# The Macroeconomic Consequences of Bank Capital Requirements

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## Abstract

In the light of the recent crisis, there is now considerable concern about financial cycles and their implications for business fluctuations. Macroprudential policy has thus become part of the policy paradigm. In this work, a model of business cycles is developed which analyzes the macroeconomic consequences of a minimum bank capital standard. Numerical examples suggest that capital regulation can be useful in strengthening the resilience of the banking sector, and hence reduce macro-financial volatility.

**Keywords:** Capital Adequacy Ratio, Financial Frictions, Occasionally Binding Constraints, Macro-Financial Linkages.

**JEL Codes:** E32, E44, G01, G21

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# 1 Introduction

The 2008 financial crisis and the ensuing Great Recession have prompted a rethink of economic policy and financial regulation. At the core of this reconsideration is the growing awareness that financial disturbances can have long lasting adverse consequences on economic activity [Yellen (2013)]. The development of a policy framework responsible for financial stability is therefore at the forefront of the policy agenda. Says Bernanke (2012): *"Continuing to develop an effective set of macroprudential policy indicators and tools, while pursuing essential reforms to the financial system, is critical to preserving financial stability and supporting the U.S. economy"*.

This rethinking of financial regulation has recently led to substantial regulatory changes [De Nicolo et al. (2012)]. The new focus is on macroprudential tools, i.e., those policies intended for limiting systemic risk and ensuring the resilience of the financial sector as a whole. For instance, the new Basel III Accords raised minimum bank capital requirements, and introduced new instruments such as a leverage ratio and liquidity requirements. Alternative policies, such as caps on loan to value ratios and limits on credit growth, are also being implemented in various jurisdictions [Claessens (2015)].

While the need for macroprudential policies is now widely accepted, very little is known about their design, calibration and quantitative effects on the real economy [Claessens (2015)]. As noted by Blanchard et al. (2013), knowledge is still limited and much remains to be studied.

This paper examines the quantitative effects of bank capital requirements on the real economy. My analysis uses a nonlinear small open economy real business cycle model. I consider bank capital shocks (i.e. disruptions in the flow of resources between corporate borrowers and banks that take place in the event of default) and technology shocks. Bank capital shocks capture episodes of financial distress entailing the depletion of some assets on the balance sheet of the banking industry [Iacoviello (2015); Guerrieri et al. (2015)]. Technology shocks are a proxy for changes in the demand for loans.

I investigate three fundamental matters. First, the tradeoff between financial stability and the cost of financial intermediation associated with capital regulation. Second, what factors affect the likelihood of hitting the capital regulatory constraint. Third, the role of capital regulation in shaping business cycle fluctuations.

Within my theoretical framework, there is a key motive for capital regulation that encourages banks to hold larger equity buffers and discourages the use of external debt. I assume that banks' funding costs depend on the cross-sectional average level of bank equity capital. Individual banks, however, do not internalize this effect when deciding their balance sheet structure, and hence hold a sub-optimal low level of net worth in equilibrium. To put it differently, individual banks do not consider the fact that if they were to be better capitalized, they would make the financial sector more resilient; thereby lowering their funding costs and dampening macro-financial volatility.

My modeling approach captures a wide range of financial frictions. For example, models of default and incomplete markets [see e.g. Eaton and Gersovitz (1981); Arellano (2008); Lorenzoni et al. (2008)], borrowing constraints [see e.g. Uribe (2006); Mendoza (2010); Gertler et al. (2012)] or portfolio adjustment costs [see e.g. Schmitt-Grohé and Uribe (2003)] predict that funding costs react to aggregate debt and debt related measures. My approach is also consistent with the empirical literature documenting the inverse relationship between country risk premiums and financial resilience [see e.g. Ferrucci (2003); Dailami et al. (2008); Mody (2009); Petrova et al. (2010); Dell'Erba et al. (2013)]. In addition, it is consistent with studies showing that country spreads react to macroeconomic fundamentals; thereby exacerbating aggregate volatility [see e.g. Neumeyer and Perri (2005); Uribe and Yue (2006)].

To quantitatively assess the role of capital regulation in driving business cycles, I calibrate my model to Spain's economy. I choose Spain for two principal reasons. First, banks' activities, and hence banking regulation, are at the core of my model. In this regard, Spain is a fitting example, because traditional banks dominate the Spanish financial system.[1] Second, the 2008 crisis and its aftermath triggered a vicious cycle of soaring loans, failing bank equity, rising funding costs, tightening credit conditions, contracting output... This left a notable portion of the banking sector under-capitalized, which in turn further hurt economic performance. Increasing the resilience of the banking sector has thus become a key priority for policy makers [Linde (2016)]. As a result, banks are being forced to strengthen their capital positions. For instance, Spanish regulators implemented the new international regulatory frameworks Basel II.5 and III agreements in 2012Q1 and 2013Q1, respectively, notably increasing the strictness

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[1] In 2014, traditional banks (i.e. deposit taking institutions) accounted for 69% of total assets of financial institutions excluding the Spanish Central Bank [FSB (2015)]. This is quite a large value when compared, for instance, with the United States (26%), the United Kingdom (52%), Germany (59%) or France (62%).

of bank capital regulation. Hence, Spain is a good laboratory to perform policy counterfactuals to gauge the effects of capital requirements.[2]

The single most remarkable result is that bank capital regulation can be a powerful tool to strengthen the resilience of the banking sector, and consequently dampen business cycle fluctuations. In all experiments considered, regulatory intervention increases the banks' level of net worth and decreases its volatility. As a result, regulated banks need less external finance and enjoy lower funding costs. This affects the real economy through the amount and volatility of lending, and therefore of employment and output. As a consequence, capital regulation leads to a considerable stabilization of the economy.

A noteworthy feature of the equilibrium of my model is the power of precautionary behavior. Capital regulation affects banks' attitudes toward risk. Specifically, it encourages banks to build equity buffers in order to reduce the likelihood of hitting the minimum capital standard.[3] Consequently, the capital requirement constraint is usually either slack or not too tight. Hence, the potential costs associated with capital regulation are seldom materialized.

The finding that regulatory pressure induces banks to hold large capital buffers is in line with existing empirical evidence [see e.g. Peura and Jokivuolle (2004); Jokipii and Milne (2008)], which shows that banks usually hold capital well in excess of the minimum required by regulators.[4] Also, this is in complete agreement with recent nonlinear business cycle models proposed by Mendoza (2010), Brunnermeier and Sannikov (2014), or Akinci and Queraltó (2014), which draw our attention to the power of precautionary savings.

The remainder of the paper is organized as follows. Section 2 reviews the mechanisms for why bank capital regulation might matter for economic activity. Section 3 lays out the model and explores key analytical results. Section 4 presents the solution method, calibration, and numerical results. The final section concludes.

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[2] Furthermore, as was mentioned previously my model assumes an inverse relationship between banks' funding costs and the health of the financial sector. Appendix A.5 shows that Spain is a nice illustration of such a link.

[3] In the real world, breaching the minimum equity threshold may be very costly for financial institutions. For instance, it can result in serious reputational costs, losses of charter value and adverse market reactions [Borio and Zhu (2012)].

[4] Matching this empirical fact is a challenge for a large class of quantitative general equilibrium models with macro-financial linkages [Borio (2014)]. This is due to the fact that they often rely on linear approximations of the system dynamics. In consequence, they fail to take into consideration occasionally binding constraints. Instead, financial constraints are assumed to be constantly binding [e.g. Clerc et al. (2015), Iacoviello (2015)].

## 2 Why Might Bank Capital Regulation Matter?

Few issues in the policy debate are more contentious and elicited a wider range of firmly held views than the correct level of equity requirements. On the one hand, advocates of stricter regulation highlight the risks and inefficiencies associated with poorly capitalized institutions, and point to the high costs of the 2008 crisis [Admati et al. (2013)].

Bank capital has several benefits from a financial stability perspective. First, it improves banks' ability to absorb losses; thereby reducing the prospects of bank failure episodes [Dewatripont and Tirole (1994)]. Second, bank equity limits excessive risk taking and encourage sounder balance sheet management decisions. This occurs because thinly capitalized institutions may be tempted to take excessive risks due to limit liability. In other words, they do not fully internalized asset losses. Equity capital can contain these excesses by increasing shareholders' downside exposure [Rochet (1992)]. Thus, equity capital encourages banks to engage in more monitoring and invest in safer assets [Freixas and Rochet (2008)]. As a result, strict regulation can (i) protect creditors and taxpayers, (ii) reduce the risks of spillovers from the financial sector to the real economy, and (iii) foster sustainable economic growth.

On the other hand, opposers of more stringent regulation argue that the latter would notably raise the cost of financial intermediation, and hence impose insidious costs on economic activity. For instance, Kashyap et al. (2008) suggest that demanding financial institutions to maintain significantly higher equity buffers will raise their expected cost of funds; thereby impairing economic performance.

The main concern is the prospect that stricter capital regulation could restrict banks' ability to extend credit. This could actually happen whenever equity is *significantly* more expensive than debt [Borio and Zhu (2012)]. Therefore, equity requirements, while reducing the likelihood of financial crises, would also raise banks' overall funding costs, and hence hinder economic activity.

Although this sort of concern may sound intuitively reasonable, it differs substantially from the dominant paradigm in the academic literature: the Modigliani Miller Theorem. In their seminal paper, Modigliani and Miller affirmed that a firm value is independent of its capital structure. In the specific case of the banking sector, this theorem states that the debt-equity mix with which banks are funded affects neither their overall funding costs nor their lending activities. Consequently, increased capital requirements should not penalize economic growth.

Nonetheless, further theories provide a rationale for why the Modigliani Miller Theorem may not apply. Loosely speaking, the basic logic is that the existence of various market frictions breaks down the neutrality between the composition of banks' liabilities and credit supply. Frictions that are often referred to comprehend (i) the "debt overhang" problem [Myers (1977)], (ii) adverse selection in the equity market [Myers and Majluf (1984)], and (iii) tax shields and government guarantees that subsidize debt financing [Admati et al. (2013)].

As for the empirical literature, it suggests that higher bank capital is associated with a lower probability of failure [see e.g. Wheelock and Wilson (2000); Cole and White (2012); Beltratti and Stulz (2012); Fahlenbrach et al. (2012)]. It has also been well documented that more stringent regulation results in a more stable and robust credit supply in the long run [see e.g. Bernanke and Lown (1991); Kapan and Minoiu (2013)]. The intuition is straightforward. Equity capital improves banks' ability to resist both financial and real disturbances [Diamond and Rajan (2000)].

Another line of research has studied the effects of more stringent capital regulation on credit availability [see e.g. Francis and Osborne (2012); Brun et al. (2013); Aiyar et al. (2016)]. Overall, in the short run increases in equity requirements seem to put a brake on bank lending. A recent review of the literature on this topic [Martynova (2015)] found that raising the minimum capital standard by $1\%$ is likely to reduce bank lending by $1.2\%$-$4.5\%$ in the short run.

Capital requirements are being increasingly used, despite the controversy and that little is known about their usefulness in reducing systemic vulnerabilities [De Nicolo et al. (2012)]. To see this point more clearly, Figure 1 presents information on the proportion of countries that have implemented the new bank capital regulation embedded in the Basel II.5 and III Accords.[5]

The new Basel Accords are designed to tackle the market failures brought to light by the global financial crisis. They consist of a number of fundamental reforms to the bank capital regulatory framework. The main objective is to boost the resilience of individual financial institutions by raising both the quantity and quality of the regulatory capital base. By doing so, the reforms also contain systemic risks that can build up across the financial industry over time. In other words, the Accords add a macroeconomic dimension to prudential regulation.

As shown in Figure 1, there has been a very significant tightening of capital requirements

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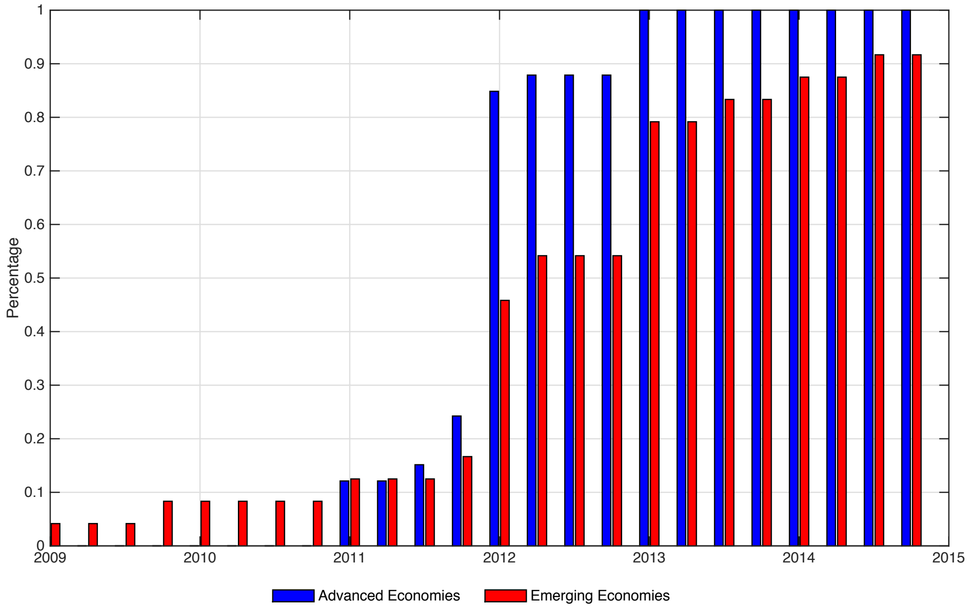
[5] The sample includes 33 advanced economies and 24 emerging economies. The data has been compiled by Cerutti et al. (2016).

Figure 1: Implementation of the Basel Accords



since the global financial crisis, as regulators have implemented the new international regulatory framework. Interestingly, instruments linked to capital buffers have been actively used both by advanced and emerging economies. Therefore, it appears that equity requirements will play a key role in the design of macroprudential regulation worldwide in years to come.

# 3 A Model of Business Cycles with Capital Requirements

I begin this section by describing the structure of the model and the optimization problems of the economy's agents. I then analyze the key optimality conditions in order to provide the essential intuition regarding capital requirements.

## 3.1 Setup

Consider a discrete time economy populated by four types of agents: households, international investors, firms and banks. The representative household consumes, works and holds bank deposits. The representative firm operates a linear technology that requires labor to produce output. Following Mendoza (2010), Christiano et al. (2010), and others, input costs must be financed in advance of sales. Hence, the representative firm demands loans at the beginning of each period and repay them at the end.

In order to meet the demand for loans by local borrowers, a domestic representative bank borrows funds from both foreign lenders and domestic depositors. Note then the dual nature of the banking activity. The bank is a borrower vis-a-vis international investors and domestic households, whereas it is a lender when it comes to its relationship with local firms.

To make matters more interesting and realistic, in the model business fluctuations are partly driven by exogenous disruptions in the flow of resources between firms and banks. This type of shock is inspired in Iacoviello (2015) and Guerrieri et al. (2015). The shock can be viewed as losses for the banking industry stemming, for example, from a wave of non performing loans. More generally, it can simply be considered as a shock that depletes some assets on the balance sheet of the banking sector. Importantly, the shock is a pure financial shock, since real resources are not destroyed [Guerrieri et al. (2015)]. Therefore, its macroeconomic consequences can be interpreted as spillover effects from the financial sector to the real economy.

As was stated in the Introduction, my model features a pecuniary externality affecting banks' activities; which leads them to be undercapitalized. This market failure induces the need of some kind of regulatory intervention. I consider bank capital requirements; which set a lower bound on the bank capital to assets ratio.

### Households

The representative household chooses sequences of consumption ($C$), hours worked ($H$) and bank deposits ($D$) in order to maximize its expected lifetime utility[6]:

$$E_t \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma} \left[ C_t - \chi \frac{H_t^{1+\omega}}{1+\omega} \right]^{1-\sigma}, \tag{1}$$

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[6] I follow Mendoza (2010), Gertler et al. (2012) and others, and define utility as in Greenwood et al. (1988). This functional form eliminates the wealth effect on labor supply. That is, the latter only depends on the real wage and not on consumption. This preference specification yields sensible fluctuations in hours worked in the absence of labor market frictions.

where $\beta \in (0, 1)$ is the discount factor parameter and $E_t$ is the conditional expectation operator. Its choices are constrained by:

$$C_t + D_t = w_t H_t + (1 + r^d_{t-1}) D_{t-1} + Q_t + \Xi_t, \tag{2}$$

where $w$ is the wage rate, $Q$ are wealth transfers between the bank and the household -to be specified below-, $r^d$ is the interest rate of deposits, and $\Xi$ are dividends from local firms.

### Firms

A representative firm produces the final good $(Y)$ according to:

$$Y_t = A_t H_t, \tag{3}$$

where $H_t$ is the amount of labor services used, and $A_t$ is a technology shock. The latter evolves according to a 2-states Markov chain[7] with transition matrix $\Pi$.

As noted above, the wage bill must be paid in advance of sales. In consequence, each and every period the firm demands an amount of loans $(L)$ equal to:

$$L_t = w_t H_t. \tag{4}$$

Therefore, the representative firm chooses labor inputs to maximize dividend payments to the household $(\Xi)$:

$$\Xi_t = A_t H_t - (1 + r^l_t) w_t H_t + \epsilon_t, \tag{5}$$

taking as given input prices $w$ as well as the interest rate of loans $r^l$. The term $\epsilon_t$ is a redistribution (or equivalently, bank capital) shock.[8] As noted above, it captures transfers of resources between banks and firms. Accordingly, the same shock appears in the law of motion for bank equity capital with opposite sign. I assume that the stochastic process for $\epsilon$ follows:

$$\epsilon_t = \delta \epsilon_{t-1} + u_t, \tag{6}$$

where $\delta \in [0, 1)$ and $u \sim i.i.d.N(0, \sigma^2_u)$.

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[7] Given that the model is solved employing a policy function iteration algorithm, the use of a continuous support for the stochastic shock is not feasible. I therefore discretize the stochastic variable according to a 2-states Markov chain.

[8] This modeling device can be found in Iacoviello (2015) and Guerrieri et al. (2015).

**Banks**

Suppose a competitive environment in which each period a representative bank extends loans ($L$) to the representative firm. These loans are financed by combining borrowed funds from foreign investors ($F$), deposits from domestic households ($D$) and the bank's own net worth ($N$). Thus, the bank's balance sheet at period $t$ is[9]:

$$L_t = N_t + F_t + D_t. \tag{7}$$

The bank can also issue new equity (capital inflows) as well as pay dividends (capital outflows). Net external capital flows ($Q$) are thus positive whenever the overall amount of dividend payments exceeds the amount of new equity raised, and vice versa.

In order to restrict the bank's ability to accumulate enough equity capital to fund all loans internally, I assume that the bank faces quadratic adjustment costs when the current level of equity differs from its steady state value ($\bar{N}$). Formally, adjustment costs are represented as:

$$\Gamma(N_t) = \frac{\tau}{2}\left(\frac{N_t}{\bar{N}} - 1\right)^2, \tag{8}$$

where $\tau \geq 0$. These costs are needed to guarantee stationarity of the state variables.[10] The value of $\tau$ is chosen so that these costs are minimal and do not affect the dynamic properties of the model.

Equity capital therefore evolves by:

$$N_{t+1} = N_t + r_t^l L_t - r_t^f F_t - r_t^d D_t - Q_t - \Gamma(N_t) - \epsilon_t, \tag{9}$$

where $r^f$ is the rate of return on international liabilities. The term $\epsilon$ is the bank capital shock, that when positive, transfers wealth from banks to firms. Hence, operating profits and new issues of equity feed to the total net worth of the bank, whereas dividend payments represent a leakage.

One point here deserves further comment. As noted above, banks are not usually able to recapitalize themselves immediately and costlessly. If this were true, capital regulation would

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[9] It is important to stress that $[L, D, F]$ are control variables, whereas $N$ is a state variable. Accordingly, $N_t$ is predetermined at time $t$, and hence cannot jump.

[10] See Schmitt-Grohé and Uribe (2003) for alternative ways of obtaining this.

be pointless. With this mind, two layers of imperfections relating to external capital flows are introduced. First, as in Bianchi and Bigio (2014) and Iacoviello (2015), the bank's preferences are designed in such a way that a stable path of net external capital flows is preferred[11]. Second, Eq.9 implies that when the bank raises new equity at time $t$, the collected funds are only available to make new loans at time $t+1$. The bank is therefore prevented from increasing its equity stock at the very moment of being subject to capital regulation (i.e. just before undertaking new lending).

Regarding capital adequacy regulation, the bank faces an equity requirement constraint. The latter ensures that bank capital is at least a fraction $\kappa$ of loans:

$$\frac{N_t}{L_t} \geq \kappa. \tag{10}$$

I am now in a position to state the bank's optimization problem. The objective of the bank is to maximize the discounted sum of future net payouts to the household. Formally, the bank's problem is to choose sequences $\{L_t, F_t, Q_t\}_{t=0}^{\infty}$ to maximize:

$$E_t \sum_{t=0}^{\infty} \beta^t \Lambda_{t,t+1} \log(1+Q_t), \tag{11}$$

subject to Eq.7, Eq.9 and Eq.10. Here $\Lambda_{t,t+1}$ is the household's stochastic discount factor.

### International Capital Markets

As stated above, the representative bank borrows funds from domestic households and international investors. More precisely, I assume that a large mass of foreign lenders is willing to lend to the local banking sector any amount at rate $r_t^f$. The existence of only one type of bank liability implies that the rate paid to domestic depositors equals the one paid to foreign lenders. That is, $r_t^f = r_t^d \; \forall t$. Furthermore, the small open economy assumption implies that this rate is determined by the foreign lenders.

A full model of the determination of country risk is beyond the scope of this paper. Nonetheless, a minimal framework of country risk is required in order to perform the quantitative analysis. To make matters interesting and realistic, I suppose that economic fundamentals drive

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[11] This formulation is equivalent to a formulation where the bank pays convex adjustment costs when it sheds or raises external capital.

risk premium. As noted by Neumeyer and Perri (2005), this notion can be grounded on models of default and incomplete markets [see e.g. Eaton and Gersovitz (1981); Arellano (2008); Lorenzoni et al. (2008)] in which the risk of default is high when economic fundamentals are weak and vice-versa. Also, theoretical frameworks with imperfect enforcement of contracts, occasionally binding borrowing constraints or portfolio adjustment costs predict that interest rate premiums increase with the level of total indebtedness [Schmitt-Grohe and Uribe (2015)].

Likewise, this idea is supported by the empirical literature examining the relationship between country spreads and various macro-financial indicators, such as debt and debt related variables, the fiscal balance or GDP growth [see e.g. Ferrucci (2003); Uribe and Yue (2006); Reinhart and Rogoff (2011); Petrova et al. (2010); Reinhart and Rogoff (2013); Fogli and Perri (2015)].

A related topic that has recently received considerable attention is the link between country spreads and financial fragility. Generally speaking, financial sector vulnerabilities have been shown to be strongly associated with higher risk premiums [see, for example, Mody (2009); Petrova et al. (2010)]. The basic logic is that financial sector stress projects a deterioration of growth prospects. In turn, the weaker economic outlook increases default probabilities; thereby exerting further pressure on the financial industry, and hence increasing risk country premiums. Put it differently, the health of the financial sector, economic activity and the country risk premium tend to be self-reinforcing forces.

All told, country spreads are broadly viewed as a comprehensive indicator of a country's overall risk premium, arising from market, credit, liquidity, and other risks [Petrova et al. (2010)]. Within my model, a parsimonious way to model this is to assume that the interest rate, $r_t^f$, is a decreasing function of the cross-sectional average level of equity capital ($\hat{N}$) across local banks.[12] Formally, I opt for the logistic function:

$$r_t^f = \psi_0 \left[1 + e^{\psi_1(\hat{N}_t - \bar{N})}\right]^{-1}. \tag{12}$$

Here $\bar{N}$, $\psi_0$ and $\psi_1$ are positive parameters. Specifically, $\bar{N}$ is the threshold around which the dynamics of $r^f$ change. As $\hat{N}_t - \bar{N}$ approaches minus (plus) infinity, $r^f$ approaches $\psi_0$ (zero). The parameter $\psi_1$ is the smoothness parameter. As $\psi_1$ increases, the dynamics of $r^f$ change

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[12] This modeling device is essentially the same as that used by Schmitt-Grohé and Uribe (2003), García-Cicco et al. (2010), Akinci and Queraltó (2014), and others, with some adjustments.

more abruptly depending on whether $\hat{N}$ is greater than or less than $\bar{N}$.[13]

The intuition behind Eq.12 is straightforward. Foreign lenders regard the cross-sectional average level of equity capital as an indicator of the strength of the domestic banking industry. As a consequence, a decreasing (increasing) level of average equity causes the premium to increase (decrease) as investors' perceived risk of investing in the domestic economy increases (decreases).

A point here deserves further comment. The fact that $r_t^f$ depends on the cross-sectional average of equity gives rise to a pecuniary externality, which banks do not internalize when deciding their balance sheet structure. Specifically, individual banks do not take into consideration that their own net worth accumulation behavior affects $r_t^f$. Instead, they take it as exogenously given, and hence out of their control.[14] This assumption is not innocuous. Note that because all banks are identical, in equilibrium I have that $\hat{N}_t$ must equal $N_t$. The representative bank, ignoring the implications of its actions on $r_t^f$, holds a suboptimally low level of bank equity capital. As a consequence, it is exposed to higher interest rates than a social planner that internalizes Eq.12. Hence, this externality makes the competitive equilibrium inefficient and induces the need for regulatory intervention.

Of course, the purpose of Eq.12 is not to provide a satisfactory model of country risk, but only to capture the idea that a country's risk premium, economic performance and financial vulnerability tend to go together. In addition, this reduced form approach predicts that banks' funding costs are associated with their risk profiles; which is consistent with conventional wisdom and has been stressed by a number of others [see e.g. Admati et al. (2013); Arnold et al. (2015)].

### Competitive Equilibrium

A competitive equilibrium consists on sequences of prices $\{w_t, r_t^d, r_t^l, r_t^f\}_{t=0}^{\infty}$ and allocations $\{C_t, H_t, D_t, L_t, F_t, Q_t, N_t, \epsilon_t\}_{t=0}^{\infty}$ that satisfy households', firms' and banks' optimality conditions, the law of motion for net worth, the bank's balance sheet identity, labor market clearing, and the following market clearing condition:

$$Y_t = A_t H_t = C_t. \tag{13}$$

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[13] In the extreme case where $\psi_1$ approaches infinity, Eq.12 converges to the Heaviside function.

[14] Clerc et al. (2015) have coined the term *bank funding costs externality* to describe this effect.

## 3.2 The Role of Capital Requirements

### Equilibrium Conditions

Let me now look at the distortions introduced by the capital requirement constraint. First, it affects the bank's intertemporal decision rules. To see this point more clearly, the Euler equation for net worth is given by:

$$\eta_t = \beta_b E_t \left[ \Lambda_{t,t+1} \left[ \eta_{t+1}(1 + r^f_{t+1} - \frac{\tau}{\bar{N}} \left( \frac{N_t}{\bar{N}} - 1 \right) + \mu_{t+1} \right] \right], \tag{14}$$

where $\eta$ is the Lagrange multiplier on the law of motion for net worth, which equals the marginal utility of payouts to the household, and $\mu$ is the Lagrange multiplier on the capital requirement constraint. As usual, the Euler equation balances the marginal cost of accumulating an extra unit of equity, given by $\eta$, with its marginal benefit. When the constraint is expected to bind next period (i.e. $E_t \Lambda_{t,t+1} \mu_{t+1} > 0$) the marginal benefit of an extra unit of equity is not just given by the present discounted value of the payments it generates (i.e. $E_t \Lambda_{t,t+1} \eta_{t+1} (1 + r^f_{t+1} - \frac{\tau}{\bar{N}} (\frac{N_t}{\bar{N}} - 1)))$, but by a larger value. This occurs because, in this case, this extra unit of equity eases the capital requirement constraint next period. Thus, it carries a shadow benefit equal to $E_t \Lambda_{t,t+1} \mu_{t+1}$. Capital regulation therefore encourages precautionary behavior, which in turn reinforces the resilience of the banking industry.

Second, the effects of the constraint on the lending rate can be derived from the bank's intratemporal optimality conditions. It can be shown that:

$$r^l_t = r^f_t + \kappa \frac{\mu_t}{\eta_t}. \tag{15}$$

This is a standard condition equating the marginal product of loans with their marginal cost. During periods in which the constraint binds (i.e. $\mu_t > 0$), the bank faces a higher effective marginal financing cost, capturing a shadow penalty for trying to expand lending when equity requirements are tight.

This result is fairly intuitive. Given that in the model equity is a predetermined variable[15], cutting back on lending is the only available channel of adjustment when the constraint binds. Therefore, the lending rate must adjust upwards in order to ensure market clearing in the domestic credit market.

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[15] The stickiness of bank equity has recently been documented by Adrian and Shin (2011).

**A Key Trade-off**

The analysis above suggests a trade-off between financial stability and the cost of financial intermediation. On the one hand, a minimum equity threshold generates a buffer that banks can use in case of distress. Hence, it reduces the probability of capital shortfalls and the credit crunches associated with them. Moreover, as will become clear, by limiting credit growth in the upturn of the cycle, capital requirements mitigate the build-up of vulnerabilities in the bank's portfolio.

On the other hand, the term $\frac{\kappa}{\eta_t}\mu_t$ in Eq.15 explicitly captures the notion that stricter capital regulation might be passed on to borrowers in the form of higher lending rates, and hence hinder economic activity.

# 4 The Quantitative Analysis

In the next section, I resort to numerical simulations to (i) investigate the quantitative properties of my model, as well as to (ii) perform policy counterfactuals in order to analyze the effectiveness of bank capital regulation.

I solve the model using the policy function iteration algorithm described in Richter et al. (2014); which is grounded on the work on monotone operators in Coleman (1991). Since this method allows me to solve the model fully nonlinearly, I can successfully deal with large and persistent deviations from the non-stochastic equilibrium. Also, I can easily handle the occasionally binding capital requirement constraint. Furthermore, I can capture precautionary behavior, as the technique fully accounts for shock uncertainty.

## 4.1 Calibration

The values assigned to the model's parameters are listed in Table 1. This calibration aims to explain the Spanish business and financial cycle. To do so, I use quarterly data for the period 1997Q3 to 2011Q4.[16] The reason why I only use data until 2011Q4 is because Spanish regulators implemented the Basel II.5 and III agreements in 2012Q1 and 2013Q1, respectively. In

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[16] More details on the data are provided in appendix A.1.

other words, capital requirements began to be significantly higher in 2012Q1. Since my main aim is to perform policy counterfactuals to assess the impact of more stringent regulation, it is convenient to calibrate the model using data before the tightening took place. To be consistent, in my baseline calibration, I then set the minimum capital standard, $\kappa$, at 0.

Regarding the non-financial sector, there are 3 standard parameters for which I choose conventional values. First, I set $\beta = 0.995$ so that the household discounts the future at a $2\%$ rate per annum. Second, the CRRA coefficient is set to $\sigma = 1$. Third, the Frisch labor supply elasticity, $1/\omega$, is set to 0.33, which is consistent with Chetty et al. (2012). In addition, I set the weight on leisure in the household utility function, $\chi$, at 26.86, implying a share of active time spent working of one third in the deterministic steady state.

Turning now to the financial sector, the steady state level of bank capital, $\bar{N}$, is not uniquely pinned down by the parameter values, so I set it to match the average of the ratio between capital and total assets of Spanish Monetary Financial Institutions. During the sample period that value is equal to $7.7\%$. As for the equity adjustment cost parameter, $\tau$, I set it to the minimum value that guarantees that the equilibrium solution is stationary.

Information on the Solow residuals is employed to calibrate the parameters associated with the 2-state Markov chain governing labor productivity. Specifically, the approach laid out in Tauchen and Hussey (1991) is used to discretize an AR(1) process with standard deviation and persistent parameters equal to 0.003 and 0.956, respectively. More details on this will be given in Appendix A.2.

To calibrate the parameters associated with the default shock, $\delta$ and $\sigma_u$, I use the net charge-offs to assets ratio of credit institutions.[17] More precisely, I estimate an AR(1) process, and let $\delta$ be the persistent parameter of such a regression and $\sigma_u$ be the standard deviation of the residuals.

It remains to specify the values for the parameters linked to the international capital market (see Eq.12). Regarding $\psi_0$, in the non-stochastic steady state of the model, there is a linear mapping between the discount factor parameter, $\beta$, and $\psi_0$. This can be seen immediately from Eq.12 and Eq.14 evaluated at steady state. Specifically, $\psi_0 = 2(\beta^{-1} - 1)$; thereby imposing $\psi_0 = 0.01$.

As for $\psi_1$, the calibration strategy is to match a standard deviation of the (annualized) real

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[17] I use the 3-period backwards moving average to smooth fluctuations in the time series.

Table 1: Baseline Parameter Calibration

| Parameter | Symbol | Value | Source/Target |
|---|---|---|---|
| **Non Financial Sector** | | | |
| Discount Factor | $\beta$ | 0.995 | Int. rate 2% an. |
| Risk Aversion | $\sigma$ | 1.000 | Standard RBC value |
| Inverse Frisch Elast. | $\omega$ | 3.000 | Standard RBC value |
| Labor Disutility | $\chi$ | 26.86 | SS labor 30% |
| **Financial Sector** | | | |
| Equity Adjustment Cost | $\tau$ | 4e-05 | Stationary equilibrium |
| Long Run Level Bank Capital | $\bar{N}$ | 0.025 | SS leverage 7.7% |
| **Exogenous Processes** | | | |
| Technology Persistence | $\rho$ | 0.956 | Solow Residuals |
| Technology Shock Standard Deviation | $\sigma_A$ | 0.003 | Solow Residuals |
| Persistence Defaults | $\delta$ | 0.737 | Net charge-offs |
| Standard Deviation Default Shock | $\sigma_u$ | 0.001 | Net charge-offs |
| **International Capital Markets** | | | |
| Upper bound $r^f$ | $\psi_0$ | 0.010 | Int. rate 2% an. |
| Smoothness Parameter | $\psi_1$ | 16,329 | SD Int. rate 1.8% an. |

interest rate[18] of $1.88\%$. This is a natural target as its theoretical counterpart is directly linked to $\psi_1$. The calibration procedure employs a grid search method. Specifically, I proceed as follows. First, I construct an equally space grid for $\psi_1$ on the region $[1, 22111]$ with 2,212 grid points. Second, I define the criterion function

$$\Omega = [SD(r_{\text{data}}) - SD(r_{\text{model}})]^2,$$

where $SD(r_{\text{data}})$ is the standard deviation of the real interest rate observed in the data and $SD(r_{\text{model}})$ its theoretical counterpart. Third, I solve the model, perform a 500,000 period time simulation and calculate the standard deviation of $r^f$ at each grid point. Lastly, I evaluate the criterion function at each grid point, and select the one that yields the smallest value of the criterion. The resulting parameter estimate is $\psi_1 = 16,329$.[19, 20]

## 4.2 Business and Financial Cycle Statistics

This subsection aims to assess the ability of the model to account for Spanish business and financial cycle facts. I begin by simulating a 500,000 period time series, and then calculate key statistical moments. The results are reported in Table 2.[21] It is important to recall that the only moment used in the calibration exercise is the standard deviation of the interest rate, $r^f$.

Overall, the business cycle moments of the model are roughly in line with the data. In particular, the model does a fair job at matching the volatility of the Spanish economy. The model also captures the fact that interest rates are countercyclical (i.e. negative contemporaneous correlations with output). In addition, it does well at the dynamic correlations: the equity to assets ratio negatively leads interest rates at different time-horizons.

There are some discrepancies between the model and the data. For instance, the contemporaneous cross-correlations between output and the equity to assets ratio in the model is far

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[18] The 10-year Spanish government bond is the instrument whose yield is used as the nominal interest rate. The real rate is obtained by subtracting the GDP deflator inflation from the nominal rate.

[19] Appendix A.6 shows that the optimization problem is well defined; thus corroborating the validity of my methodology.

[20] Appendix A.7 presents the relationship between interest rates and bank capital once $\psi_0$, $\psi_1$ and $\bar{N}$ have been calibrated.

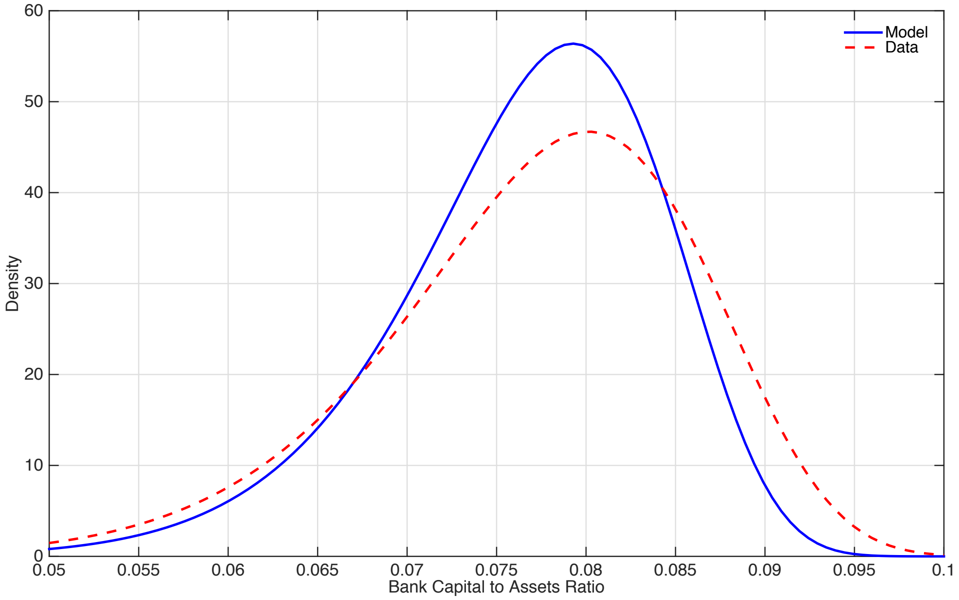
[21] Regarding the data, my measure of Spanish output is the real GDP in logs. To isolate the cyclical component of the series, I use the Hodrick-Prescott filter. My measure of bank capital to loans ratio is the capital and reserves to assets ratio of Spanish Monetary Financial Institutions. The real interest rate is measured as the 10-year government bond minus the GDP deflator inflation.

Table 2: Empirical and Simulated Business Cycle Statistics

| | Data | Model ($\kappa = 0$) |
|---|---|---|
| **Standard Deviation** ($\%$) | | |
| $Y_t$ | 1.193 | 1.341 |
| $N_t/L_t$ | 0.676 | 0.633 |
| $r^l_t$ | 0.473 | 0.444 |
| **Contemporaneous Cross-Correlations** | | |
| $Y_t$, $r^l_t$ | -0.107 | -0.106 |
| $Y_t$, $N_t/L_t$ | -0.664 | -0.082 |
| **Dynamic Cross-Correlations** | | |
| $N_{t-8}/L_{t-8}$, $r^l_t$ | -0.611 | -0.682 |
| $N_{t-12}/L_{t-12}$, $r^l_t$ | -0.817 | -0.619 |
| **First Order Autocorrelation** | | |
| $Y_t$ | 0.928 | 0.745 |
| $N_t/L_t$ | 0.800 | 0.966 |
| $r^l_t$ | 0.733 | 0.993 |

Note: The variables $Y$, $N/L$, and $r^l$ denote, respectively, output, equity to loans ratio and the lending rate. The variable $Y$ is HP filtered in logs. The sample contains the period 1997-2011 at quarterly frequency.

Figure 2: The Unconditional Distribution of Bank Capital to Loans Ratio



Note: The figure shows the Weibull probability density function of the equity to assets ratio both in the data and in the model. The density for the model is computed via a 500,000 periods simulation.

from the one observed in the data. Another failure of the model is that the series for the equity to assets ratio and the interest rate are too persistent with first order autocorrelation coefficients in the neighborhood of 0.97.

As a last exercise to assess the quantitative properties of my theoretical framework, Figure 2 compares the density of the equity to asset ratio both in the data and in the 500,000 period simulation of the model. Remarkably, the model replicates reasonably well the observed distribution. For instance, both in the model and the data the distribution is leptokurtic (kurtosis of 5.6 in the data and of 4.3 in the model). That is, they have fatter tails than the normal distribution, and thus produce more outliers. Hence, the model approximates the density satisfactorily, mainly because it is able to capture the asymmetric behavior of the equity to assets ratio.

I therefore conclude that the quantitative properties of my model seem overall consistent with Spanish business cycle features.

## 4.3 Macroprudential Policy: Capital Requirements

Let me now consider bank capital requirements that work to offset banks' incentives to adjust their liability structure in favor of external debt. This is done by letting the minimum equity threshold, $\kappa$, be greater than 0. In what follows $\kappa$ is set to $9\%$. That value equals the core capital-ratio target for Spanish banks imposed by the Spanish Central Bank since 2013.

As discussed in Section 2, there is extensive literature in corporate finance and banking that suggest that capital requirements involve a tradeoff between financial resilience and economic performance. The next exercise evaluates whether such a tradeoff is built into the policy functions of the calibrated version of my model. Specifically, I compare the policy functions of two alternative economies. The first economy features an active bank capital constraint (i.e. $\kappa = 9\%$) and is labeled the *Regulated* Economy. In the second model economy (my baseline) equity regulation is turned off (i.e. $\kappa = 0\%$). This economy is labeled the *Unregulated* Economy.

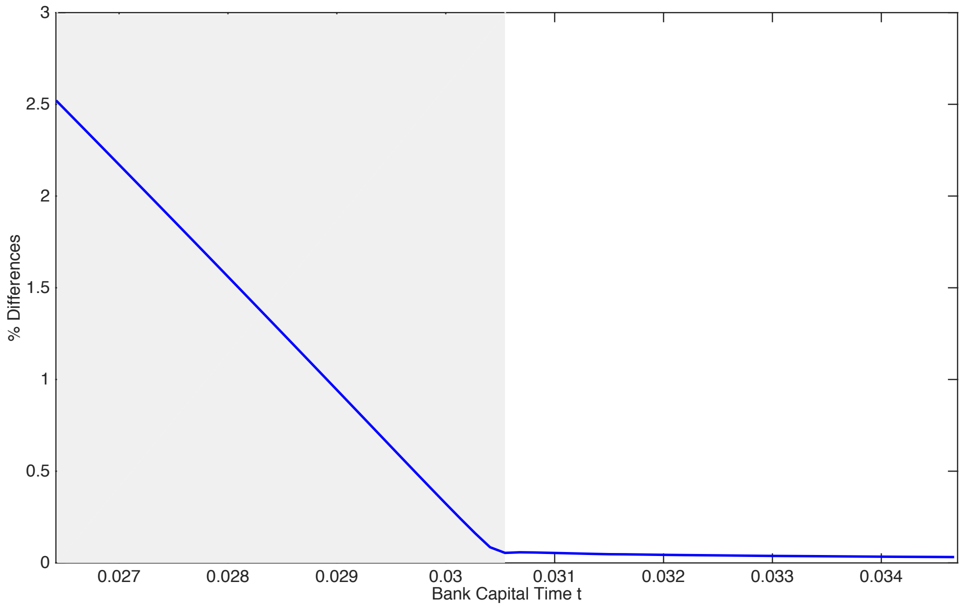
Figure 3 depicts the decision rules for bank net worth at $t + 1$, $N_{t+1}$, and output at $t$, $Y_t$, along the bank capital axis when $A_t = A_2$ and $\epsilon_t = 0$. The bank capital interval is centered on 0.0305 with a width of $\pm 13.5\%$, $[0.026, 0.035]$. In order to isolate the effects of regulation, Figure 3 plots the policy functions of the Regulated Economy in $\%$ deviations (output) and $\%$ differences (net worth) from the Unregulated Economy. The shaded areas represent the states of the economy where the constraint binds in the Regulated Economy.

Remarkably the model captures the notion that capital requirements have clear benefits from a financial stability perspective, but may also hinder economic activity. To better understand this result, I begin by examining the region of the state space where the constraint binds. On the one hand, capital regulation strongly promotes the accumulation of equity. The top panel shows a significant difference in the bank's capital accumulation behavior in both economies. Specifically, the representative banks in the Regulated Economy consistently accumulates more equity capital than its counterpart in the Unregulated Economy. Moreover, this gap monotonically increases with the tightness of the constraint. It is in this sense that a minimum equity threshold acts as a buffer against losses; thus boosting financial stability.

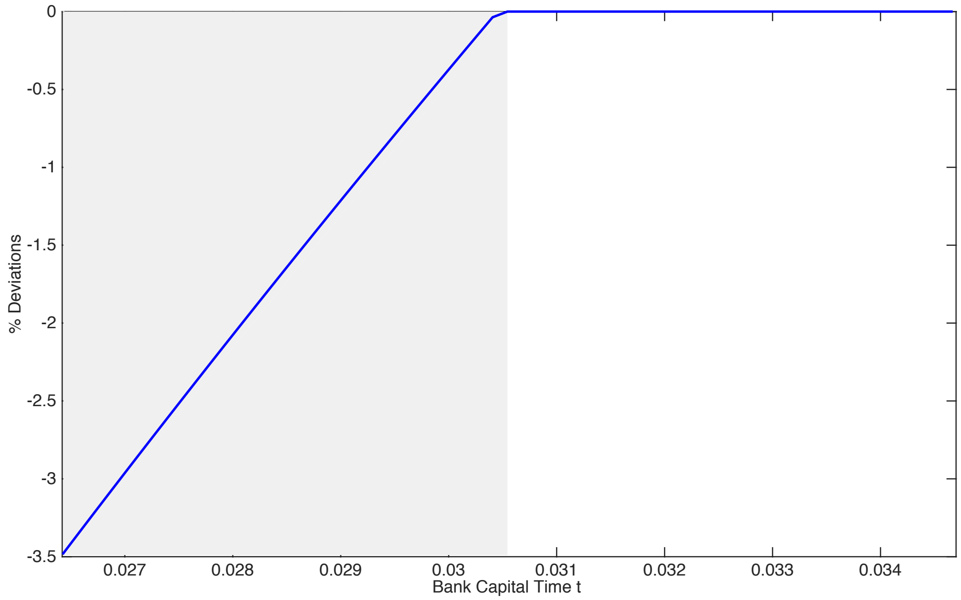
On the other hand, capital regulation restricts the supply of credit, increases lending rates, and hence lowers output. For instance, the bottom panel reveals that when current bank capital is 0.027, output in the Regulated Economy is roughly $3\%$ lower than in the Unregulated

Figure 3: Policy Functions

(a) Bank Capital Time t+1



(b) Output Time t



Economy. This difference is monotonically reduced as current bank capital increases (i.e. as the tightness of the constraint decreases).

The last areas to consider are the states where the constraint does not bind. In those states, the policy functions for output are identical. This implies that capital regulation does not impose an insidious cost on economic activity as long as they are not actually binding. In terms of equity accumulation the differences in the policy functions are small but not insignificant. For instance, when current bank capital is 0.034, equity accumulation is 0.018 (in $\%$ terms) larger in the Regulated Economy, which represents a $0.7\%$ of the steady state level of equity.

I therefore conclude that the quantitative solution of my model blends the two main views underlying the on-going discussion and research about the effects of capital requirements.

A subsequent, natural question that emerges is: under which conditions is the minimum capital standard more likely to be breached? In the model, binding events may be driven by changes in the condition of the borrowing sector, namely technology shocks. For example, a high level of productivity boosts the demand for capital working loans as the representative firm enlarges its production capacity. Bank capital, however, is sticky in the short run, and cannot adjust immediately to the new business environment. As a consequence, the equity to assets ratio declines ; thereby increasing the prospect of breaching the minimum capital standard. Likewise, banks may be brought up against the regulatory constraint due to unfavorable realizations of the bank capital shock. The intuition is straightforward. Adverse financial conditions impair banks' net worth, thereby triggering capital shortfalls. Lastly, binding events may be triggered by the (endogenous) banks' equity accumulation behavior.

Of course, these hypotheses are not mutually exclusive. The analysis that follows is designed to determine which among these factors are the most important sources of binding events. This is a quantitative question, which I settle by simulating a version of the model in which capital regulation is activated (i.e. $\kappa = 9\%$).

To be more precise, I first perform a 500,000 period simulation of the model. Second, I identify all the quarters in which the constraint binds. Then, I construct a dummy variable equal to 1 when the constraint binds and 0 otherwise. Third, I estimate a logistic regression. Specifically, I regress my dummy variable on the four period backward moving average of the productivity shock, the bank capital shock, and bank equity capital. The results are reported in Table 3.

Table 3: Prediction of Binding Events

| Regressors | (1) | (2) | (3) |
|---|---|---|---|
| Mov. Aver. $\epsilon$ | 669.9*** | - | 363.8*** |
| Mov. Aver. $A$ | - | 114.5*** | 159.1*** |
| Mov. Aver. $N$ | - | - | -5361*** |
| Pseudo-$R^2$ | 12.79 | 11.48 | 31.5 |

Note: Logit regression using a dummy equal to one when the capital requirement constraint binds (and zero otherwise) as dependent variable. All models include a constant term. The regression sample includes 498,996 observations and the bank is constrained in 17$\%$ of the periods. The variables $Y$, $N/L$, and $r^l$ denote, respectively, output, equity to loans ratio and the lending rate. Mov. Aver. refers to the 4 periods backwards moving average of the indicated variable. Reported $R^2$ are the McFadden Pseudo-$R^2$. $^{***}p < 0.01$.

I begin by considering the realizations of the exogenous disturbances separately (columns 1 and 2), and find that the fit is not extraordinary. Although both regressors are highly statistically significant, they account for no more than 13$\%$ of the variations in the probability of breaching the minimum capital standard. Next, I include the moving average of bank equity capital (column 3). Interestingly, in this case the pseudo-$R^2$ goes up to 31.5%; which highlights the endogenous nature of binding events in the model. To put it differently, a decline in the accumulation of bank capital over the previous four quarters is indicative of a heightened risk of breaching the minimum capital standard.

These findings lead to an interesting observation. As expected, the minimum equity threshold can be reached during periods of financial distress. However, it can also be breached during economic booms. In these instances, capital regulation can be seen as an automatic stabilizer that limit credit growth in the upturn of the cycle. This substantiates previous findings in the literature [see e.g. De Nicolo et al. (2012); Cerutti et al. (2015); Akinci and Olmstead-Rumsey (2015)] that instruments linked to capital buffers restrict risk taking and reduce the procyclicality of bank credit growth.

## 4.4 Counterfactuals

This subsection performs two policy counterfactuals to quantitatively gauge the impact of capital regulation on the Spanish economy. As will become clear, the main benefit from capital regulation is the reduction in macro-financial volatility.

### Counterfactual A: Business Cycle Statistics

I now proceed to use my model to assess the effects of capital requirements on business cycle statistics. To this end, I conduct a 500,000 period stochastic time series simulation with no regulation in place. Then, I use the same shock sequence in the counterfactual scenario where capital requirements are active ($\kappa = 9\%$). Lastly, I calculate some key statistics of both economies. The results are reported in Table 4.

Table 4 is revealing in several ways. First, the level of output is largely unaffected by the minimum capital standard. Second, the bank holds, on average, an amount of equity that exceeds the minimum imposed by regulation. As was discussed in Section 3, regulatory intervention promotes precautionary behavior by encouraging banks to build up equity buffers in order to stay clear of the minimum capital standard. The intuition is straightforward. Within my framework, breaching the minimum capital standard is costly for banks, because it prevents them from smoothing exogenous disturbances.[22] As a result, regulated banks adjust their balance sheet structure to reduce the prospect of hitting the constraint. Third, equity requirements substantially reduce the lending rate. This occurs because capital regulation boosts financial resilience (i.e. leads to better capitalized banks). This, in turn, increases the confidence of foreign lenders, and hence results in lower banks' funding costs. Forth, capital requirements notably reduce macro-financial volatility. For example, the standard deviations of output and the equity to assets ratio are 1.5$\%$ and 67$\%$, respectively, lower in the Regulated Economy.

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[22] As was mentioned in the Introduction, in the real world when a bank fails to meet its capital requirement, both markets and regulators may restrict the bank's activities in several ways [Borio and Zhu (2012)]. For instance, regulators may limit the flow and size of dividend payments [Furfine (2001)]. Also, depositors might sanction under-capitalized banks by withdrawing deposits or demanding higher interest rates [Berger and Turk-Ariss (2015)].

Table 4: Simulated Business Cycle Statistics

| | Unregulated Economy | Regulated Economy | Dev. $\%$ |
|---|---|---|---|
| **Mean** | | | |
| $Y_t$ | 0.333 | 0.334 | 0.300 |
| $N_t/L_t$ | 0.077 | 0.092 | 19.48 |
| $r_t^l$ | 0.005 | 0.001 | -80.00 |
| **Standard Deviations** ($\%$) | | | |
| $Y_t$ | 1.341 | 1.321 | -1.565 |
| $N_t/L_t$ | 0.633 | 0.208 | -67.40 |
| $r_t^l$ | 0.444 | 0.128 | -71.17 |
| Time at the constraint ($\%$) | - | 17.15 | - |

Note: The variables $Y$, $N/L$, and $r^l$ denote, respectively, output, equity to loans ratio and the lending rate. Business cycle statistics have been computed from a 500,000 period time series simulation of the model. The column Dev. $\%$ represents the percentage deviation of the outcome in the Regulated Economy with respect to the outcome in the Unregulated Economy.

### Counterfactual B: The Dynamic Effects of Bank Capital Shocks

As mentioned in Section 3, my model considers a specific form of bank equity shortfalls, namely a lump-sum transfer of resources from banks to firms. Iacoviello (2015) suggests that this shock can be seen as losses for the banking industry generated, for instance, by a wage of non performing loans. Furthermore, as noted by Guerrieri et al. (2015), this shock is purely financial, since it does not destruct real resources. As a result, its macroeconomic consequences can be interpreted as spillover effects from the financial sector to the real economy.

The next experiment performs a dynamic simulation for both the Regulated Economy and Unregulated Economy in response to a sequence of default shocks that impairs the balance sheet of the bank. More precisely, I feed into the model a sequence of unexpected shocks to $u_t$ (see Eq.6), each quarter equal to $0.39\%$ of annual outstanding loans, which lasts 16 quarters and causes the ratio loan losses to total loans to rise from $0\%$ to $1.5\%$. The shock here mimics the increase in the ratio non-performing loans to gross loans suffered by Spanish banks from 2007 to 2011. During this period, such a ratio rose from $0.8\%$ to $6\%$.

Figure 4 plots the generalized impulse response functions as in Koop et al. (1996) in order to take nonlinearities into account.[23] Let me begin by considering the responses of the Unregulated Economy (solid blue line). The shock damages the bank's balance sheet by impairing the value of its assets (i.e. loans minus non performing loans), relative to its liabilities. This strengthens the friction in the market for external funds as foreign investors revise down their view of the domestic financial sector. As a result, the bank's funding costs increase. This is passed on to borrowers in the form of higher lending rates. Capital working loans therefore fall; dragging employment and output down.

In the aggregate, financial vulnerability strongly deteriorates economic performance. Note that the decline in output is not just large, but also very persistent. Ten years after the initial shock, output is still $0.12\%$ below its long run average.

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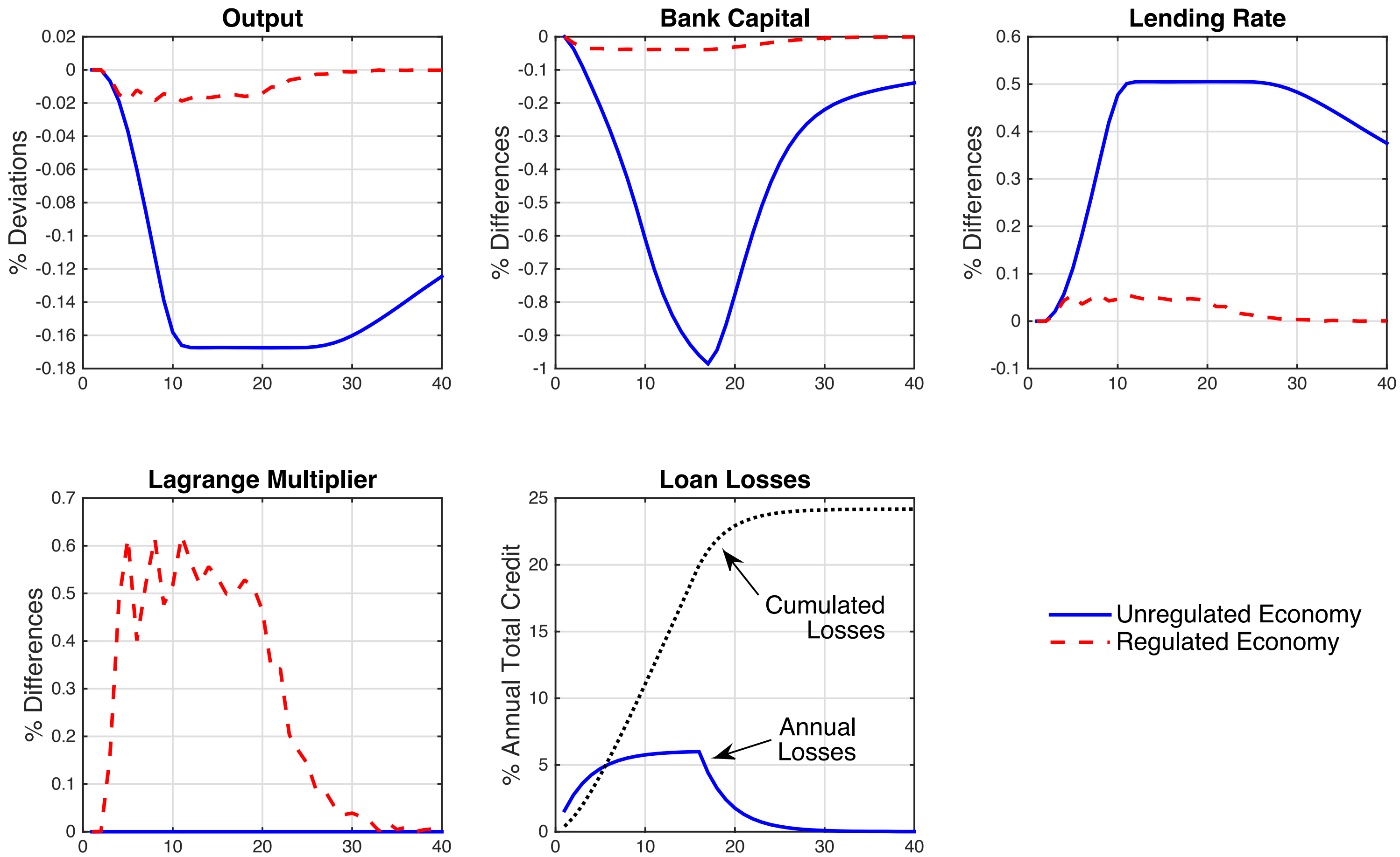
[23] Please refer to Appendix A.4 for details about non linear impulse responses.

Figure 4: Dynamics After a Bank Capital Shock



Note: The figure depicts the responses of macro-financial aggregates to a shock that leads after 4 years to loan losses for banks equal to 6 percent (per annum) of total loans. Flow loan losses (solid blue line) are multiplied by 4 to express as a fraction of annual total credit.

Turning now to the responses of the Regulated Economy (dashed red line), Figure 4 shows that with capital requirements in place, the same sequence of shocks induce a milder decline in equity capital. Moreover, it is important to stress that the path of output is persistently lower in the Unregulated Economy compared to the case when a minimum capital standard is in place.

Two related mechanisms are at play. First, as I noted earlier, capital regulation encourages precautionary behavior. That is, it compels the bank to build up an equity buffer; thus strengthening its balance sheets and boosting its ability to absorb losses. By doing so, capital regulation leads to easier credit conditions during periods of financial distress, and hence contains the economic damage of loan losses.

Second, due to the country-risk premium, there exists a pecuniary externality which banks do not internalize when managing their balance sheets. Specifically, as was mentioned before, individual banks ignore the effect of their own level of net worth on the country-risk premium. Capital regulation partially corrects this market failure by forcing banks to maintain a minimum level of net worth. As a matter of fact, the right bottom panel reveals that the wave of loan losses brings the bank up against the minimum equity threshold (i.e. the Lagrange multiplier on the capital requirement constraint $\mu_t$ becomes positive). This in turn contains the decline of bank capital, improves banks' access to international capital markets, and lessens the contraction of output.

All told, these findings support the idea that capital requirements are indeed a powerful tool to strengthen financial resilience. By doing so, equity regulation reduces macro-financial volatility and smooths business cycle dynamics.

# 5 Concluding Remarks

This paper develops a business cycle model to assess the quantitative relevance of an occasionally binding bank capital requirement constraint. I focus on financial shocks, because they are now considered as the likely cause of many economic crisis. However, I also take into account technology shocks, since they are at the core of the vast majority of dynamic models.

I perform a non-linear analysis, which has two essential benefits. First, I am able to consider the kink that the occasionally binding constraint imposes on the policy functions of the model. Second, I am able to capture precautionary behavior linked to the possibility that the constraint may become binding in the future as a result of shocks yet unrealized.

I use my model to examine three fundamental matters. Firstly, the tradeoff between financial stability and the cost of financial intermediation associated with capital requirements. Secondly, what factors affect the likelihood of hitting the constraint. Thirdly, the role of capital regulation in shaping business cycle fluctuations.

Considered together, the results of this study suggest that bank capital requirements strengthen the resilience of the banking sector, and smooth business cycle fluctuations. In other words, bank capital requirements lead to a considerable stabilization of the macroeconomy.

In spite of the growing literature on macroprudential tools, particularly on capital requirements, many unknowns still exist, and a large research agenda remains. In order to justify policy intervention, further research on the choice and calibration of prudential regulation is essential. Also, it is crucial to gain evidence on the quantitatively effectiveness of macroprudential tools to make the policy design more transparent and accurate.

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# Appendix

## A.1 Data Description

The dataset includes quarterly and annual data for Spain. The data come from four sources: (i) the European Central Bank (ECB), (ii) the Central Bank of Spain (BDE), (iii) the Organization for Economic Co-operation and Development (OECD), and (iv) the World Bank (WB). Information regarding individual time series is provided in table 5.

Table 5: Data Sources

| Variable | Source | Period |
|---|---|---|
| Gross Domestic Product | OECD | 97Q3-11Q4 |
| Gross Domestic Product: Implicit Price Deflator | OECD | 97Q3-11Q4 |
| Total Employment | OECD | 97Q3-11Q4 |
| 10-year Spanish Government Bond | OECD | 97Q3-11Q4 |
| 10-year German Government Bond | OECD | 97Q3-11Q4 |
| Net Charge-offs to Assets Ratio of Banks and Credit Finance Establishments | BDE | 97Q3-11Q4 |
| Total Loans of Banks and Credit Finance Establishments | BDE | 97Q3-11Q4 |
| Equity of Banks and Credit Finance Establishments | BDE | 97Q3-11Q4 |
| Capital and Reserves of Monetary Financial Institutions | ECB | 97Q3-11Q4 |
| Total Assets of Monetary Financial Institutions | ECB | 97Q3-11Q4 |
| Banks' Non Performing Loans to Gross Loans | WB | 07A-11A |

## A.2 Construction of Solow Residuals

Solow residuals are defined as

$$SR_t = log(Y_t) - log(H_t),$$

Table 6: Discretized State Space

| State Variables | Lower Bound | Upper Bound | Grid Points |
|---|---|---|---|
| $A$ | $A_1$ | $A_2$ | 2 |
| $N$ | $0.6\bar{N}$ | $1.4\bar{N}$ | 150 |
| $\epsilon$ | $-0.3\bar{N}$ | $0.3\bar{N}$ | 10 |

Overbar variables refer to the deterministic steady state.

where $Y_t$ denotes real gross domestic product and $H_t$ total employment.

I begin by linearly detrending my empirical measure of labor productivity, $SR_t$. This is done by fitting a linear and quadratic time trend to the original series. Then I take the measured residuals, which can be interpreted as the detrended TFP series, and estimate an AR(1) process:

$$a_t = \rho a_{t-1} + v_t,$$

where $a$ is the detrended Solow residuals. I obtain the following estimates: $\rho = 0.956$ and the standard deviation of $v_t$ of 0.0029. Lastly, I discretize such a process as a 2-state Markov chain using the approach laid out in Tauchen and Hussey (1991).

## A.3 Solution Method

The model is solved using the policy function iteration with time iteration and linear interpolation algorithm described in Richter et al. (2014). Information regarding the construction of the discretized state space is provided in Table 6. The continuous state variables are $N$ and $\epsilon$. These are chosen from evenly spaced grids of $100$ values of bank capital, $N = \{N_1 < N_2 < ... < N_{150}\}$, and $10$ values of the default shock, $\epsilon = \{\epsilon_1 < \epsilon_2 < ... < \epsilon_{10}\}$. Hence, the state space of the model has $150 \times 10 \times 2$ nodes.

Under the AR(1) specification for the bank capital shock (see Eq.6), conditional expectations cannot be computed analytically. Calculation is therefore accomplished via quadrature methods. Specifically, I use Gauss Hermite quadrature to integrate across $\epsilon_{t+1}$. In doing so I use 15 Gauss Hermite nodes for the exogenous disturbance $u$.

The following outline summarizes the policy function iteration algorithm I employ. The general procedure for implementing the algorithm is laid out in Richter et al. (2014).

1. Obtain an initial conjecture for $Q_t$ on each grid point from the log-linear solution of the model. I use Chris Sims' *gensys.m* program to obtain this conjecture.
2. Using initial guesses and the equilibrium conditions of the model, solve for all time $t$ variables.
3. Using linear interpolation, compute the time $t+1$ value for $Q_{t+1}$.
4. Calculate the time $t+1$ values of the variables appearing inside time $t$ expectations.
5. Compute conditional expectations.
6. Minimize the Euler equations. To this end, I use Chris Sims' *csolve.m* optimization routine. The output of *csolve.m* is the updated decision rules.
7. If the distance between the updated and guessed policy values is smaller than a tolerance parameter, an approximation to the decision rules has been obtained. Otherwise, employ the updated policy function as the new initial conjecture and return to step 2.

## A.4 Non-linear Impulse Response Functions

The general procedure for calculating non-linear or generalized impulse response functions (GIRFs) can be found in Koop et al. (1996). The reader is referred there for a formal statistical background.

As remarked by Weise (1999), there are four major differences between the impulse responses originated from a linear model and those generated from a nonlinear model. First, linear impulse responses are invariant to history, whereas nonlinear responses are state-dependent. In other words, nonlinear responses are sensitive to initial conditions. As a result, in the nonlinear case the history of shocks must be treated as a random variable.

Second, in the linear case future shocks can be set to their expected value -that is, to zero. This is not the case for nonlinear models: future shocks must be drawn from a particular distribution and their effects averaged out over a large number of draws.

Third, linear responses are invariant to the size of the shock. In contrast, in nonlinear model disturbances of different sizes give rise to different impulse responses.

Fourth, linear responses are symmetric. That is, the responses to positive and negative disturbances are mirror images of each other. This is not the case for nonlinear models.

For all of the foregoing reasons, impulse responses generated from nonlinear models should be calculated as the average of Monte Carlo simulations of the model [Gavin et al. (2015)]. The following algorithm is used to compute the generalized impulse response functions:

1. The model is simulated $N$ times conditional on $N$ random histories of shocks, $\Xi^A = \{A_t, u_t\}_{t=0}^T$. Let $\bar{x}_t^A = \frac{1}{N}\sum_{i=0}^N x_t^i(\Xi^A)$ be the average across these simulations.
2. The first $\tau$, for $\tau = 1, ..., \tau^*$, elements of each history of shocks are replaced by the $\tau$ shocks of interest. A new collection of exogenous disturbances, $\Xi^B$, is therefore created.
3. The model is (re-)simulated conditional on $\Xi^B$. Let $\bar{x}_t^B = \frac{1}{N}\sum_{i=0}^N x_t^i(\Xi^B)$ be the average across the second set of simulations.
4. GIRFs may then be defined in percentage change as $(\bar{x}_t^B/\bar{x}_t^A - 1) * 100$ or in percentage difference as $(\bar{x}_t^B - \bar{x}_t^A) * 100$.

In this paper, I set $T$ to 40 and $N$ to 40,000.

## A.5 Spain's Risk Premium and Financial Resilience

At the core of the model is the negative link between interest rates and financial vulnerability. Figure 5 offers historical evidence of how Spain's country spread relates to the health of the banking sector. Specifically, it plots Spain's risk premium[24] and the bank capital to loans ratio of Spanish banks from 1980 to 2015. As expected, the figure shows a clear inverse relationship between both magnitudes (there is a statistically significant cross-correlation of -0.34). To put it differently, sovereign bond spreads, and hence overall funding costs, have historically reacted to the leverage ratio of the Spanish banking industry (or equivalently, to their capability to pay back obligations). This historical evidence lends support to the idea that: as financial vulnerability increases, the market revises down its view of Spain's economic outlook, and hence sovereign spreads rise.

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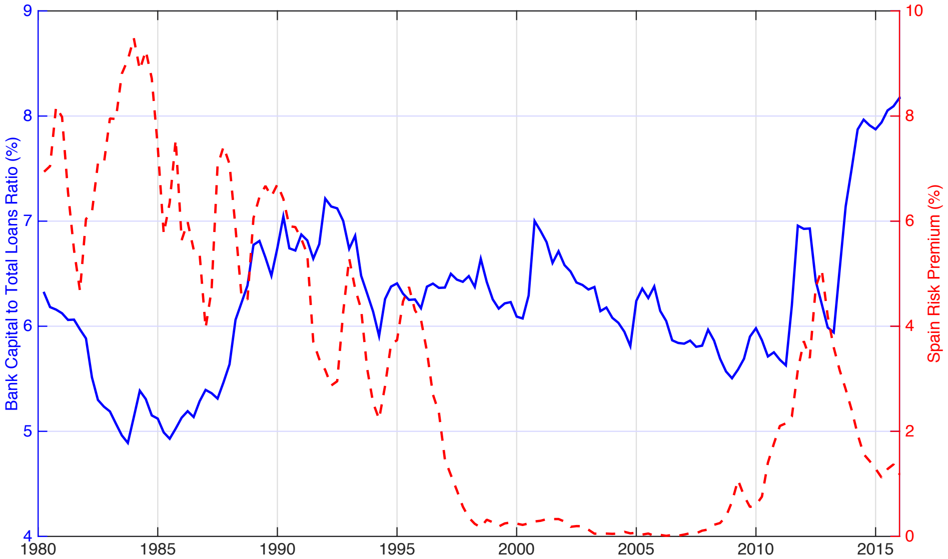
[24] Spain's risk premium is the spread between 10-year Spanish government bond, and the 10-year German bond. Given that the German bond is considered a risk-free asset, the spread is the premium paid for the risk of default.

Figure 5: Spain's Risk Premium and Financial Resilience



Note: Dynamics of Spain's risk premium and the bank capital to loans ratio of Spanish banks and credit finance establishments. Spain's risk premium is the spread between 10-year Spanish government bond, and the 10-year German bond. The sample contains the period 1980-2015. Data are at a quarterly frequency and are reported in % terms.

## A.6 Grid Search Method

This subsection shows that the optimization problem to estimate $\psi_1$ is well defined. To this end, Figure 6 plots the value of the criterion function, $\Omega$, in the neighborhood of the solution, $\psi_1 = 16,329$. The figure suggests that the existence of local minima can be excluded; thereby corroborating the validity of me methodology.

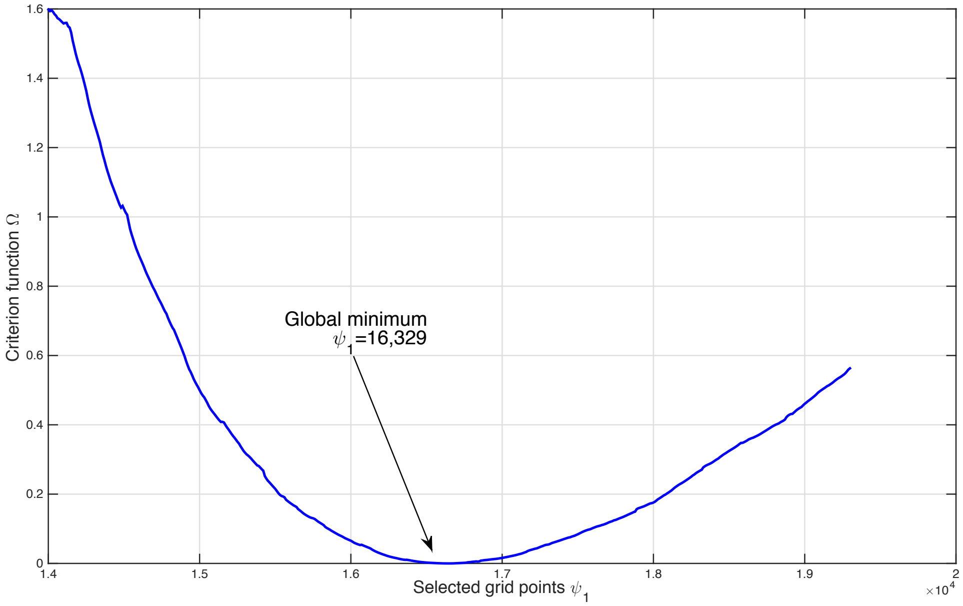
## A.7 Interest Rates and Bank Capital

My model assumes that the interest rate, $r_t^f$, is a decreasing function of the cross-sectional average level of bank equity capital, $\hat{N}_t$. As was noted in Section 3, I opt for the logistic function (see eq.15). After the calibration exercise, the relationship between $r_t^f$ and $\hat{N}_t$ is given by:

$$r_t^f = 0.01[1 + e^{16,329(\hat{N}_t - 0.025)}]^{-1},$$

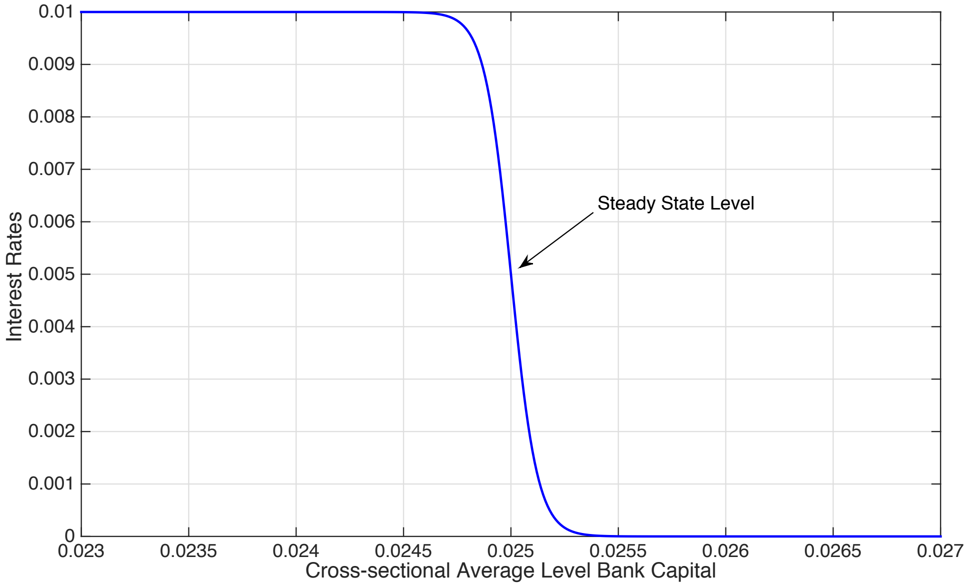
which is depicted in Figure 7.

Figure 6: The Criterion Function in the neigborhood of the global minimum



Note: The figure exhibits the value of the criterion function, $\Omega$, in the neighborhood of the global minimum, $\psi_1 = 16,329$.

Figure 7: Interest Rates and Bank Capital



Note: The figure shows the relationship between interest rates, $r_t^f$, and the cross-sectional level of bank capital, $\hat{N}_t$, when $\psi_0 = 0.01$, $\psi_1 = 16,329$ and $\bar{N} = 0.025$.