Macroprudential Regulation and Macroeconomic Activity*

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Abstract

I develop a dynamic stochastic general equilibrium model to examine the impact of macroprudential regulation on the bank's financial decisions and the implications for the real sector. I model an occasionally binding capital requirement constraint and analyze its costs and benefits. This friction means that the banks refrain from valuable lending. At the same time, capital requirements provide structural stability to the financial system. I show that higher capital requirements can dampen the business cycle fluctuations and raise welfare. I also show that switching to a countercyclical capital requirement regime can help reduce volatility and raise welfare. Finally, by means of the welfare analysis, I also obtain the optimal level of capital requirement.

Keywords: Capital Requirement, Prudential Regulation, Financial Accelerator, Procyclicality

"The reason I raise the capital issue so often, is that, in a sense, it solves every problem" - Alan Greenspan to the Financial Crisis Inquiry Commission

1 Introduction

The banking sector is one of the most regulated ones in the world today. There are different forms of regulation but capital regulation is of paramount importance because bank capital is an extremely good indicator of the financial soundness of the bank and

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also its risk taking abilities. Berger et. al. (1995) and Kahn and Santos (2005) contain surveys on the motivations behind capital regulation. Bank equity is of utmost importance but has not really been given its due by traditional monetary macroeconomics albeit the trend seems to be changing recently. In most bank related work, the focus is on reserve/liquidity requirements and how they affect the decision to accept demand deposits. In these studies, the bank capital regulation is mostly discussed as an afterthought. My work aims to fill this gap by focusing on bank capital requirements and studying the implications for the real economy.

This paper contributes to two strands of literature. The first one is the literature that addresses the question whether capital requirements are a boon or a bane for the economy. Giammarino (1993) and Hellman et. al. (2000) talk about the benefits of capital requirements owing to the moral hazard problem arising from deposit insurance. Admati et. al. (2013) proposes implementing much stricter capital requirements. The authors say that the capital requirements should be as high as 20-25%. This is much higher than the current FDIC regulations which is around 10%, for Tier 1 and Tier 2 capital taken together. The question that immediately comes to mind is, are there no costs of these capital requirements? If there are indeed no costs, why not have 100% capital requirements and have all bank assets financed by equity. Van den Heuvel (2008) talks about the welfare implications of these requirements and shows that increasing capital requirements can lead to a non negligible decline in welfare. Do the costs outweigh the benefits? Or is it the other way around? What is the net impact on welfare? There has been no consensus reached on this entire issue and is the subject matter of a large body of ongoing work. I explore these questions in greater detail by incorporating both the costs and benefits of capital requirements in a single framework.

The second strand of literature that my work relates to is the one that explores how financial frictions might have adverse real consequences. Kiyotaki and Moore (1997), Bernanke et. al. (1999), and Gertler and Kiyotaki (2010) are some of the major papers in this literature, by no means an exhaustive list though. Gertler and Kiyotaki (2010) studies financial intermediation and its effect on the business cycle. However it assumes an always binding flow of funds constraint which is necessary to derive some intuitive analytical results. Additionally, there is no capital requirement constraint in that model. In this paper I study macroprudential policy keeping the set up similar to Aiyagari and Gertler (1999) and Gertler and Kiyotaki (2010). I not only allow for an explicit capital requirement constraint for the bank but also acknowledge the fact that such a constraint is only occasionally binding. The difference between actual bank equity and the minimum requirements is defined as the capital buffer. The bank holds a capital buffer so that it remains compliant with the regulatory requirements should there be an economic downturn. There is one immediate benefit of this approach. De Wind (2008) and Den Haan and Ocaktan (2009) document that it might well be that the constraint is binding in the steady state but not off steady state. Even in that case, the steady state results are greatly affected. However, it must be acknowledged that solving such models with occasionally binding constraints can be computationally intense. Standard perturbation methods cannot be applied. I use the penalty function method, originally proposed by Judd (1998). Other applications of this method can be found in Den Haan and Ocaktan (2009) and Preston and Roca (2007) among others.[1]

To elaborate a bit more, I develop a dynamic stochastic general equilibrium model with a representative household, a representative bank and a non financial firm sector. The role of the bank is to intermediate funds between the household and the non financial firms. The financial friction in this model is an occasionally binding capital requirement constraint on the bank. In the absence of regulation, the bank has an incentive to increase leverage and thereby increase its lending. Given that the impact of an economic downturn is proportional to the leverage, the economy will shrink more if the banks assets start defaulting. The mechanism will be the standard pecuniary externalities and the financial accelerator mechanism, to be explained in detail later. I explore two alternative capital requirement regimes in this paper. In the first half of the paper, I maintain a fixed capital requirement regime. Later, I introduce countercyclical requirements and show that it moderates the business cycle and also raises net welfare. This paper is the first that studies an occasionally binding bank capital requirement constraint in a dynamic general equilibrium setting. Another contribution of this paper is methodological. Having always binding constraints do help us derive closed form solutions but we should be looking to incorporate asymmetries to make the models suitable for policy analysis. The motivation for this lies in the fact that recessions tend to be sharper than booms, as has been observed in the data. To achieve this end, I use the penalty function methodology to solve the model and perform a third order approximation.

The rest of the paper is organized as follows. Section 2 presents some stylized facts about the equity-asset ratio of commercial banks in the United States, sections 3 and 4 introduce the model and discuss the numerical solution methodology. Section 5 puts forward the calibration, section 6 studies the countercyclical capital requirement regime, section 7 presents the numerical results, and section 8 discusses the welfare analysis. Finally, section 9 concludes. The tables and figures have been placed in the appendix.

2 Stylized Facts about the Equity-Asset Ratio

At the very outset, let us look at some stylized facts about the equity-asset ratios of the commercial banks in the United States.

Figure (1) shows the time plot of the equity asset ratio since 1985. The equity shown above is obtained by subtracting the total liabilities from the total assets. The data covers a hundred and four quarters from 1985:Q1 to 2010:Q4. The source of the data is the consolidated report of condition and income, referred to as the call reports.[2] The equity asset ratio exhibits a procyclical pattern as one would expect. The reason for that is that during the recessions, the credit risk materialization is high and the amount of non performing assets (NPA) on a banks balance sheet rises which in turn

[1] For details, see section 5 on numerical solution.

[2] These data can be downloaded from the website of the Federal Reserve Bank of Chicago.

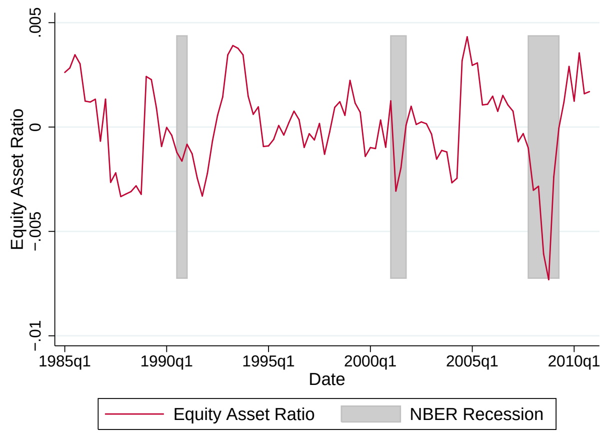

Figure 1: Time plot of the Equity-Asset Ratio

causes the equity to shrink, liabilities roughly remaining constant.

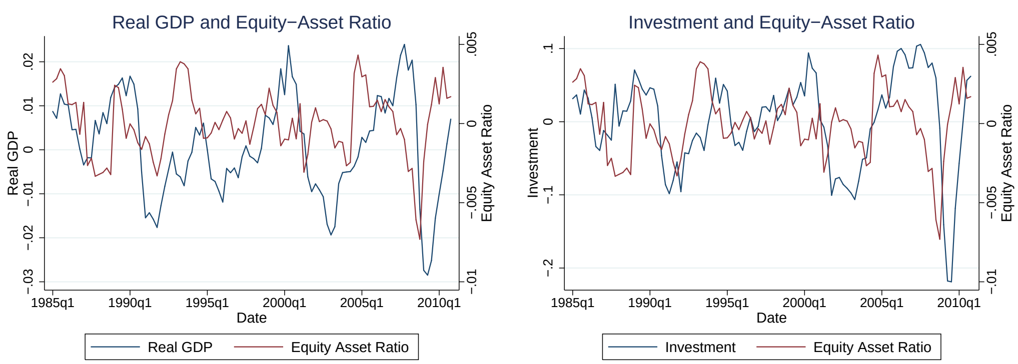

Figure 2: Equity-Asset Ratio, Real GDP and Investment

Figure (2) shows the comovement of the equity-asset ratio with two main real variables namely the output gap and the gross private domestic investment in the economy.[3]

The series co-moves or rather the equity-asset ratio seems to lead the series for output and investment. Intuitively, as the equity-asset ratio declines, the regulatory constraints start to bind. The adjustment cannot come from the numerator as it is difficult to raise fresh equity when the economic scenario is adverse. So the bank has to adjust the assets. The deleveraging by banks in turn creates a credit crunch causing a decline in investment and output. The data shows that this feedback takes roughly four quarters.

[3]The data are available in the FRED database of the Federal Reserve Bank of St. Louis. The output gap is the HP filtered real GDP series using the smoothing parameter $\lambda = 1600$.

3 The Model

The model builds on Aiyagari and Gertler (1999) and Gertler and Kiyotaki (2010). Owing to the presence of financial frictions, the model deviates from the Modigliani-Miller framework. I abstract from some of the other frictions like nominal price and wage rigidities and habit formation in consumption.

3.1 The Environment

There is a continuum of non financial firms of mass unity, split into capital goods producers and final goods producers. The latter firms produce the final output of the economy by employing labor and capital as inputs. The production function takes the standard Cobb-Douglas form which is:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}, \tag{1}$$

where A_t is the total factor productivity (TFP) and is governed by a Markov process and $0 < \alpha < 1$.

These firms hire labor from the households and buy capital goods from the capital goods producing firms. To buy capital goods, the firm requires external financing through the bank. The price at which these loans are obtained are same as the gross profits per unit of investment which means that the final goods producers earn zero profits. Denoting I_t as the aggregate investment and δ as the constant rate of depreciation, the law of motion for aggregate capital stock is given as:

$$K_{t+1} = [c(\frac{I_t}{K_t})K_t + (1-\delta)K_t)]\theta_t, \tag{2}$$

where the interpretation of θ is as follows. Following Gertler and Kiyotaki (2010), I define θ as a capital quality shock. This is different from physical depreciation, which is captured by δ. The reference of the capital quality shock can be found in Merton (1973) and is a simple way of introducing an exogenous source of variation in the value of equity. Since the market price of capital will be endogenous in this framework, θ will act as an exogenous trigger of asset price dynamics. I assume that it follows a Markov process. The concave capital production function is discussed later in the section on capital goods producers.

The aggregate output of the economy is divided into household consumption, c_t, and investment, I_t. The resource constraint in this model is written as:

$$Y_t = c_t + I_t, \tag{3}$$

The interactions between the agents in the economy can be represented by means of the flowchart in figure (3).

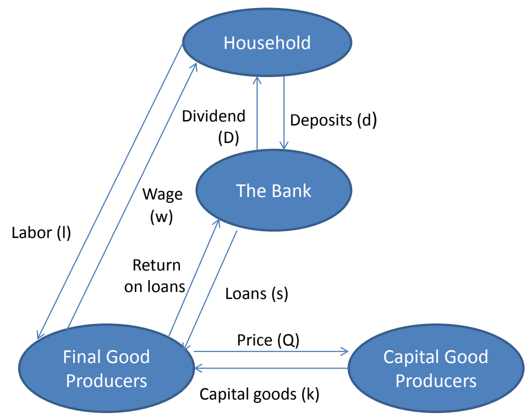

Figure 3: Flowchart of agents

3.2 The Household

There is a representative household that lends to non financial firms through the bank. They also hold one period risk-free deposits and own unit equity in the bank. The bank in return transfers dividends back to the household. The households also supply labor and earn wage income. The objective of the household is to maximize utility subject to the budget constraint. The household preferences are given by:

$$U(c_t, d_t, l_t) = \frac{\left[ac_t^{1-b} + (1-a)d_t^{1-b}\right]^{\frac{1-\phi}{1-b}}}{1-\phi} - \chi \frac{l_t^{1-\varphi}}{1-\varphi} \tag{4}$$

where $(0 < a < 1)$, is the share parameter, $b, \varphi, \phi, \chi > 0$ and $b, \varphi, \phi \neq 1$, χ is the parameter measuring the disutility from supplying labor, φ is the Frisch elasticity of labor supply, and $1/b$ is the constant elasticity of substitution between consumption and deposits. Consumption and deposits become perfect substitutes as b approaches zero. The household derives utility from consumption and liquidity services. Since I want to measure the net welfare from imposing higher capital requirements, it is important to model preferences over liquidity in a way that is not too restrictive. To this end, I follow Sidrauski (1967 a,b) modeling method and put deposits in the utility function. Let W_t denote the wage rate, d_t denote the deposits made this period, R_t the gross return on deposits, and D_t the dividends received from the bank. The household budget constraint is:

$$c_t + d_t = W_t l_t + D_t + R_t d_{t-1} \tag{5}$$

The left hand side shows the household expenditures. It consumes and sells deposits to the bank. The right hand side shows the total receipts which consists of labor income, dividends and earnings from one period bank deposits. The household maximizes the expected discounted lifetime utility subject to the budget constraint to yield the the optimality conditions:

$$\frac{u'_l(c_t, d_t, l_t)}{u'_c(c_t, d_t, l_t)} = W_t \tag{6}$$

$$u'_d(c_t, d_t, l_t) + \beta u'_c(c_{t+1}, d_{t+1}, l_{t+1}) R_{t+1} = u'_c(c_t, d_t, l_t) \tag{7}$$

where,

$$u'_c(c_t, d_t, l_t) = \left[ac_t^{1-b} + (1-a)d_t^{1-b}\right]^{\frac{b-\phi}{1-b}} ac_t^{-b},$$

$$u'_l(c_t, d_t, l_t) = \chi l_t^{-\varphi}$$

$$u'_d(c_t, d_t, l_t) = \left[ac_t^{1-b} + (1-a)d_t^{1-b}\right]^{\frac{b-\phi}{1-b}} (1-a)d_t^{-b}$$

Equation (7) differs from the standard Euler equation in that the household now derives utility from holding deposits besides consumption. The right hand side shows the loss in utility by putting one unit more in deposits while the left hand shows the gain in utility from holding a unit deposit this period and the next periods gain in utility from consumption. Equation (6) is the standard equation governing the labor-leisure choice.

3.3 The Bank

The primary role of the bank in this model is to intermediate funds between the household and the non financial firms. This may be justified on the grounds that it minimizes transaction costs. The only way the firms can finance their investment is by taking loans from the bank. To finance these assets, the bank has to raise deposits from households and pay them a deposit interest rate. The bank also has to satisfy an additional capital requirement constraint. This simply states that the bank has to finance a certain fraction of its assets (loans in this model) by equity. Stated differently, this imposes an upper bound on the amount of retail deposits that can be raised.

The bank maximizes the present discounted value of current and all future dividends while satisfying the flow of funds constraint, the capital requirement constraint, and a non negative dividend constraint. At the beginning of every period the aggregate state is realized but not the capital quality shock. The bank has to decide on its volume of loans, deposits and dividend payout before this shock is realized and this assumption is of paramount importance. Owing to this timing structure, the bank will have an incentive to hold precautionary buffers and not remain at the minimum stipulated level. If the bank maintains a capital ratio that is equal to the minimum requirements, then in the event of an economic downturn, there is a high probability that the bank might find itself non-compliant with the regulations. This discussion motivates the capital requirement constraint to be only occasionally binding. In my solution methodology, I adopt a penalty function approach where the amount of penalty imposed is proportional to the shortfall in capital and that is motivated by the FDIC penalty structure in the United States. I do not claim to replicate the realistic penalty imposed but my approximation certainly has elements of the idea.[4] In what follows, I present the bank's optimization problem and provide an intuitive analytical explanation of the occasionally binding capital constraint before presenting the simulation results. The bank maximizes the present discounted value of current and future dividends:

$$V_t = E_t \sum_{i=0}^{\infty} \Lambda_{t+i} D_{t+i} \tag{8}$$

The dividends are defined as the difference between net assets at the beginning of the period and at the end of the period. It is written as follows:

$$D_t = [(Z_t + (1-\delta)Q_t)\theta_t s_{t-1} - R_t d_{t-1}] - (Q_t s_t - d_t) \tag{9}$$

The first parenthesis shows the net assets (total receipts less payments due) at the beginning of the period while the second parenthesis shows the net assets at the end of the period. Z_t is the dividend payment, at t, on the loans the bank had made in $t-1$. Q_t is the price of loans and s_{t-1} is the volume of loans made last period. As has been mentioned earlier, R_t is the deposit rate. The last equation can also be thought of as balance sheet constraint. Rearranging the terms we get:

$$Q_t s_t - d_t = [(Z_t + (1-\delta)Q_t)\theta_t s_{t-1} - R_t d_{t-1}] - D_t$$

This equation simply states that the assets minus liabilities have to equal the bank capital net of dividends. In addition to the flow of funds constraint above, the bank also has to satisfy a capital requirement constraint or a margin constraint which can be written as follows:

$$[(Z_t + (1-\delta)Q_t)\theta_t s_{t-1} - R_t d_{t-1}] - D_t - \kappa Q_t s_t \geqslant 0 \tag{10}$$

The most simple interpretation of this constraint is that the bank must finance a certain fraction of assets with its own resources. In other words, after the bank incurs the payoff from assets net of deposit costs and pays out dividends, it must be left with sufficient funds to finance a certain fraction, (κ), of the new loans it makes in that

[4] In the context of the United States, the FDIC requires all regulated financial institutions to provide some details (financial and others) every year. It monitors whether the financial institutions are sound enough and one of the main indicators of financial soundness is the capital position of the bank. If the bank's regulatory capital ratio falls below 8%, the FDIC declares it as undercapitalized. It can bring about a change in management if the capital ratio is below 6%. In extreme cases, if the distress persists and the capital ratio falls below 2%, the bank can be declared as insolvent and taken over. However, the bank will try to avoid being declared as undercapitalized because of loss in franchise value and possibility of losing its customer base.

period. It may be helpful to look at equations (9) and (10) together. Substituting out dividends in (10) yields:

$$(1-\kappa)Q_t s_t \geqslant d_t$$

This is just setting an upper bound on the amount of deposits that the bank can accept. More precisely, the bank can, at most, finance $(1-\kappa)$ fraction of its new loans with deposits. The remaining will have to be financed with equity.

Finally, I need one more condition for the capital constraint to have force. If it were easy to issue fresh equity instantaneously and costlessly, then the bank would have no incentive to manage its capital in a prudent manner because the market would always stand ready to bail it out. In terms of the model, the following constraint is tantamount to saying that the bank cannot issue new equity. The only way to raise capital is by retained earnings.

$$D_t \geqslant 0 \tag{11}$$

I refer to the last constraint as the dividend constraint. If the capital requirement constraint is binding, the dividend constraint has to bind. To see that this is intuitive, I consider the counter factual. What would have happened if the capital constraint were binding but not the dividend constraint? In such a scenario, the bank could easily reduce the dividend payments and once again satisfy the capital constraint. So it is essential that when the equity constraint is binding, dividend payments have been reduced to zero.

I present some analytical results and provide an intuitive explanation of the occasionally binding capital constraint. The bank's optimization yields the following first order conditions:

$$E_t[\Lambda_{t,t+1}\gamma_{t+1}R^e_{t+1}] = \gamma_t - (1-\kappa)\mu_t \tag{12}$$

$$E_t[\Lambda_{t,t+1}\gamma_{t+1}R_{t+1}] = \gamma_t - \mu_t \tag{13}$$

$$\Omega_t + \mu_t = \gamma_t, \gamma_t \geqslant 1 \tag{14}$$

In the last equation, $\gamma = 1$ if $D_t > 0$. Also the return on loans is given as:

$$R^e_{t+1} = \theta_{t+1}\frac{(1-\delta)Q_{t+1} + Z_{t+1}}{Q_t}$$

Ω and μ are the multipliers on equations (9) and (10) respectively. The following cases are possible:

1. Case 1: $\mu_t = 0$: This is the case when the equity constraint is not binding. The Euler equation assumes the standard form and the risk-free rate is the inverse of the expectation of the stochastic discount factor. In this case, we are in the

standard asset pricing world. The bank accepts deposits and makes loans while remaining compliant with the imposed regulations. The financial friction is not relevant in this case.

2. Case 2: $\mu_t > 0$: The expected returns on loans can be written as:

$$E_t R^e_{t+1} = \frac{\gamma_t - (1-\kappa)\mu_t - cov(\Lambda_{t,t+1}\gamma_{t+1}, R^e_{t+1})}{E(\Lambda_{t,t+1}\gamma_{t+1})}$$

And, given the equation for risk-free rate, I derive the expression for excess returns as:

$$E_t R^e_{t+1} - R_{t+1} = \left[\frac{\kappa\mu_t - cov(\Lambda_{t,t+1}\gamma_{t+1}, R^e_{t+1})}{E(\Lambda_{t,t+1}\gamma_{t+1})}\right] \tag{15}$$

In this case, the capital requirement constraint is binding in the current period. The asset pricing formula will differ from the frictionless case. The risk premium is above the fundamental level. If the bank is not able to issue fresh equity instantaneously, it will have to reduce its asset holdings to improve its capital ratio. In terms of the model, the bank is the sole holder of securities issued by the non financial firms. When the bank is capital constrained, its demand for such securities falls and thereby in equilibrium, asset prices have to fall as well. For asset markets to clear, the supply of new capital has to decline. In other words, given the fall in asset prices, the capital goods producers are less willing to invest and supply new capital to the final goods producers. This in turn leads to a decline in aggregate output. This is how pecuniary externalities lead to adverse real effects in the model.

It is extremely important to note that the pecuniary externalities give rise to a financial accelerator mechanism in this model. Following the first round decline in asset prices, bank capital also falls because the value of its assets have declined, liabilities roughly remaining constant. This further tightens the capital requirement constraint and brings about a second round decline in demand for assets supplied by the non financial firms. Market clearing would imply a second round decline in supply of new capital and hence output.

3. Case 3: $\mu_t = 0, \mu_{t+1} > 0$: In this case, the covariance between $\gamma_{t+1}(= \mu_{t+1} + \Omega_{t+1})$ and R^e_{t+1} is negative. If μ_{t+1} is positive it means the equity constraint is binding at $t+1$. This will force the asset price, Q_{t+1}, to be below its fundamental level and hence the return on loans, R^e_{t+1}, will also be lower. This in turn will lead to the complications discussed in the last case and worsen the economic downturn. We thus find that it does not really matter whether the capital requirement constraint binds today or is likely to do so in the near future. The implications for the real sector can be equally severe under both circumstances. It is precisely this externality that the macroprudential regulator aims to resolve.

3.4 Capital Goods Producers

These firms produce the capital good by using the final output. They sell these goods to the final goods producing firms who need capital and labor to produce their output. They take the evolution of the capital stock as given and choose investment by maximizing the following profit function:

$$maxE_t \sum_{i=0}^{\infty} \Lambda_{t+i}[Q_{t+i}c(I_{t+i}/K_{t+i})K_{t+i} - I_{t+i}], \tag{16}$$

where the capital production function is given by:

$$c(I_t/K_t) = (\tfrac{b_1}{1-a_1}(\tfrac{I_t}{K_t})^{1-a_1} + c_1)$$

The capital production function is concave and is similar to the ones used in Jermann (1998) and Boldrin et. al. (2001). Profit maximization yields the following optimality condition:

$$Q_t = \frac{1}{b_1}\left(\frac{I_t}{K_t}\right)^{a_1} \tag{17}$$

With higher asset prices, these firms invest more leading to higher capital and output. On the contrary if the bank is in distress and has to deleverage, asset prices will fall and hence lead to a decline in investment and output.

3.5 Final Goods Producers

These firms operate a CRS technology and use labor and capital as the inputs for their production process. The production function is standard Cobb-Douglas. The wage rate and the gross return on capital are given as follows:

$$W_t = (1-\alpha)\frac{Y_t}{L_t} \tag{18}$$

$$Z_t = \frac{Y_t - W_t L_t}{K_t} = \alpha A_t (\frac{L_t}{K_t})^{1-\alpha} \tag{19}$$

α is the share of output going to capital. Final goods producers earn zero profits. Exploiting perfect competition, the price of loans and the gross profit per unit of unit of investment are identical in this set up.

3.6 Market Clearing

There are four markets in the model namely, the goods market, the labor market, the securities market and the deposit market. The final output is used for consumption and investment and so the goods market clearing condition or the resource constraint once again is:

$$Y_t = c_t + I_t \tag{20}$$

The security market clearing comes in next. The total amount of securities issued/supplied must be equal to the aggregate capital accumulated and hence the condition is:

$$s_t = (c(\frac{I_t}{K_t})K_t + (1-\delta)K_t) \tag{21}$$

The labor market clearing condition requires that:

$$\frac{u'(l_t)}{u'(c_t)} = \frac{(1-\alpha)Y_t}{L_t} \tag{22}$$

Finally, the deposit market clears by Walras law.

3.7 Timing

At the beginning of the period, the aggregate state of the economy i.e. the TFP shock is realized. The capital quality shock is realized at the end of the current period. In other words, when the bank is making lending decisions it knows A_t but not θ_t. Next the capital quality shock is known and so is the bank's net income which is receipts from assets less deposit costs. If this is positive, the bank pays dividends and proceeds to the next period. If this is not the case, the regulator will set dividends equal to zero and prevent the bank from engaging in valuable lending.

3.8 Discussion: Some Key Features

Before proceeding to the solution methodology, it is useful to discuss a few key elements of the model and clarify concepts. I present a framework within which we can analyze the consequences of introducing a specific type of macroprudential policy (bank capital requirements) on macroeconomic performance and stability.

Modeling macroprudential policy in a DSGE setting is largely work in progress. Like most macroeconomic models, this paper also does not explicitly include the distortion that macroprudential policy should ideally address, namely, systemic risk.[5] This partly reflects the elusive nature of this risk, which impedes a fully rigorous modeling. Indeed, systemic risk can arise and propagate within a given set of financial institutions, across different firms, markets or geographical areas. Because of these difficulties most papers take the presence of the regulator as exogenous and study the effect of its policy on the economy. In this paper, the presence of an exogenous regulator is motivated by the presence of pecuniary externalities that give rise to the financial accelerator mechanism as discussed in subsection (3.3). The bank is not able to internalize the impact of its actions on asset prices and on the real sector. The macroprudential regulator tries to solve this market failure by ensuring that the bank is well capitalized.

In what follows, I show that both higher capital requirements and countercyclical regulation can mitigate the economic downturn. The capital requirement constraint

[5] See Gerali et. al. (2010), Angelini et. al. (2014), Gambacorta and Signoretti (2014) among others.

does not bind in the steady state. The bank holds a small precautionary buffer to prevent the capital constraint from binding in an adverse scenario. This can be justified by the fact that the bank is the sole bearer of risk in this model. The depositors get paid either by the bank or the regulator, in case the bank receives a sufficiently big shock. If the bank is unable to pay its depositors, the regulator sets dividends equal to zero and prevents the bank from making new loans. The bank tries to avoid this situation where it is prevented from engaging in profit making activities. I impose this voluntary buffer to be a constant proportion of the minimum requirements, specifically 1%.[6] Thus, the voluntary buffer is bigger for higher levels of capital requirements. Under the countercylical capital requirement regime, the pecuniary externalities are mitigated owing to the lack of necessity to reduce the demand for assets, rapidly.

4 Numerical Solution: Using The Penalty Function Methodology

In models with occasionally binding constraints, the standard perturbation methods cannot be employed as the policy function is non differentiable in the vicinity of the steady state. Some people may put forward a global solution but due to the curse of dimensionality, this may not be feasible if the state space is rich. As Brzoza-Brzezina et. al. (2013) documents, these methods can be time consuming in small models and impossible in larger models used by central banks. In this paper I use the penalty function approach, originally proposed by Judd (1998). This approach has also been used by Preston and Roca (2007), Kim et. al. (2009), Den Haan and Ocaktan (2009) and more recently by Abo-Zaid (2015).[7] I must highlight the fact that this is one way to solve such dynamic asymmetric models. Besides the global methods, other methods like the OccBin and the endogenous grid point methodology are also available. This is an additional way to solve such models which should be viewed as complementary to the others.

Recently there has been some discussion about the accuracy of the approximations using the penalty function methodology. De Wind (2008) shows that for a simple model with a penalty function, higher order perturbation can be a feasible solution. Brzoza-

[6]This is done only to make sure the constraint does not bind in the steady state. The number 1% of the minimum requirements is simply a thought experiment. One could argue if the voluntary buffer should be directly or inversely proportional to the regulatory requirements but that is a separate policy question which is not the aim of this paper.

[7]More examples are Christiano and Fischer (2000), Mendoza (2010) and Brunnermeier and Sannikov (2011). Preston and Roca (2007) uses an interior function to ensure satisfaction of intertemporal budget constraints and hence in their framework, this interior function (penalty) approaches infinity as the capital holdings of agents approaches the borrowing limit. Kim et. al. (2009) uses a similar method to solve a heterogeneous agent model with aggregate uncertainty. It shows that the model does pretty well to minimize Euler equation errors provided the capital at the beginning of the period is large enough. Den Haan and Ocaktan (2009) also uses this methodology to solve a heterogeneous agent model. Abo-Zaid (2015) applies this method to solve a model with the zero lower bound.

Brzezina et. al. (2013) acknowledges this result but adds that this result does not translate into more sophisticated models. A few points are worth noting here. First, the case considered in Brzoza-Brzezina et. al. (2013) is a specific case i.e. a particular model and a particular form of the penalty function. So it would be unfair to generalize based on one specific example. Second, with regard to this paper, the model presented is relatively small and simple. The general consensus is that this methodology works well for such small models. Third, as I demonstrate later, the model is able to fit the data reasonably well. The optimal level of capital requirement is also comparable to the one being considered currently by policymakers. All of the above factors put together seem to suggest that this method is indeed a reasonable candidate to solve this model.

The idea is simple. I allow anything to be feasible but let the objective function have some unfavorable consequences if the constraint is violated. More precisely, the penalty imposed is zero when the constraint is satisfied and goes to infinity as the constraint is violated. Thus, this model nests the original model. In this way, the original model with inequality constraints can be converted into one that has only equality constraints. Now the standard perturbation methods can be applied to solve this model. There are a few penalty functions in the literature but I use the one presented in De Wind (2008). The primary reason for choosing this functional form is that it is asymmetric and generates a skewed response to shocks as we observe in the data. Always binding constraints and symmetric penalty functions do not generate such a model behavior. Further, the penalty parameter in this specification can be altered easily to change the curvature and without affecting the model properties. The form of the penalty function is as follows:

$$P = \psi^{-2} exp[-\psi((Z_t + (1-\delta)Q_t)\theta_t s_{t-1} - R_t d_{t-1} - D_t - \kappa Q_t s_t)]$$

The term within the parenthesis is the capital buffer. If this term is positive, it means that the bank is adequately capitalized and there is no penalty. The penalty increases once the constraint is violated.

The objective function of the bank is modified as follows:

$$V_t = E_t \textstyle\sum_{i=0}^{\infty} \Lambda_{t+i}[D_{t+i} - \frac{d_{t+i-1}}{\psi^2} exp[\frac{\psi}{d_{t+i-1}}(\kappa Q_{t+i}s_{t+i} + D_{t+i}$$

$$-(Z_{t+i} + (1-\delta)Q_{t+i})\theta_{t+i}s_{t+i-1} + R_{t+i}d_{t+i-1})]]$$

where the penalty function is normalized to preserve the constant returns structure.

Once the penalty function is incorporated in the objective function, there is no need to write the capital requirement constraint separately while solving the problem. The parameter ψ governs the curvature of the penalty function. Solving the above modified objective function subject to the budget constraint for the bank yields expressions similar to the ones obtained earlier:

$$E_t[\Lambda_{t,t+1}(\lambda_{t+1} + \Omega_{t+1})R^e_{t+1}] = \kappa\lambda_t + \Omega_t$$

$$E_t[\Lambda_{t,t+1}(\lambda_{t+1} + \Omega_{t+1})R_{t+1}] = \Omega_t$$

$$R^e_{t+1} = \theta_{t+1}\frac{Z_{t+1}+(1-\delta)Q_{t+1}}{Q_t}$$

$$\lambda_t + \Omega_t = 1$$

$$\text{and, } \lambda_t = \frac{1}{\psi}exp[\frac{\psi}{d_{t-1}}(\kappa Q_t s_t + D_t - (Z_t + (1-\delta)Q_t)\theta_t s_{t-1} + (R_t d_{t-1})]$$

λ_t is the punishment term. It is the shadow valuation of violating the constraint. It is also the derivative of the penalty function with respect to the capital buffer.

Some important issues need to be discussed regarding the incorporation of a non linear punishment function. The penalty function is highly non linear and so we might be tempted to put in a lot of curvature by choosing a high value of ψ. However, typically we are restricted to lower order perturbations and so putting in a lot of curvature might not be the best idea. In this paper, I solve the model using a third order approximation. The choice of the order of approximation is also straightforward. A first order approximation is immediately ruled out given the non linearity of the problem. The third order is chosen to capture the asymmetric nature of the problem. The standard deviation of the shocks are expected to affect all the terms in the policy function and not just the constant.

Figure (B.4), in the appendix, demonstrates the class of penalty functions as the amount of curvature is changed. On the horizontal axis, I plot the level of buffers from negative 5% (equivalent to bank holding 3% capital) to positive 2% (equivalent to bank holding 10% capital). On the verical axis, I plot the penalty imposed for different levels of curvature, as a function of buffers. One can think of these as the excess returns on assets which would prompt rapid deleveraging as explained earlier.[8] For $\psi = 130$, the bank gets the most severe penalty, corresponding to an excess returns of about 4% while the reverse is true for $\psi = 50$. Figure (B.4) shows that the greater the curvature the closer is penalty model to the original model. It has to be ensured that the constraint does not bind in the vicinity of the steady state and so the penalty function has to be relatively flat in this region (slope should be small near the steady state). However, a flat penalty function means that the steady state is farther away from the steep part of the function and in that case, given the magnitude of the shock, one might not get the desired asymmetry. I chose the value of ψ keeping these issues in mind and also to match the skewness of some key macroeconomic variables in the data. I use the value of ψ that helps me match the skewness with respect to investment, output and capital buffer ($\psi = 110$). The skewness results are shown in table (A.1), in the appendix.

5 Calibration

Table (A.2) in the appendix lists the values of the parameters. Most of the parameters are standard. The discount factor, β, was chosen to get an annualized risk-free return of

[8] Also see Aiyagari and Gertler (1999)

4%, the value of κ is set at 8% and depriciation is set to be 10% annually. The disutility of labor was calibrated to get a steady state labor supply of 0.3. Labor supply elasticity is set at two. The two shocks in the model are the TFP shock and the capital quality shock/financial shock. They follow independent Markov processes as follows:

$$lnA_t = (1-\rho_A)lnA + \rho_A lnA_{t-1} + u_t$$

$$ln\theta_t = (1-\rho_\theta)ln\theta + \rho_\theta ln\theta_{t-1} + v_t$$

The TFP shock has more persistence and less volatility than the financial shock. The AR(1) coefficient and the standard deviation of this shock is in line with the standard business cycle literature being 0.9 and 0.01 respectively. Estimates of Solow residuals yield a highly persistent AR(1) process in levels. The standard deviation replicates US postwar quarterly output growth volatility. The calibration of the financial shock follows Gertler and Karadi (2011). The persistence of this shock is 0.75 and it has a standard deviation of 5%. The target is to get a ten percent decline in effective capital stock over eight quarters, investment remaining roughly same. Next we turn to the parameters of the utility function. Following standard business cycle literature, the inverse of the intertemporal elasticity of substitution, ϕ, is set equal to 2.0. The values of the share parameter, a, and the elasticity of substitution between consumption and deposits, b, are chosen to yield a deposit to consumption ratio of 0.7, a number that is consistent with the US data.

The capital goods production function is a concave and increasing function that satisfies c(δ)=δ and c'(δ)=1. The only parameter that is of importance here is the curvature of this function or how sensitive is the investment capital ratio to the price of capital, (a_1). The value of this parameter is taken from the extensive literature on Q theory. Christiano and Fischer (1998), Jermann (1998), and Boldrin et. al. (2001) use a value of 0.23 for this parameter. The other two parameters are chosen to make the steady state independent of a_1.

6 Countercyclical Capital Requirements

Capital regulations provide structural stability to the financial system which in turn makes the economy more resilient to adverse shocks. However, the question that arises is what form of prudential regulation is the best one? The Basel Committee on Banking Supervision has laid out a set of core principles popularly referred to as Basel I, II, and III. Basel I and II mainly differ in the manner in which risk weights on assets are calculated but they do not propose implementing countercyclical capital requirements. In the aftermath of the financial crisis, a consensus has emerged that we need to implement regulation keeping in mind the entire financial system, as opposed to a single entity i.e. policies that are macroprudential in nature. One such policy is implementing countercyclical capital requirements for banks. This is one of the main tenets of the

Basel III guidelines. In this section, I modify the model to incorporate time varying capital requirements and study the implications for the model economy.

Without proceeding further, a discussion of the procyclicality issue is required because it is precisely this problem that we are trying to mitigate. In the event of an economic downturn, the credit risk materialization is high and loan recovery rates are low. In such a situation the bank capital shrinks, sometimes, to the extent that the bank finds it difficult to remain solvent. The adjustment in the capital asset ratio could come from the numerator or the denominator. However, since it is difficult to raise fresh equity in times of financial distress, banks will have to deleverage to boost the capital asset ratio. This brings about a credit crunch and exacerbates the already existing problem. I now demonstrate how the model can be used to analyze countercyclical capital requirements, to deal with the procyclicality problem.

The bank's problem is modified so that the capital requirement is time varying and countercyclical in nature. Essentially, I allow κ to vary with time and this is governed by the following equations. The capital requirement constraint can be written as:

$$[(Z_t + (1-\delta)Q_t)\theta_t s_{t-1} - R_t d_{t-1}] - D_t - \kappa_t Q_t s_t > 0$$

where κ_t evolves as follows,

$$\kappa_t = (1-\rho_\kappa)\overline{\kappa} + (1-\rho_\kappa)\Lambda_\kappa(logY_t - logY_{t-1}) + \rho_\kappa \kappa_{t-1} \tag{23}$$

If Λ_κ is positive, this means that the capital requirements are countercyclical. In good times, the banks will have to hold more capital while in downturns these requirements are relaxed. This should help us mitigate the procyclicality problem. The bank does not have to deleverage rapidly if the capital requirements are gradually reduced when the economic situation is adverse.

The exact calibration of the law of motion of the capital requirement is very much work in progress. I perform two thought experiments and try to simulate the path of the economy in response to a negative financial/capital quality shock. The benchmark is the model with flat capital requirements with $\kappa = 0.08$. I consider a mildly countercyclical policy and an aggressive countercyclical policy. The first regime corresponds to a decline in capital requirements from 8% to 7.5% over six quarters after the financial shock. The second regime corresponds to the more aggressive countercyclical capital requirement regime with κ declining from 8% to 6% over six quarters.[9]

7 Numerical Results

In this section, I discuss the results of the numerical solution. The tables are in appendix A while the figures can be found in appendix B.

[9] $\Lambda_\kappa = 10.5$ corresponds to the first case while $\Lambda_\kappa = 41.8$ corresponds to the latter.

7.1 Exploring the Asymmetry in the Model

As mentioned previously, the penalty structure in the model is asymmetric and non linear. It might be helpful to look at the differential behavior of the model in response to an equal magnitude positive and negative financial shock. The results are presented in figure (B.5). The bank in the model holds a capital buffer of about 1% in the steady state. As is evident from the figure, the response to a positive shock is much subdued. In contrast, when the negative shock hits, the capital buffer shrinks and the bank hinges towards the minimum requirements. At this stage the penalty term becomes different from zero. The excess returns rise above the fundamental value and this leads to a decline in asset prices and investment. In turn, output and consumption decline as well. Exactly the opposite happens if the economy is hit by a positive shock. However, the response is much dampened as the bank is accumulating capital, penalty is close to zero, there is credit available to undertake investment, asset prices are high and the output and consumption situation are also robust. Figure (B.5) replicates a key feature of the economy in general which is that recessions tend to be sharper than booms and the skewness figures presented in the appendix, lend credence to this fact. This is one key feature absent in standard RBC models. However, we should be studying such models with asymmetries especially when exploring important policy questions.

7.2 Changing the Capital Requirement

Figure (B.6) plots the impulse response, of the key real variables in the model, to the financial shock. The model was solved for three different levels of capital requirements i.e. 8, 10 and 16%. Higher capital means that banks have more resources to absorb shocks and lower leverage. The banks with lower capital are the ones that are highly levered and the impact of an economic downturn, on these banks, is much greater than their well capitalized counterparts. The solution methodology assumes that the bank holds a voluntary buffer in the steady state. I impose this buffer to be 1% of the minimum requirements. Figure (B.6) shows that as capital requirements increase, the fluctuations in the macro variables are reduced. The intuition for this result is that the bank is much well equipped to handle a downturn under 16% capital requirements because the size of the buffer is also larger, magnitude of the shock remaining the same.

7.3 Time Varying Capital Requirements

Figure (B.7) plots the evolution of the same macro variables under three different capital requirement regimes. The black line is the model with flat capital requirements, the red line is the model with mildly countercyclical capital requirements while the blue line is the model with strongly countercyclical capital requirements. Clearly the models with time varying requirements generate less volatility than the benchmark model with flat requirements. The intuition is straightforward. If the banks do not have to meet stricter capital standards during a downturn, they will not have to deleverage rapidly.

This can help mitigate the credit crunch problem. The banking sector will continue lending and financing investment. After the financial crisis, a consensus has emerged that there is need to shift to such macroprudential policies. My model makes a similar policy recommendation. After having looked at the volatility implications of higher and time varying capital requirements, I now move on to the welfare implications of such policies.

8 Welfare Implications

It has been mentioned in the literature that the introduction of capital requirements might lead to a loss in welfare because it constrains the ability of banks to make loans by creating deposit type liabilities. There might also be gains from imposing such requirements as they provide stability to the financial system. In the model, households value bank deposits. Deleveraging pressures on banks lead to a reduction in lending, decline in retail deposits and thereby welfare. On the other hand, capital requirements reduce volatility in the real variables. Given that the model is solved using a third order approximation, a reduction in output and consumption volatility can lead to an increase in household welfare. This higher order approximation of the policy functions is essential to capture the impact of the capital quality shock on both first and second moments of the real variables.

The welfare analysis is done separately for the two different regimes of regulation. More precisely, I ask two main questions in this section: (i) Given that we operate under flat capital requirements, can we improve social welfare by having higher levels of such requirements? (ii) Comparing flat capital regulations to Basel III type countercyclical capital regulations, which regime gives rise to higher welfare?[10] Following Faia and Monacelli (2007), the objective is the utility function of the representative household which can be written recursively as follows:

$$W_{0,t} = U(c_t, d_t, l_t) + \beta E_t \left\{ W_{0,t+1} \right\} \tag{24}$$

Table (A.4) reports the stochastic steady state numbers of consumption and welfare under the flat capital requirement regime. The thought experiment here is as follows. I simulated the model separately for three different levels of capital requirement, namely 8, 10 and 16%, conditional on the capital quality shock occurring.[11]. We are interested in knowing what is the welfare gain/loss from operating at 16% instead of 8%? To report the welfare in consumption equivalent terms, I compute what amount of additional consumption (ΔC), in a world with $\kappa = 8\%$ or $\kappa = 10\%$, would generate the same steady state welfare as the case with $\kappa = 16\%$. We see that there can be net

[10]This exercise is however aimed to be qualitative at this stage as we would need to know the exact law of motion of the countercyclical capital requirements to be able to conduct a fully rigorous welfare evaluation. However, this information is confidential at this point and is indeed a topic of ongoing research.

[11]Refer the calibration section for a characterization of this shock.

gains from implementing higher capital requirements. In other words, the reduction in consumption volatility seems to outweigh the effect of the reduction in retail deposits. The reader should bear in mind that I am only analyzing the respective steady state welfare under three different levels of κ. I do not consider transitions between them first because that is not what the current policy guidelines state and second, such an analysis is much more meaningful under countercyclical capital requirements which is as follows.

How do the welfare figures look like if we transition to a world with countercyclical capital requirements, in line with one of the main tenets of Basel III? The simulations in this case are different from the previous ones in that now following the occurrence of the capital shock, the capital requirements are also lowered.[12] These welfare simulations also consider the transitions from the intial higher to the final lower level of capital requirements. The results are presented in table (A.5). It can be seen that the welfare is higher under the countercylical scheme than under the fixed capital requirements. In fact the strongly countercyclical regime generates a gain which is equivalent to about 0.27% of annual consumption. These numbers are non-trivial when compared to the welfare cost of business cycles. The intuition for this result is simply that a reduction in capital requirements, following an adverse shock, causes the regulatory constraint to be slack and the bank does not have to reduce assets rapidly. This in turn mitigates the economic downturn.

Following this exercise, two questions may arise. First, do the benefits of capital requirements always outweigh the costs? Second, what is the rationale behind the choice of $\kappa = 16\%$ as a desired level of capital requirement? The model was simulated under different levels of κ to find the optimal level of capital requirement. Table (A.6) reports the mean welfare from a 1000 period simulation of the model economy, conditional on the capital quality shock occurring. The welfare is maximized at 16% or in other words $\kappa = 16\%$ is the optimal level of capital requirement in this model economy. Thereafter, the costs seem to outweigh the benefits as welfare declines. It must be noted that this number is quite close to the current Basel III guidelines. The current regulations require banks to hold 8% total capital plus an additional 2.5% capital conservation buffer plus an additional 2.5% countercyclical buffer. This adds up to 13%. There could also be an additional surcharge on systemically important financial institutions. Thereby the model predictions do seem to be in line with the current set of regulations.

9 Conclusion

This paper presents a model to analyze macroprudential policy in a world of occasionally binding capital constraints. I show that higher capital requirements can help banks absorb shocks better. Effect on welfare is a strong point of criticism against higher

[12]A mild countercyclical policy entails a decline in capital requirements from 8% to 7.5% over six quarters after the shock while an aggressive countercyclical policy would reduce κ from 8% to 6% over six quarters.

capital requirements. Based on this analysis, I propose that we might be operating in a suboptimal world with low regulatory requirements. I show that there can be welfare gains from implementing higher capital requirements. I also modify the model to analyze countercyclical capital requirements. Such requirements do make the economy resilient to downturns and in terms of welfare, the society is much better off than under the time invariant policies. Based on my welfare analysis, I also derive the optimal level of capital requirement which is in line with the current policy guidelines.

A lot of research is currently being undertaken to understand the impact of macro-prudential regulation both from a theoretical and empirical perspective. In my opinion, one of the more important issues that needs to be addressed is the optimal timing in implementing the countercyclical capital requirements. If capital requirements are raised too rapidly in booms, we might hamper growth. If they are reduced too rapidly in downturns, banks might lower lending standards and accumulate more non performing assets on their balance sheets. This would lead to more defaults. So what should be the optimal design of such prudential regulations? I believe more research along these lines is essential, especially at this time when the Basel III guidelines are being phased in.

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A Tables

Table 1: Skewess: Model Vs. Data

	Investment	**Output**	**Cap. Buffer**
Data	-0.8462	-0.0054	-0.4782
Model	-0.7556	-0.0035	-0.5112

Table 2: Calibration

Parameter	**Symbol**	**Value**
Discount Rate	β	0.99
Capital Requirement	κ	0.08
TFP shock persistence	ρ_A	0.90
Volatility of TFP shock	σ_u	0.01
Depreciation	δ	0.025
Penalty parameter	ψ	110
Share of Capital	α	0.33
Risk Aversion	ϕ	1.5
Mean of TFP	$\overline{A}$	1.00
Disutility of labor	χ	10.36
Inverse of Frisch Elasticity of labor supply	φ	0.5
Utility fn. share parameter	a	0.95
Intratemporal el. of Substitution	$1/b$	0.39
Persistence of Financial shock	ρ_θ	0.75
Volatility of Financial shock	σ_θ	0.05
Capital pdn. fn. Parameter	a_1	0.23

Table 3: Business Cycle Statistics

	Output		Consumption		Investment	
	Data	Model	Data	Model	Data	Model
Standard Deviations	0.0115	0.0162	0.0056	0.0060	0.0419	0.0331
1st order autocorrelations	0.88	0.90	0.83	0.91	0.87	0.66
Correlation with output	1.00	1.00	0.88	0.93	0.91	0.95

Table 4: Welfare: Flat Capital Requirements

Variable	$\kappa = 0.08$	$\kappa = 0.10$	$\kappa = 0.16$
Consumption	0.4382	0.4385	0.4386
Welfare	22.61	23.05	23.26
Welfare Decline (in cons. terms)	–	**0.27** %	**0.36** %

Note: The numbers in the third row represent annual gain in permanent consumption by increasing the capital requirements.

Table 5: Welfare: Countercyclical Capital Requirements

Variable	Flat κ	Mild cc κ	Strong cc κ
Consumption	0.4382	0.4383	0.4385
Welfare	22.61	22.71	23.05
Welfare Gain (in cons. terms)	−−	**0.09%**	**0.27%**

Note: The numbers in the third row represent annual gain in permanent consumption by moving to a regime with countercyclical capital requirements.

Table 6: Optimal Capital Requirement

	$\kappa = 8$	$\kappa = 10$	$\kappa = 12$	$\kappa = 14$	kappa=16	$\kappa = 18$
Welfare	21.38	21.40	21.42	21.43	21.44	21.42
% change	–	0.0936	0.0935	0.0466	0.0466	-0.0933

Note: Table reports the mean welfare over a 1000 period simulation of the model.

B Figures

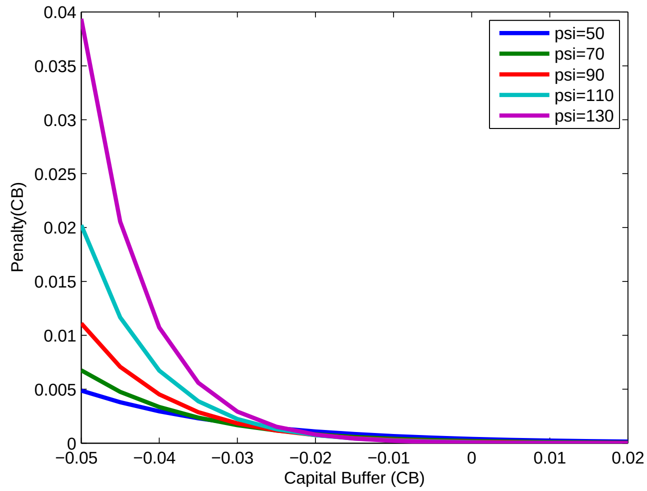

Figure 4: Penalty function for different levels of curvature

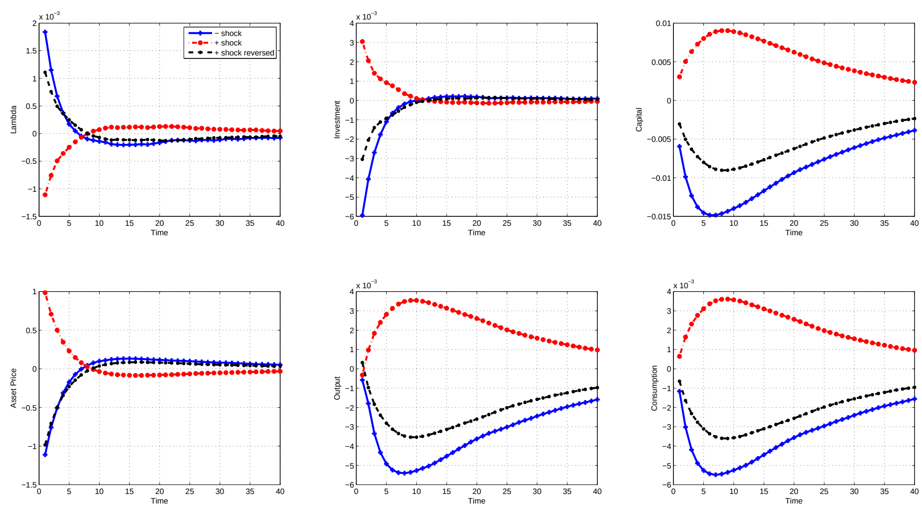

Figure 5: Asymmetric response to a unit financial shock

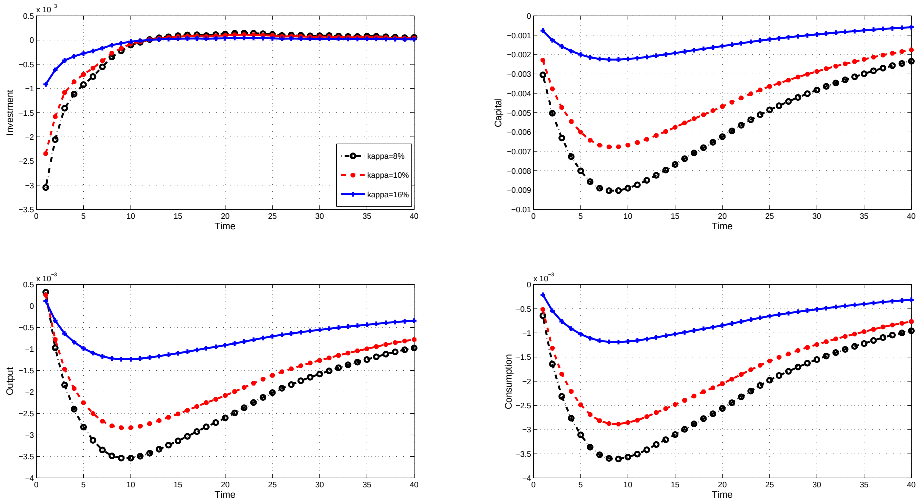

Figure 6: Altering the capital requirement

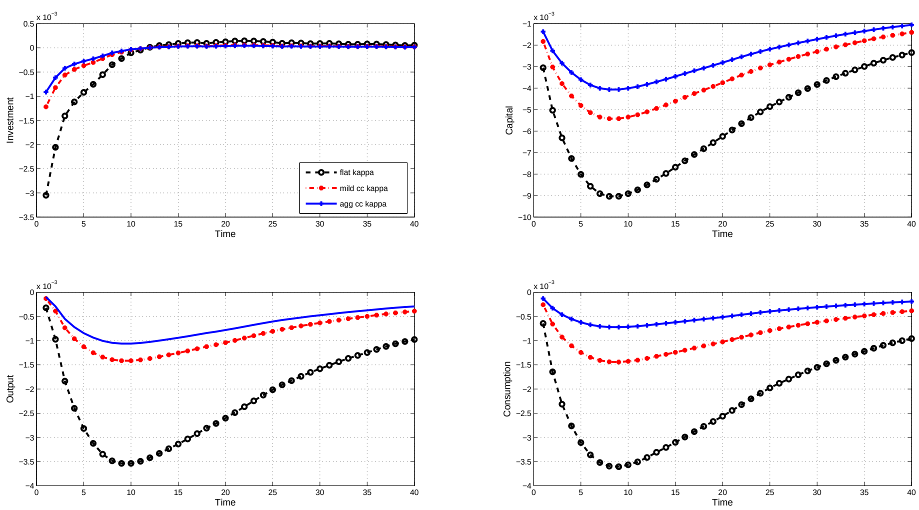

Figure 7: Flat vs countercyclical capital requirements