bank capital requirements is to make the financial system more resilient, reducing the probability of banking crises and their associated output losses. However, the global financial crisis has highlighted the limitations of risk-sensitive bank capital ratios (regulatory capital divided by risk-weighted assets). To tackle this problem the Basel III regulatory framework has introduced a minimum leverage ratio, defined as a banks Tier 1 capital over an exposure measure, which is independent of risk assessment. This paper seeks to answer three questions: 1) How does the leverage ratio behave over the cycle compared with the risk-weighted asset ratio?; 2) What are the costs and the benefits of introducing a leverage ratio?; 3) What can we learn about the behav-

[11] Note that this is just a thought experiment to gain intuition. One could experiment with any other sensitivities as well.

ior of the two ratios in the long run and their optimal calibration? To this end, we have used a medium sized DSGE model that features a banking sector, financial frictions, and economic agents with differing degrees of creditworthiness as a means of evaluating the regulator's problem. In particular, we build on the model by Angelini et al. (2014), augmenting it in two ways. First, we introduce a leverage ratio, independent of risk assessment, whose deviation from the minimum requirements produces additional capital adjustment costs. Second, we allow the risk weights on lending to households and non-financial firms to be different in the steady state. This modification allows us to mimic the real characteristics of the evolution of bank-risk-setting behavior and to generate different interest rates for the two classes of loans. We document three main findings: 1) The leverage ratio acts as a backstop to the risk-sensitive capital requirement: it is a tight constraint during a boom and a soft constraint in a bust; 2) the net benefits of introducing the leverage ratio could be substantial; 3) the steady state value of the regulatory minima for the two ratios strongly depends on the riskiness and the composition of bank lending portfolios.

Our paper presents a novel analysis on the interaction between the leverage ratio requirement and risk weighted capital requirement, but the simplified nature of the model used does not allow us to treat all aspects of the problem. In particular, the model does not feature an inherent source of inefficiency which regulation would be targeted to correct. For this reason, we maintain the analysis on a purely positive ground and simply study the dynamics of the two regulatory ratios and how the cyclicality of risk weights drives a wedge between them. One possible extension could be to introduce explicitly a source of market failure (together with credit risk and bank default) and to conduct a fully-fledged welfare analysis. This is an interesting area of analysis for future research.

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A Figures and Tables

Figure 1: Flowchart of Agents

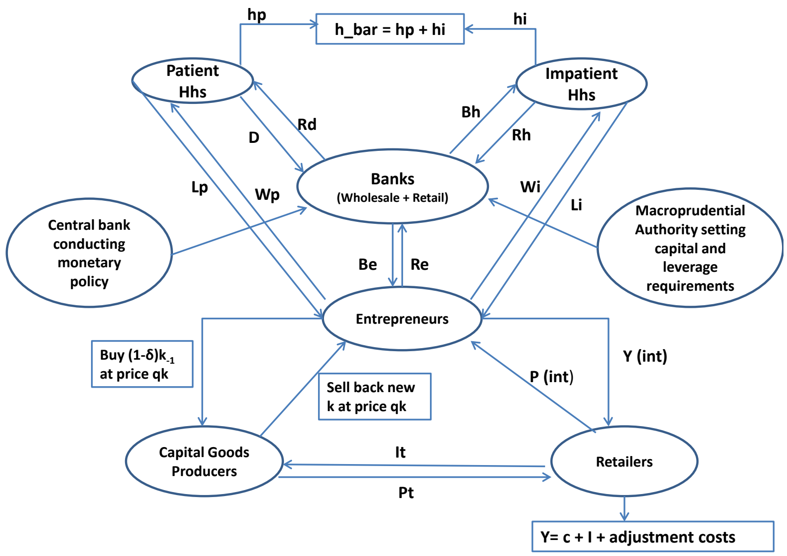
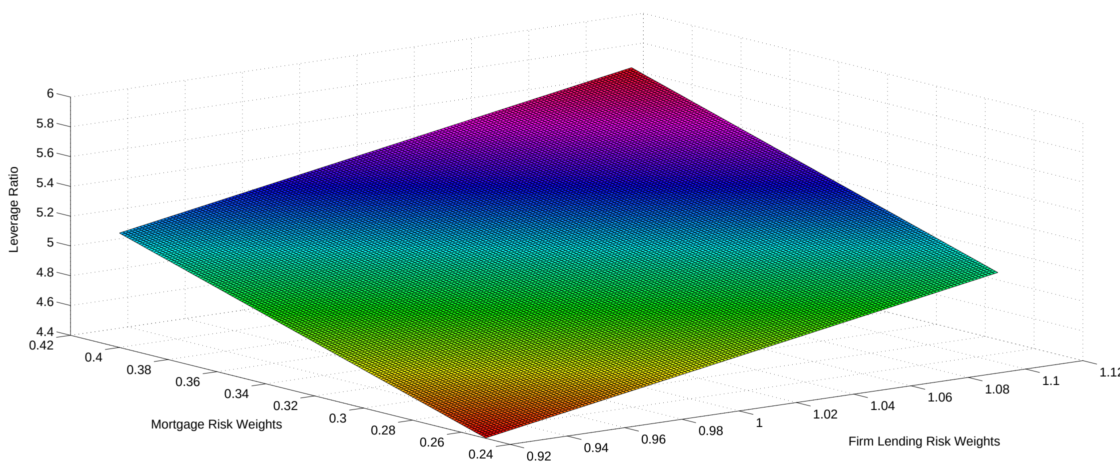
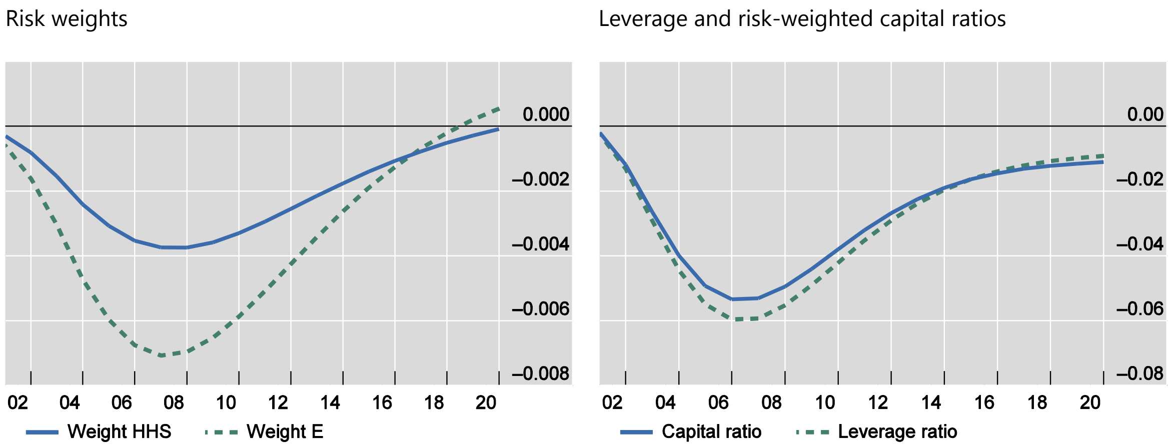


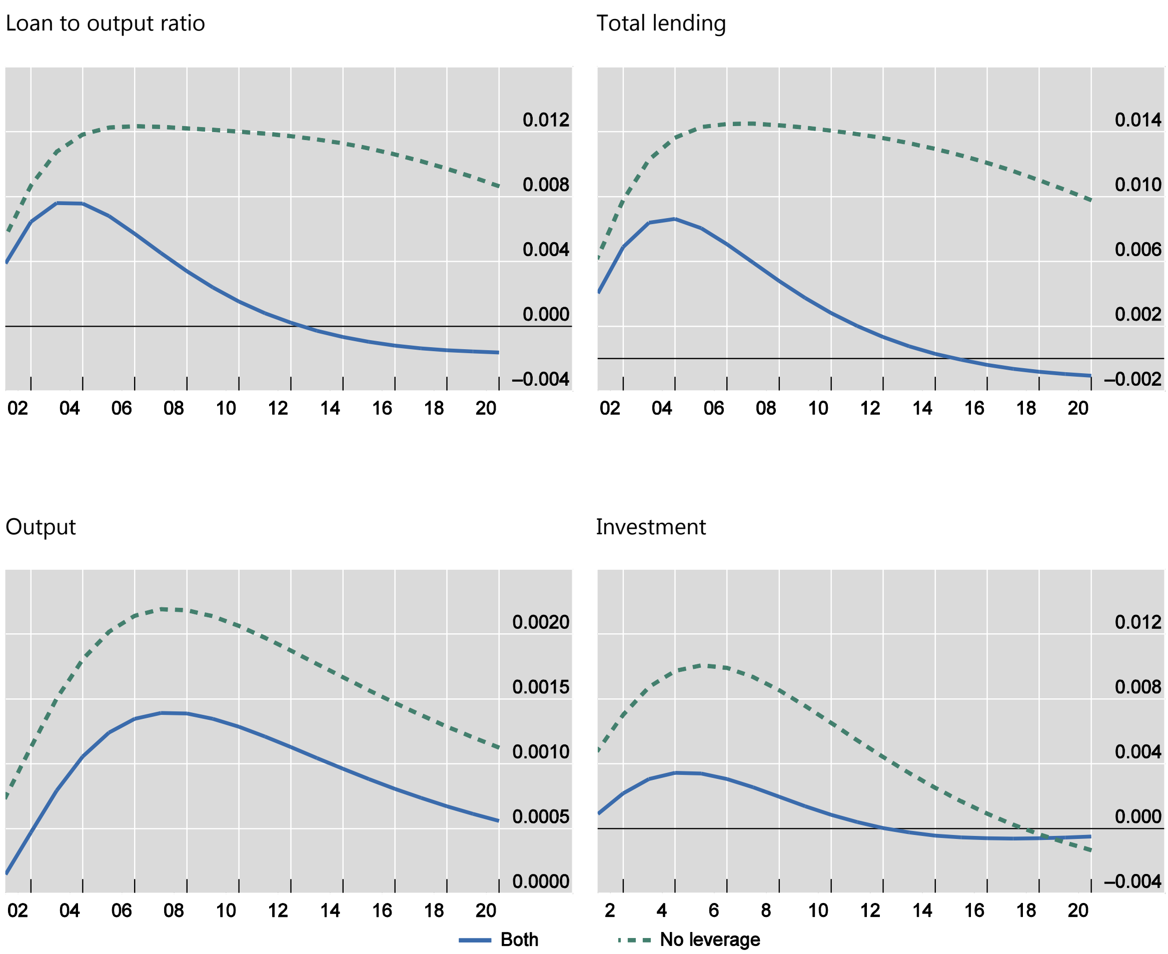
Figure 2: Leverage Ratio and Steady State Risk Weights



Risk weights, capital and leverage ratios (1% TFP Shock) Figure 3



IRF to a 1% positive TFP shock Figure 4

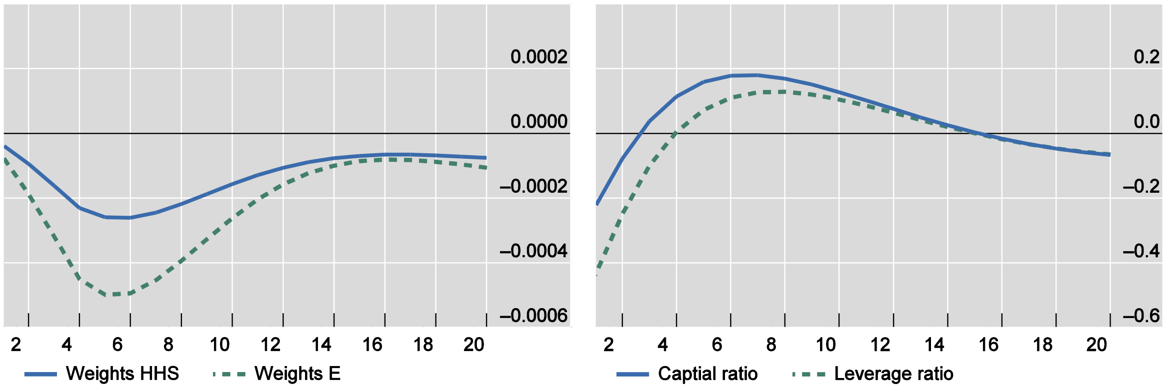


Risk weights, capital and leverage ratios (LTV Shock)

Figure 5

Risk weights

Leverage and risk-weighted capital ratios

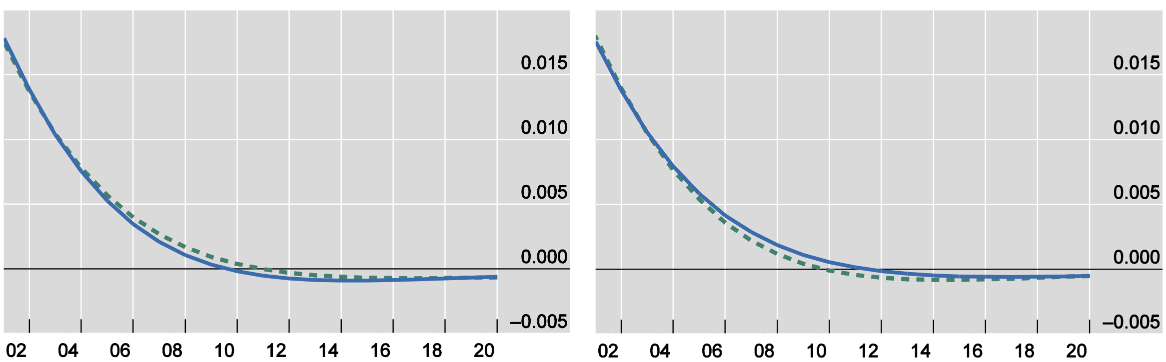


IRF to a LTV shock

Figure 6

Loan to output ratio

Total lending



Output

Investment

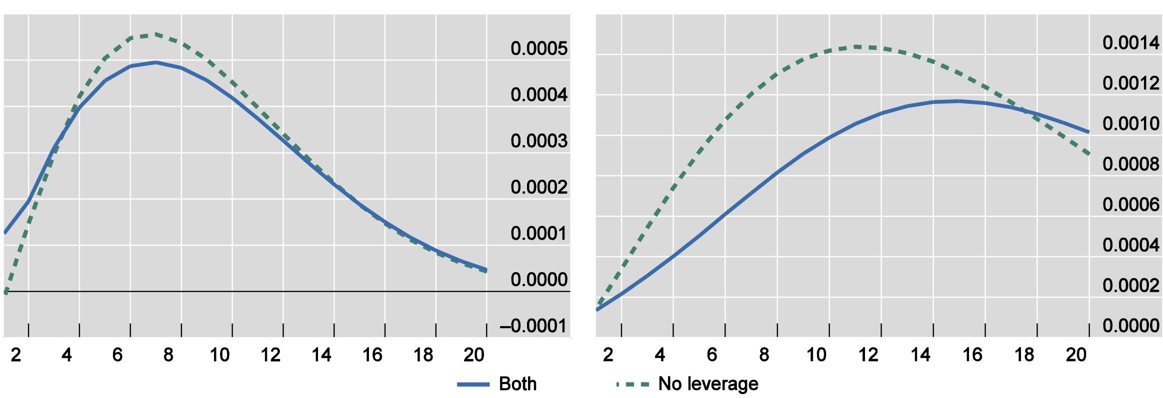


Table 1: Cyclicality of capital Ratios

Models	Business Cycle		Financial Cycle	
	(Real GDP growth)		(Credit Gap)	
	$LR = \frac{Tier1}{EM}$	$RWR = \frac{Tier1}{RWA}$	$LR = \frac{Tier1}{EM}$	$RWR = \frac{Tier1}{RWA}$
Baseline model	-0.052**	-0.048	-0.005*	-0.003
	(0.026)	(0.038)	(0.003)	(0.004)
Controlling for different regimes of capital regulation	-0.055**	-0.045	-0.005*	0.004
	(0.026)	(0.037)	(0.003)	(0.004)

Source: Brei and Gambacorta (2016). (1) The empirical specification in the baseline model includes bank-specific controls, bank-fixed effects and a lagged value of the dependent variable. The model is estimated with GMM and allows for the presence of a structural break during the global financial crisis. (2) The second model controls for (i) the shift from Basel I to Basel II, and (ii) the presence of an additional leverage ratio requirement in Canada and US. The figures show the impact after one year of a 1% increase in the cycle measure (1995-2007).

Table 2: Calibration

Parameter	Symbol	Value	Target/Source
Discount Rate Patient	β^P	0.99	Annual risk free rate of 4%
Discount Rate Impatient	β^I	0.975	Iacoviello (2005)
Discount Rate Entrepreneurs	β^E	0.975	Iacoviello (2005)
Habit Formation	a^P, a^I, a^E	0.86	Gerali at al. (2010)
SS Capital Requirement	ν^b	0.085	Basel committee guidelines
Leverage Requirement	ϕ^b	0.05	Basel committee guidelines
Depreciation (physical capital)	δ	0.025	Annual 10%
Depreciation (bank capital)	δ^b	0.11	SS capital/loan ratio = 8.5%
Adj. Cost (bank capital)	κ_{Kb}	8.00	RW capital ratio (SS) = 8.5%
Adj. Cost (bank capital)	κ_{Lb}	7.63	Leverage ratio (SS) = 5%
Share of Capital	α	0.25	Standard
Goods mkt. markup	ε^h	6	Gerali et al. (2010)
Lab. mkt. markup	ε^l	5	Gerali et al. (2010)
Inverse of Frisch Elasticity of labor supply	ϕ	0.5	Labor supply elasticity = 2
Utility fn. weight of housing	ϵ_t^h	0.2	Iacoviello & Neri (2010)
LTV household	m_t^I	0.70	Calza et al. (2013)
LTV firms	m_t^E	0.35	Gerali et al. (2010)
Markdown deposits	ε^d	-1.46	Gerali et al. (2010)
Markup Mortgage	ε^{bH}	2.79	Gerali et al. (2010)
Markup Firms	ε^{bE}	3.12	Gerali et al. (2010)
Persistence of TFP shock	ρ_A	0.90	Std. business cycle literature
Volatility of TFP shock	σ_u^2	0.01	Std. business cycle literature
Mean of TFP	$\overline{A}$	1.00	Std. business cycle literature
Persistence of house pref. shock	ρ_{ϵ_h}	0.96	Iacoviello & Neri (2010)
Volatility of house pref. shock	σ_{ϵ_h}	0.043	Iacoviello & Neri (2010)

Table 3: Costs Vs Benefits

	$\omega^H = 0.35, \omega^E = 1.00 \Rightarrow \phi^b = 0.052$		$\omega^H = 0.37, \omega^E = 0.92 \Rightarrow \phi^b = 0.050$	
Output	Y^{ss}	σ_Y	Y^{ss}	σ_Y
K	0.2196	0.0839	0.2232	0.0796
K+L	0.2180	0.0605	0.2194	0.0599
% decline	**0.70**	**28.48**	**1.70**	**24.75**
Consumption	C^{ss}	σ_Y	C^{ss}	σ_Y
K	0.1166	0.0686	0.1165	0.0664
K+L	0.1106	0.0537	0.1100	0.0534
% decline	**5.14**	**21.72**	**5.51**	**19.57**
Loan/Output	$(L/Y)^{ss}$	$\sigma_{L/Y}$	$(L/Y)^{ss}$	$\sigma_{L/Y}$
K	0.9448	0.1845	0.9541	0.1829
K+L	0.9355	0.1612	0.9435	0.1625
% decline	**1.00**	**12.62**	**1.11**	**11.15**
Tot. Loans	L^{ss}	σ_L	L^{ss}	σ_L
K	1.1735	0.1858	1.1813	0.1805
K+L	1.1645	0.1624	1.1784	0.1604
% decline	**0.80**	**12.59**	**0.20**	**11.13**

Note: This table reports the theoretical moments from a thousand period simulation of the model conditional on the TFP shock occurring. We simulate the model with and without the leverage ratio requirement. We also conduct the analysis for two different sets of steady state risk weights.

Table 4: Shock to the LTV ratio on entrepreneurial loans

Variable	Moments	K	K+ L	% decline
Output	Mean	0.2566	0.2514	**2.02**
	SD	0.0391	0.0371	**5.11**
Consumption	Mean	0.1353	0.1311	**3.10**
	SD	0.0323	0.0307	**4.96**
Loan to Output	Mean	0.9260	0.9250	**0.11**
	SD	1.2093	1.1085	**8.33**
Total Loans	Mean	1.1826	1.1772	**0.46**
	SD	1.2204	1.1175	**8.46**

Note: This table reports the theoretical moments from a thousand period simulation of the model conditional on the LTV shock occurring. The loan to value ratio for entrepreneurial lending is shocked to increase 20pp from 35%. We report the mean and standard deviations for our key variables of interest, namely, output, consumption, loan to output ratio and the total lending.

Table 5: Altering the sensitivity of risk weights to output

	Baseline Case			High Sensitivity		
	K	K+L	% decline	K	K+L	% decline
Loan to Output Ratio	0.186	0.161	**13.44**	0.235	0.166	**29.37**
Total Loans	0.186	0.162	**12.90**	0.263	0.177	**32.69**
Output	0.085	0.061	**28.23**	0.086	0.056	**34.88**
Consumption	0.070	0.054	**22.85**	0.071	0.052	**26.76**

Note: This table reports the theoretical moments from a thousand period simulation of the model conditional on the TFP shock occurring. The exercise is repeated for a scenario in which the risk weights are ten times more countercyclical than the first case. We find that when the risk weights are highly sensitive to output fluctuations, there can be larger gains from introducing the leverage ratio requirement.