

MONETARY POLICY AND ANTI-CYCLICAL BANK CAPITAL REGULATION

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The financial crisis of 2008–2009 revived attention given to booms and busts in bank credit, and their effects on real activity. This interest sparked two different strands of research in macro. The first one focuses on monetary policy in the context of financial frictions. The second studies capital regulation in banking. To the best of our knowledge, so far these two topics have mostly been studied in isolation from each other. Thus, we still lack an understanding of how monetary policy and bank capital regulation interact in the presence of financial fragility. This paper aims to contribute to furthering this understanding. Specifically, we ask how the monetary policy rule should look like in the presence of cyclical capital requirements. We extend the dynamic stochastic general equilibrium model with bank capital in Aliaga-Díaz and Olivero by introducing price rigidities in the spirit of the New-Keynesian literature. We find that: First, anticyclical requirements have important stabilization properties relative to the case of constant requirements. This is true for all types of fluctuations that we study, which include those caused by productivity, preference, fiscal, monetary, and financial shocks. Second, output and consumption volatilities present in the no regulation economy can be recovered with anti-cyclical requirements as long as the policy rate responds only slightly to credit spreads. Third, monetary policy rules that respond to credit conditions also perform better in terms of welfare. (JEL E32, E44)

I. INTRODUCTION

The financial crisis of 2008–2009 directed *policy* makers' attention towards frictions in credit markets causing boom and bust credit cycles and creating a financial accelerator that amplified the real effects of the crisis on output and consumption. It has been frequently argued that bank capital requirements can act as destabilizers. In an attempt to address these

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concerns, Basel III introduced a capital buffer to be built up in good times and reduced in downturns to potentially maintain lending and help to alleviate recessions. Frictions in banking working to exacerbate the effects of shocks have also been a recurrent theme in the academic literature. This work studies how in economic downturns banks' non-performing loans will rise so that, even in the absence of regulations, banks may choose to raise new capital or reduce their lending to ensure their costs of funds do not rise and their solvency is not put at risk. If groups of banks attempt to recapitalize at the same time, recapitalization may become expensive or may simply not be possible. If so, a reduction in bank credit will occur, exacerbating the economic downturn. In such a context, the imposition of capital and provisioning requirements may amplify these effects and thus have

ABBREVIATION

DSGE: Dynamic Stochastic General Equilibrium GDP: Gross Domestic Product RBC: Real Business Cycle TFP: Total Factor Productivity further consequences for the rest of the economy. This is especially true if the reduction in bank credit effectively impacts labor hiring, investment, and production for bank-dependent firms who find it costly to switch to other sources of external finance.

Equity regulation has been studied quite extensively but mostly in the context of the real business cycle (RBC) literature with perfectly flexible prices and thus, no role for monetary policy. As a result, the literature still lacks an understanding of how monetary policy and bank capital regulation interact with each other in the presence of both real and financial shocks to either induce further procyclicality in credit markets or to help attenuate it. This paper aims to contribute at furthering this understanding.

To do so we extend the model in Aliaga-Díaz and Olivero (2012) in two ways: first, by introducing price rigidities in the spirit of the New-Keynesian literature, and second, by allowing for time-varying capital requirements. The model structure then becomes well suited to studying this interaction between time-varying (cyclical) capital regulation and monetary policy, which, with just one exception, has been mostly neglected by the literature.

We use the model to address the role of cyclical bank capital regulations in the transmission of a wide set of aggregate shocks including supplyside (productivity) shocks, financial shocks to the demand for credit, and demand-side shocks to preferences, government absorption, and the stance of monetary policy.

From our general equilibrium analysis we find that, when constant, bank capital requirements induce a financial accelerator originating from the supply-side of credit markets. In other words, in the presence of adverse aggregate shocks, key macroeconomic variables are more negatively affected than in a no regulation environment.¹

This result supports why policy has made the case for anti-cyclical capital requirements, such that in good times banks are required to hold a higher minimum capital-to-assets ratio, building a buffer of capital. This buffer is then available during bad times, and allowed to be reduced to potentially avoid curtailing lending and generating a credit crunch. Thus, anti-cyclical requirements may be used to partially offset the effects of aggregate shocks on bank-dependent borrowers.

We find that indeed, anti-cyclical requirements reduce volatility and the response of economic activity to aggregate shocks. These results are sensitive to the size of the buffers of capital that banks hold above minimum requirements. In particular, the impact of introducing an anticyclical rule based on total capital is significantly reduced when calibrating the model so that in equilibrium banks hold a large buffer of capital. The explanation is the following: due to a precautionary savings motive for banks, banks' optimal response to a capital requirement is to accumulate capital in excess of the minimum required as a buffer against future shocks. Depending on the parameters of the model, banks will maintain a sizable capital buffer in the stochastic steady state. When an anti-cyclical rule is introduced, banks will anticipate capital requirements falling in economic downturns. This may reduce the optimal buffer held by banks above the requirements and the effect of anti-cyclical capital rules may be stronger than if banks' desired buffer holdings did not respond to the change in regulatory design. The effects of anti-cyclical rules are found to be strongest when the parameters of the model are such that the optimal buffer held by banks above requirements is fairly small.

We also look for the type of monetary policy that would potentially allow central banks to offset the accelerator properties of capital regulation. We find that the output and consumption volatilities present in the no regulation economy can be recovered with anti-cyclical requirements as long as monetary policy makes the interest rate respond only slightly to credit spreads. We also find that this stabilization property of the Taylor rule is not present when the policy rate responds to the volume of credit (regardless of how aggressive the response). Designing monetary policy to respond to credit conditions allows the economy to enjoy the benefits of a sounder and more highly capitalized banking sector, without the undesired macroeconomic repercussions of increased volatility. The best of both worlds seems to be possible once monetary policy pays attention to developments in credit markets. Our welfare analysis also concludes that welfare increases when interest rates respond to spreads.

^{1.} The intuition is that after an adverse aggregate shock, bank profitability declines, bank equity decreases, and banks must cut back on the supply of credit to be able to meet the minimum capital-to-assets ratio imposed by the regulation. Since, by assumption, bank-dependent firms find it costly to switch to other financing mechanisms, this indirect effect of the shock, working through the supply of bank credit, amplifies the direct effect on the demand for credit, investment, and production. Hence, standard constant capital requirements amplify the volatility of macroeconomic variables.

We should make certain caveats regarding these results. First, we assume that banks behave optimally and maintain buffers over capital requirements to diminish the probability that they hit the requirement. We rule out what might be labeled as strategic behavior; for example the case of a bank speculating that the regulator may forebear or even reduce requirements in the case of bank capital falling below the required capital levels. Second, we focus on average capital holdings. As large banks typically have lower buffers than others (which makes amplification more likely), and as they have a larger weight in the aggregate supply of credit, we are then likely to be underestimating the stabilization effects of anti-cyclical rules.

Following this introduction, the structure of the paper is as follows. The literature is reviewed in Section II. The model is presented in Section III. Section IV discusses the calibration of the model to the United States and the numerical solution method. Section V includes a discussion of three sets of results: (a) impulse responses, (b) model simulations with alternative assumptions regarding the strength of the anti-cyclical requirements and the shape of the policy rule followed by the monetary authority, and (c) welfare calculations. In this section we discuss what type of interest rate policy rules working in conjunction with anti-cyclical requirements allow for the economy to essentially recover the volatility observed in a no regulation environment, and to achieve the highest possible welfare (among all the rules considered). Section VI concludes.

II. LITERATURE REVIEW

Our work is closely related to the large body of literature on what can be broadly labeled the "bank capital channel."

A paper close to ours in the sense that it shares the advantage of using the model with price rigidities to study capital regulation in conjunction with monetary policy is Meh and Moran (2010). Their results are similar to ours, that is, (1) bank capital significantly amplifies and propagates the effects of productivity shocks, not so much those of monetary shocks, and (2) shocks to bank capital itself create large declines in output and investment. However, they do not allow the interest rate rule to respond to any targets other than the output gap and inflation, like financial targets as in our case. Introducing these additional arguments in the policy rule is important since it addresses the question of which type of interest rate rule is more desirable in the face of existing capital adequacy regulations that can potentially induce an undesirable credit crunch, but that are still needed from a banking regulation standpoint. Also, highly related to our work is Angeloni and Faia (2013) who also study the interaction between capital regulation and monetary policy. However, their focus is on risky banks subject to bank runs and they do not consider either financial or preference shocks as we do. Also, they allow the interest rate rule to respond to asset prices or bank leverage, but not to the volume of credit or spreads as in our case.

Aikman and Paustian (2009) also provide a model with bank capital but do not focus on the cyclicality of the regulation. Van den Heuvel (2008) and Aliaga-Díaz and Olivero (2010) are similar to ours in the sense that the presence of bank capital is imposed onto the model and motivated by regulatory requirements. However, none of these allow the regulation to change over the cycle as in Basel III. Also, Aliaga-Díaz and Olivero (2010) features no nominal rigidities and is therefore limited to the study of supply-side productivity shocks only.

Gertler and Kiyotaki (2010) build a model in which banks are subject to idiosyncratic liquidity risk so that an interbank market appears endogenously to allow banks with an excess demand for funds to borrow from those with an excess supply. The reason why banks hold capital arises endogenously from an agency problem according to which the banker managing each bank may "walk away" with a fraction of the bank's assets. Boccola (2014) models this same friction that gives rise to bank capital holdings and extends it by introducing government bond holdings by banks. He uses the model to study the passthrough of sovereign risk from the government to the banking sector and production. However, neither Gertler and Kiyotaki (2010) nor Boccola (2014) study the implications of making requirements cyclical. Also, since their models do not feature nominal rigidities, they cannot be used to study the interaction between bank capital regulation and monetary policy.

Repullo and Suárez (2008) is closely related to our work in that they do allow banks to hold buffers of capital. However, since the demand for credit and production are both exogenous, they cannot use this framework to study the general equilibrium effects of aggregate shocks. Also, even though they do look at requirements that are a function of the economy's state of nature, they allow for just two potential values of the required ratio.²

Covas and Fujita (2010) develop a dynamic stochastic general equilibrium (DSGE) model to study the effects of procyclical capital requirements in a model in which liquidity provision is the main function of banks. They conclude that regulation amplifies fluctuations only slightly, but that this effect is stronger around business cycle peaks and troughs. Since their framework is one of flexible prices, they do not study the interaction between monetary policy and capital regulations.

The open economy macro literature has also explored the role of bank capital in the international propagation of shocks. Some of the references in this line of work are Kollmann, Enders, and Muller (2011), Guerrieri, Iacoviello, and Minetti (2012), and Kalemli-Ozcan, Papaioannou, and Perri (2011).

Lastly, another strand of the literature in macroeconomics does introduce price rigidities in a New-Keynesian fashion, and does study the interaction between financial factors and monetary policy. However, it does so while disregarding the role of bank capital. Some of the papers in this strand are Curdia and Woodford (2010), Airaudo and Olivero (2016), Gilchrist, Sim, and Zakrajsek (2014), and García-Cicco and Kawamura (2014), among many others. An extensive review of the work on New-Keynesian models extended with credit frictions is beyond our current scope. Here we just intend to underscore the fact that this literature has mostly disregarded the role of bank capital.

III. THE MODEL

In this paper, we take from Aliaga-Díaz and Olivero (2012) their DSGE model with a banking sector that provides loans to firms, and extend it in two ways. First and to be able to study monetary policy, we introduce price stickiness in the spirit of the New-Keynesian literature. Second, we allow for bank capital requirements to be cyclical and dependent on the state of the economy. More specifically, requirements are increased during periods of economic growth and reduced during economic downturns. These two extensions together allow us to study which type of interest rate rule is desirable in the face of existing capital adequacy regulations that can potentially induce an undesirable credit crunch.

Our framework introduces various sources of uncertainty, and the economy is subject to productivity, financial, fiscal, and monetary policy and preference shocks.

The economy consists of five different sectors: households, the government, non-financial firms (both manufacturers and retailers), and financial firms, which we choose to call "banks" since they are subject to capital requirements à la Basel III. We describe each of these sectors in detail in subsections III.A to III.E. Since it is the banking sector where we introduce new frictions, we present the banks' problem first.

A. Banks

Banks are perfectly competitive. They choose their optimal dividend payout policy (Δ_t) and retention of earnings for equity build-up purposes (RE_t) to maximize the present value of the expected stream of dividend payments to their owners, the households, discounted at their intertemporal marginal rate of substitution. The choice of Δ_t and RE_t pins down the optimal plans for equity (e_{t+1}), demand deposits (D_{t+1}), and bank loans (L_{t+1}).

Banks are subject to a corporate income tax with tax rate τ_1 . Interest payments on deposits are tax-exempt, which determines a tax-advantage of using debt rather than equity to finance loans, and makes bank deposits cheaper than equity. Profit maximizing banks balance this benefit of deposits against the cost of violating the capital regulation when using more deposits and less equity. The introduction of this tax guarantees that the bank problem is stationary and that the financial structure does not drift towards an all-equity financing steady state (see Aiyagari and Gertler 1998).³

Since by assumption the only source of financing for firms in the manufacturing sector is bank lending, banks are these firms' only claim holder, and thus they earn the firms' profits (V^M) .

It is worth pointing out that our "banks" are really bank capitalists, that is, bankers that maximize the total discounted proceeds of their equity. In other words, we do not have bank managers performing other functions like monitoring, provision of liquidity insurance, etc.

^{2.} Estrella (2004), Repullo (2004), Peura and Keppo (2006), and Zhu (2008) are other papers that share some features with Repullo and Suárez (2008).

^{3.} In some related work (see, e.g., Kilponen and Milne 2007) the Modigliani-Miller theorem holds for the target level of capital, that is, at the margin banks are indifferent between debt and equity financing. This is not the case in our model.

Macro-Prudential Regulation. Here banks are subject to a capital requirement according to which at least a fraction γ of their loans has to be financed with their own equity as specified in Equation (1). Furthermore, this requirement is of the Basel III-type regulation, for which the spirit is "to ensure that the banking sector in aggregate has the capital on hand to help maintain the flow of credit in the economy without its solvency being questioned when the broader financial system experiences stress after a period of excess credit growth..." (Basel Committee on Banking Supervision 2009).

To capture this spirit in the model we allow for capital requirements to vary over the cycle, and we follow de Resende et al. (2016) by specifying the requirements as a function of the economy's credit conditions. Thus, the fraction γ is timevarying, and specified as a function of an index of credit conditions (CC) as in Equation (2). Credit conditions are in turn defined as a weighted average of the deviations from steady state of aggregate output (\tilde{Y}) and aggregate loans (\tilde{L}) as in Equation (3).⁴

This regulation is introduced in Equations (1)-(3):

(1)
$$e_{t+1} \ge \gamma_t L_{t+1}$$

(2)

$$\ln\left(\frac{\gamma_t}{\overline{\gamma}}\right) = \psi_1 \ln\left(\frac{\gamma_{t-1}}{\overline{\gamma}}\right) + (1 - \psi_1) \psi_2 CC_t$$

(3)
$$\operatorname{CC}_{t} = \eta \left(\widetilde{Y}_{t} - \widetilde{Y} \right) + (1 - \eta) \left(\widetilde{L}_{t+1} - \widetilde{L} \right)$$

where a tilde is used to denote aggregate quantities not internalized by each individual bank when optimizing over profits, and $(\widetilde{X}_t - \widetilde{X})$ denotes deviations of any aggregate variable \widetilde{X}_t from its steady state value (\widetilde{X}) .

Banks are also subject to a non-negativity constraint on dividends since; otherwise, they could post negative returns which would be equivalent to issuing new equity. This would allow them to undo the regulatory constraint. Therefore, the constraint reads:

(4)
$$\Delta_t \ge 0.$$

Last, banks earn an exogenous benefit of holding equity $\phi(e_{t+1})$ with $\phi' > 0$ and $\phi'' > 0$. This introduces concavity to the banks' objective (profit) function, which plays an important role in pinning down the composition of the banks' portfolio even in the case of non-binding regulatory capital constraint.

Taking all this into account, the optimization problem for the representative bank becomes:

(5)
$$\max_{L_{t+1}, D_{t+1}, e_{t+1}} E_0 \sum_{\substack{t=0\\\text{s.t.}}}^{\infty} \beta^t \mathcal{F}_{0, t} \Delta_t$$

(6)
$$\left(\Delta_t + \operatorname{RE}_t\right) = \Theta_t (1 - \tau) \left(i_t^L L_t - r_t D_t\right) + \Phi\left(e_{t+1}\right) + V_t^M$$

(7)
$$\operatorname{RE}_{t} = \left(e_{t+1} - e_{t}\right)$$

where $\mathscr{F}_{0,t} \equiv \beta^H \frac{U_{C,t}}{U_{C,0}} \frac{P_0}{P_t}$ is the representative household's stochastic discount factor, and Equation (6) is the cash flow equation. Notice that in Equation (6) profits are affected ex-post by a time-varying factor θ_t , intended to capture in a reduced form the effect of borrowers' default on bank profits. The process followed by θ is explained in more detail in the calibration section.⁵

As in Peek and Rosengren (1995), Aiyagari and Gertler (1998), Gertler and Kiyotaki (2010), Meh and Moran (2010), Aliaga-Díaz and Olivero (2011), and Gertler and Karadi (2011) among others, here banks are not allowed to issue new equity, but they can retain earnings to accumulate equity according to Equation (7). Notice that the bank's optimal choice of retained earnings in each period still allows for cyclical dynamics of equity that are not just governed by the initial buffer. Banks can always retain earnings to accumulate equity over time. If banks could issue "new" equity, they would be able to completely and instantaneously (within a quarter) undo the effects of the regulation. Specifically, when a negative aggregate shock hits the economy reducing equity below the required minimum and making the constraint binding, banks could automatically

^{4.} An alternative definition for the index of credit conditions more closely resembling what is contemplated by the regulation is the credit-to-GDP ratio. However, Repullo and Saurina (2011) show that this ratio is generally countercyclical which makes capital buffers display properties opposite to what was originally intended by the regulation.

^{5.} We could have chosen to model borrowers default endogenously. However, that would have been outside of our current scope, and would have complicated the analysis significantly without further benefits in terms of understanding the link between capital requirements, monetary policy, and real activity.

issue more equity and avoid a credit crunch by preventing the constraint from binding altogether.

Combining Equation (6) with Equation (7) and using the balance sheet condition according to which bank loans equal deposits plus their equity, we obtain:

(8)

$$e_{t+1} = \left[1 + (1 - \tau_1) i_t^L\right] L_t
- \left[1 + (1 - \tau_1) r_t\right] D_t + \phi (e_{t+1}) + V_t^M - \Delta_t.$$

Optimizing with respect to L_{t+1} and D_{t+1} , we obtain the following FOCs:

(9)

$$\begin{split} \beta^{H} \left[\left(1 + \Omega_{t+1} \right) \right] \left[\left(\left(1 - \tau_{1} \right) \left(1 + i_{t+1} \right) + \tau_{1} \right) \right] \\ &+ \frac{\partial \varphi \left(e_{t+1} \right)}{\partial e_{t+1}} = \left[\left(1 + \Omega_{t} \right) + \left(\gamma_{t} - 1 \right) \Lambda_{t} \right] \end{split}$$

(10)

$$\beta^{H} \left[\left(1 + \Omega_{t+1} \right) \right] \left[\left(\left(1 - \tau_{1} \right) \left(1 + r_{t+1} \right) + \tau_{1} \right) \right] \\ + \frac{\partial \varphi \left(e_{t+1} \right)}{\partial e_{t+1}} = \left[\left(1 + \Omega_{t} \right) - \Lambda_{t} \right]$$

where Λ_t and Ω_t are the shadow values on the capital and dividends constraints, respectively.

Euler Equations (9) and (10) describe the optimal inter-temporal decisions of the bank as regards loans and deposits, respectively.

B. Manufacturers

In the intermediate goods sector a continuum of manufacturing firms indexed by $j \in (0, 1)$ produces homogeneous goods in a perfectly competitive market. Each firm j produces $y_{j, t}$ and sells it at a unit price of $Q_{j, t}$. To be able to do so, each firm j demands labor $(H_{j, t})$ and capital $(K_{j, t})$ from the households and bank borrowing $(L_{j, t+1})$ from the banks to maximize the expected present discounted value of lifetime cash flows. The discount rate used here is the opportunity cost of funds for the firms' owners (the banks), given by the gross interest rate on deposits $(1 + r_t)$.

Manufacturers operate a CRS technology in labor and utilized capital given by:

(11)
$$y_{j,t} = A_t \left(u_{j,t} K_{j,t} \right)^{\alpha} H_{j,t}^{1-\alpha}$$

where u_t denotes the capital utilization rate and A_t denotes aggregate total factor productivity (TFP),

which evolves according to the following logstationary stochastic process:

$$\ln A_{t} = \rho_{A} \ln A_{t-1} + \epsilon_{A,t},$$
(12) $\rho_{A} \in (0, 1), \qquad \epsilon_{A,t} \sim iid(0, \sigma_{A}^{2}).$

Manufacturers are subject to a working capital constraint that states that a fraction κ of their working capital has to be paid before sales revenues are realized. Therefore, they need to be financed externally at an interest rate cost of *i*. This constraint is imposed onto the model as an inequality condition in Equation (13) which imposes the need for bank financing onto the model.

(13)
$$P_{t}L_{j,t+1} \geq \kappa \omega_{t} \left(1 - \tau_{2}\right) \left(W_{t}H_{j,t} + P_{t}r_{t}^{K}u_{j,t}K_{j,t}\right)$$

In Equation (13) the term ω_t captures financial shocks to the demand for credit and it follows the process in Equation (14). This is introduced to capture demand-side shocks in credit markets as one source of aggregate uncertainty:

$$\omega_t = \rho_\omega \omega_{t-1} + \varepsilon_{\omega,t},$$
(14) $\rho_\omega \in (0, 1), \qquad \varepsilon_{\omega,t} \sim iid \left(0, \sigma_\omega^2\right).$

The final cost of working capital is lowered by the presence of a subsidy with rate τ_2 from the government to manufacturers. This subsidy is introduced in the spirit of the New-Keynesian models to guarantee that the distortion associated to price rigidities is offset in steady state.⁶

The *j*th manufacturer's optimization problem is then given by:

(15)
$$\max_{\{H_{j,t},K_{j,t},L_{j,t+1}\}} E_0 \sum_{\substack{t=1\\s.t.}}^{\infty} \Pi_{\tau=0}^{t-1} \left(1+r_{\tau}\right)^{-1} V_{j,t}^M$$
$$V_{j,t}^M = Q_{j,t} y_{j,t} + P_t L_{j,t+1} - \left(1+i_t\right) P_t L_{j,t}$$
$$- \left(1-\tau_2\right) \left[W_t H_{j,t} + r_t^K P_t u_{j,t} K_{j,t}\right]$$
s.t.

Equations (11)–(14).

Plugging Equation (13) into (15) we obtain the first order conditions with respect to $H_{j,t}$ and $K_{j,t}$, respectively:

^{6.} As standard in this literature the subsidy rate is calculated so that the marginal cost for manufacturers equals their marginal product in steady state.

(16)
$$Q_{j,t} \frac{\partial y_{j,t}}{\partial H_{j,t}} = (1 - \tau_2) \left[(1 - \kappa \omega_t) + \kappa \omega_t \frac{(1 + i_{t+1})}{(1 + r_{t+1})} \right] W_t$$

(17)
$$Q_{j,t} \frac{\partial y_{j,t}}{\partial K_{j,t}} = (1 - \tau_2) \left[(1 - \kappa \omega_t) + \kappa \omega_t \frac{(1 + i_{t+1})}{(1 + r_{t+1})} \right] P_t r_t^K u_{j,t}.$$

Equations (16) and (17) equate the marginal product of labor and capital, respectively, to their marginal cost for the firm, which includes a financial component for the share κ of working capital that the firm needs to finance externally.

C. Retailers

A continuum of mass one of retail firms, indexed by $i \in [0, 1]$ buys the homogeneous intermediate good from manufacturers to transform it into differentiated final consumption goods for the households. To do so, they just engage in simple and costless activities. The *i*th retail firm operates in a monopolistically competitive market and produces output $Y_{i, t}$ using the following technology:

(18)
$$Y_{it} = Z \widetilde{y}_{it}$$

where $\tilde{y}_{i,t}$ is the demand for the intermediate good by the *i*th firm and *Z* is a constant factor of transformation. Notice that $\tilde{y}_{i,t} = y_{j,t}$ since each retailer *i* is randomly matched to one manufacturer *j*. The *i*th retail firm sells its output at a price $P_{i,t}$ per unit, facing a standard downward-sloping demand: that is, $Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon} Y_t$ where P_t is the economy-wide price index (to be defined later in Section III.D), Y_t is aggregate demand, and $\varepsilon > 1$ is the (constant) elasticity of substitution across differentiated final consumption goods.

Retail firms are subject to Calvo-type nominal price rigidities, such that in each period they can change their price only with probability $(1 - \vartheta)$. Their profit maximization problem is standard:

(19)
$$\max_{\substack{P_{i,0}^*\\ P_{i,0}^*}} E_0 \sum_{t=0}^{\infty} \vartheta^t \mathscr{F}_{0,t} V_{i,t}^R$$
s.t.

(20)
$$V_{i,t}^{R} = \left[\left(P_{i,0}^{*} - \mathrm{MC}_{t} \right) Y_{i,t} \right]$$

(21)
$$Y_{i,t} = \left(\frac{P_{i,0}^*}{P_t}\right)^{-\varepsilon} Y$$

where $P_{i,0}^*$ is the price for retailers who *actually* change their prices, and MC denotes nominal marginal costs for both manufacturers and retailers.⁷ After taking first order conditions and rearranging terms, we obtain the optimal price setting rule for the *i*th retail firm:

(22)

$$\frac{P_{i,t}^*}{P_t} = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{k=0}^{\infty} \vartheta^k \beta^k \frac{U_{C,t+k}}{U_{C,t}} \frac{\mathrm{MC}_{t+k}^n}{P_{t+k}} \left(\frac{P_{t+k}}{P_t}\right)^{\varepsilon} Y_{t+k}}{E_t \sum_{k=0}^{\infty} \vartheta^k \beta^k \frac{U_{C,t+k}}{U_{C,t}} \left(\frac{P_{t+k}}{P_t}\right)^{\varepsilon - 1} Y_{t+k}}.$$

Since the retailers buy products from the manufacturers, the latter's marginal cost is given by:

$$MC_t = Z^{-1}Q_t.$$

The New-Keynesian Phillips curve that is derived from this optimal pricing problem is:

(24)
$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + k \widehat{m} c_t$$

where

(25)
$$\operatorname{mc}_{t} = \left(\frac{1}{(1-\alpha)}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} \\ \left(1 + k\omega_{t}\frac{(1+i_{t+1})}{(1+r_{t+1})}\right) \left(\frac{W_{t}}{P_{t}}\right)^{1-\alpha} \left(r_{t}^{K}\right)^{\alpha}.$$

D. Households

The representative household consumes a continuum of imperfectly substitutable final goods (C_t) , supplies homogeneous labor (H_t) to the manufacturers of intermediate products, invests in capital (I_t) , and saves through cash holdings (M_{t+1}) and nominal bank deposits (D_{t+1}) .

Aggregate consumption is given by a standard Dixit–Stiglitz index

^{7.} This is due to the standard assumption in NK models of retailers engaging only in costless activities.

(26)
$$C_t = \left[\int_0^1 C_{i,t}^{(\varepsilon-1)/\varepsilon} di\right]^{\varepsilon/(\varepsilon-1)}, \qquad \varepsilon > 1$$

where ε denotes the elasticity of substitution across varieties of final goods.

The household's income is given by wages, asset income (return on capital and deposits), banks', and retailers' profits rebated in a lumpsum fashion to the household, and transfers from the government. Its expenses are given by consumption, investment, and the cost of utilizing capital, which is increasing in the rate of utilization.

Households are subject to preference or demand-side shocks (ζ_t) which are meant to capture unexpected innovations to the level of private, non-business absorption.

Thus, the representative household solves the following optimization problem:

$$\max_{C_t, I_t, K_{t+1}, u_t, M_{t+1}, D_{t+1}} E_0 \sum_{\substack{t = 0 \\ \text{s.t.}}}^{\infty} \beta^H \zeta_t U\left(C_t, H_t\right)$$

(27)
$$P_{t} \left(C_{t} + I_{t} + \delta^{u} \left(u_{t} \right) K_{t} \right) + D_{t+1} + M_{t+1}$$
$$= \left(1 + r_{t} \right) D_{t} + M_{t} + W_{t} H_{t} + P_{t} r_{t}^{K} u_{t} K_{t}$$
$$+ \int_{0}^{1} V_{i,t}^{R} di + V_{t}^{B} + P_{t} T R_{t}$$

(28) $P_t (C_t + I_t) + D_{t+1} \le M_t^H + W_t H_t + P_t r_t^K u_t K_t$

(29) $K_{t+1} = I_t + (1 - \delta^K) K_t$

(30)
$$\begin{aligned} \zeta_t &= \rho_{\zeta} \zeta_{t-1} + \varepsilon_{\zeta,t}, \\ \rho_{\zeta} &\in (0,1), \qquad \varepsilon_{\zeta,t} \sim iid\left(0, \sigma_{\zeta}^2\right) \end{aligned}$$

where H_t are total hours supplied to the manufacturing sector, which, in equilibrium, equals the total demand for labor by all manufacturers $H_t = \int_0^1 H_{j,t} dj$; and K_{t+1} is the total supply of capital in period t which, due to a standard timeto-build assumption, will become available to the manufacturers for production only in period t + 1. Thus, $K_{t+1} = \int_0^1 K_{j,t+1} dj$. Equation (27) is a standard budget constraint

Equation (27) is a standard budget constraint where u_t denotes the endogenous utilization rate of capital.

Costs of capital utilization are increasing and convex in the utilization rate (i.e., $\frac{\partial \delta^{u}(u)}{\partial u} > 0$, $\frac{\partial \delta^{u^2}(u)}{\partial u^2} > 0$), and they are given by:

(31)
$$\delta_t^u\left(u_t\right) = \delta_1^u\left(u_t - 1\right)^{\delta_2^u}$$

where the relevant parameter values are chosen such that in steady state there is full utilization $(\overline{u} = 1)$, and costs are zero $(\delta^{u}(1) = 0)$.

Equation (28) is a cash-in-advance constraint which states that the household's consumption and investment expenditures cannot exceed money balances accumulated from the previous period, plus wage income, net of resources deposited at the banks. This constraint represents the implicit cost of holding intra-period deposits: money deposited at or invested in the bank yields interest, but cannot be used for transaction services. Equation (29) is the law of motion for capital where δ^K is the depreciation rate. Finally, Equation (30) presents the AR(1) process for ζ_{r} : an exogenous and stochastic preference shock.

Taking first order conditions and rearranging, we obtain the following relationships:

(32)
$$\zeta_{t}U'(C_{t}) = \beta^{H}(1+r_{t})$$
$$E_{t}\left\{\frac{1}{\Pi_{t+1}}\left[\zeta_{t+1}U'(C_{t+1})\right]\right\}$$
(33)
$$\zeta_{t}U'(C_{t}) = \beta^{H}E_{t}\left\{\left[r_{t+1}^{K}u_{t+1} + (1-\delta^{K})\right]\right]$$
$$\left[\zeta_{t+1}U'(C_{t+1})\right]\right\}$$

(34)
$$\zeta_{t}U'\left(C_{t}\right) \geq \beta^{H}E_{t}$$

$$\left\{\frac{1}{\Pi_{t+1}}\left[\zeta_{t+1}U'\left(C_{t+1}\right)\right]\right\}, \quad M_{t+1} \geq 0$$

(35)
$$r_t^K = \frac{\partial \delta^u \left(u_t \right)}{\partial u_t}$$

(36)
$$-\frac{U'(H_t)}{U'(C_t)} = \frac{W_t}{P_t}$$

where $\Pi_{t+1} \equiv \frac{P_{t+1}}{P_t}$ denotes the gross inflation rate between periods *t* and *t* + 1.

Equations (32) and (33) are standard Euler equations relating consumption growth to the ex ante real rate of return on deposits and physical capital, respectively. Equation (34) guarantees a non-negative equilibrium real interest rate. Equation (35) governs the optimal choice of the utilization rate of capital by equalizing the real marginal benefit of utilization per unit of capital (the rate of return r_t^K) to its marginal cost (the increase in the rate of depreciation δ). Finally, Equation (36) describes the household's labor supply schedule obtained by equalizing the real wage to the intratemporal marginal rate of substitution between consumption and leisure.

Given the consumption index in Equation (26), the relative consumption demand for each *i*th variety of final goods is given by:

(37)
$$C_{i,t} = \left[\frac{P_{i,t}}{P_t}\right]^{-\varepsilon} C_t$$

where $P_t = \left[\int_0^1 P_{i,t}^{1-\varepsilon} di \right]^{1/(1-\varepsilon)}$ is the aggregate consumer price index, and $P_t C_t = \int_0^1 P_{i,t} C_{i,t} di$.

E. The Government

The government is made of a consolidated fiscal and monetary authority.

The fiscal authority sets taxes on banks' profits and uses the proceeds from these taxes to finance government spending and the subsidy to firms in the manufacturing sector. Lump-sum transfers to households (TR) are added to the budget constraint to guarantee a balanced budget in each period. The government's budget constraint is:

$$\begin{aligned} & (38) \\ & \tau_1 V_t^B = P_t G_t + \tau_2 \left(w_t H_t + P_t r_t^K u_t K_t \right) + P_t \mathrm{TR}_t. \end{aligned}$$

To introduce another demand-side source of uncertainty in the model, we assume that government spending follows a log-stationary stochastic process as follows:

$$\ln\left(\frac{G_t}{\overline{G}}\right) = \rho_G \ln\left(\frac{G_{t-1}}{\overline{G}}\right) + \epsilon_{G,t},$$
(39) $\rho_G \in (0, 1), \qquad \epsilon_{G,t} \sim iid\left(0, \sigma_G^2\right)$

where bars indicate steady-state values.

The monetary authority sets the nominal short-term riskless interest rate r_t following a standard Taylor rule as Equation (40)

$$\begin{aligned} \widehat{r}_{t} &= \rho_{r}\widehat{r}_{t-1} + \left(1 - \rho_{r}\right) \\ \left[\psi_{\pi}\widehat{\pi}_{t} + \psi_{y}\widehat{y}_{t} + \psi_{L}\widehat{L}_{t+1} + \psi_{\mu}\widehat{\mu}_{t}\right] + \varepsilon_{r,t}, \\ (40) \quad \rho_{r} \in (0, 1), \qquad \varepsilon_{r,t} \sim iid\left(0, \sigma_{r}^{2}\right) \end{aligned}$$

where ϕ_{π} , ϕ_{y} , ϕ_{L} , and ϕ_{μ} denote the sensitivity of the policy rate to deviations of inflation from its efficient level, the output gap, credit, and interest rate spreads, respectively, and $\epsilon_{r,t}$ denotes unexpected shocks to the stance of monetary policy. The term involving credit L allows for a credit-augmented rule. Similarly, when ϕ_{μ} is allowed to differ from zero, the monetary authority is following a spread-augmented rule where $\mu_t \equiv \frac{i_t^L}{r_t}$ is the markup in credit markets such that $\hat{\mu}_t = (\hat{i}_t^L - \hat{r}_t)$. By allowing the Taylor rule to incorporate credit and spreads, we aim to approximate the policy recommendations that argue that central banks should respond to changes in credit conditions and spreads in addition to inflation and the output gap. A context in which capital regulation can potentially induce a credit crunch and a tightening of the spreads underscores the need to look at these extended monetary rules to help prevent these undesirable consequences of capital regulation.

IV. NUMERICAL SOLUTION AND CALIBRATION

As with all DSGE medium-scale models, the system of equilibrium conditions describing this economy is highly non-linear. Therefore, the set of optimal policy functions cannot be obtained analytically, and it has to be approximated numerically. Moreover, we allow for the capital constraint to be only occasionally binding and endogenously, as a function of the state of the economy. Having banks holding buffers of equity is consistent with the data and has non-trivial implications for the results. The effects of the regulation itself can be very different depending on whether the regulation actually binds. Moreover, a regulation that starts as actually binding in the presence of constant required ratios may become non-binding and serve as a stabilization device, once anti-cyclical requirements à la Basel III start to be implemented. The presence of these occasionally binding regulatory constraints generates a kink in the policy functions at the value of the state around which the constraint starts to bind. Therefore, the system cannot be solved using standard linearization techniques.

To solve the model we use the first order perturbation approach of Guerrieri and Iacoviello (2015), known as OCCBIN, which handles the presence of occasionally binding constraints by applying this approach in a piece-wise fashion. OCCBIN does not take into account the anticipatory effects of regime changes (it does not allow

Banking sector		
$\phi_2 = 0.01$	$\phi_1 = \left[\left(\overline{\gamma} + \text{buffer} \right) \overline{L} \right]^{(1)}$	$-\phi_2)$
Banking regulation	L J	
$\overline{\gamma} = 0.0925$	$\eta = 0.5$	
$\psi_1 = 0.75$	$\psi_2 = 0.6$	
Households		
$\beta^{H} = 0.99$	$\sigma = 5$	
$\chi = 2$	$\nu = 6$	
$\delta^{K} = 0.025$	$\delta_2^u = 2$	$\delta_1^u = \overline{r}^K / \delta_2^u$
Manufacturing sect	or	1 2
$\alpha = 0.33$	$\kappa = 1$	
$\rho_{\theta} = 0.9$	$\Theta = 50$	
Retailers		
$\varepsilon = 3$	$\vartheta = 0.67$	
Fiscal and monetary	y policy	
$\overline{G}/\overline{Y} = 0.1$	$\tau_1 = 0.4$	$\tau_2 = 0.33$
$\phi_{\pi} = 1.5$	$\dot{\phi}_{Y} = 0.1$	-
$\varphi_L = \varphi_Y$	$\varphi_{\mu} = -0.25\varphi_{\pi}$	
Shocks processes		
$\rho_A = 0.95$	$\sigma_A = 0.01$	
$\rho_G = 0.9$	$\sigma_G = 0.0125$	
$\rho_r = 0.8$	$\sigma_r = 0.0368$	
$\rho_{\zeta} = 0.95$	$\sigma_{\zeta} = 0.05$	
$\rho_{\omega} = 0.95$	$\sigma_{\omega} = 0.0115$	

TABLE 1Calibration

for precautionary savings motives of banks in determining their optimal capital buffers). Thus, all else equal, the buffer obtained with OCCBIN is likely smaller than the one that would be obtained with other solution methods. That would mean that our results overstate the effects of the regulation. However, we work around this technical issue by calibrating the buffer to match the data.⁸

We calibrate the model at a quarterly frequency to match standard RBC statistics and bank capital holdings in the United States. We then simulate the model numerically to examine the qualitative dynamics of the system in response to exogenous shocks to TFP, government spending, interest rates, preferences, and the demand for credit. The parameter values used are presented in Table 1. The moments of logged and Hodrick–Prescott filtered data for the United States that we try to match are included in the first column of Table 2.

The autocorrelation parameter in the TFP process is set to $\rho_A = 0.95$ and the standard deviation of TFP shocks to $\sigma = 0.01$, in both cases following the standard calibration for OECD countries.

The parameter α is set to match a capital share of 33%, β^H is set to match a quarterly interest rate of 1%, and δ^K is set to match a 2.5% capital depreciation rate. The manufacturers' elasticity of substitution across varieties ε is set to 3, which implies a subsidy rate of 33% ($\tau_2 = \frac{\varepsilon}{(\varepsilon-1)}^{-1} = \frac{1}{\varepsilon} = 0.33$). Following the standards in the New-Keynesian literature we set the Calvo probability of no price change to $\vartheta = 0.67$. This gives an average duration of prices equal to three quarters, consistent with the empirical evidence provided by Nakamura and Steinsson (2010).

The utility function we use is $U(C, H, \omega) = \zeta \frac{\left(C - \frac{\nu}{\chi} H^{\chi}\right)^{1-\sigma}}{(1-\sigma)}$. The parameter χ is set to 2, to match an elasticity of labor supply of 1; ν is set to match households devoting one third of their time to work; and σ , which governs the intertemporal elasticity of substitution, is chosen to pin down the volatility of consumption in the frictionless (i.e. no capital regulation) model. The process for the shock to preferences is specified as in Equation (30) where the autocorrelation parameter is $\rho_{\zeta} = 0.95$ and the standard deviation σ_{ζ} is chosen to get the volatility of output.

The exponent in the cost of capital utilization function (Equation (31)) is set to $\delta_{2}^{u} = 2$ is chosen to match the volatility of output. Then, the coefficient δ_{1}^{u} is set to $\delta_{1}^{u} = \frac{\frac{1}{\beta^{H}} - 1 + \delta^{K}}{\delta_{2}^{u}}$, which implies full utilization of capital in steady state by the first order condition for the choice of the optimal utilization rate $r_{t}^{K} = \delta_{1}^{u}\delta_{2}^{u} \left(u_{t}^{\left(\delta_{2}^{u}-1\right)}\right)$ and the Euler equation for optimal capital holdings in steady state $\overline{r}^{K} = (\overline{r} + \delta^{K})$ where $(1 + \overline{r}) = \frac{1}{\beta^{H}}$.

The standard deviation of monetary policy shocks is chosen to match the volatility of the Federal Funds rate.

The required capital-to-assets ratio is set to $\overline{\gamma} = 0.0925$ to be consistent with the regulations in the Basel III Accords and how they were implemented in the United States (see table B-I in Getter 2014). In the benefit function $\phi(e_{t+1}) = \phi_1 e_{t+1}^{\phi_2}$, the parameter ϕ_1 is set to match capital buffer holdings of 1% of total assets. The exponent ϕ_2 is set to the minimum possible value to allow solving for the equilibrium value of equity in the deterministic steady state in which the regulation is non-binding, so that $\phi_2 = 0.01$. Therefore, in the deterministic steady state, the ratio of equity to bank assets equals 10.25%, which is

^{8.} In models like ours with occasionally binding constraints and a large number of state variables, OCCBIN is more efficient than other perturbation methods that can handle occasionally binding constraints.

		$\varphi_Y = 0.1$	$\varphi_Y = 0.1$	$\varphi_Y = 0.1$	$\phi_{\pi}=0$	$\varphi_Y = 0$	$\varphi_L = \varphi_Y$	$\varphi_L = 5 \varphi_Y$	$\phi_{\mu}=-\left(\phi_{\pi}/4\right)$	$\phi_{\mu}=-\left(\phi_{\pi}/2\right)$	$\varphi_L = \varphi_Y$	$\varphi_Y = 0.1$
	Data	$\gamma = 0$	$\gamma = 9.25\%$	$\Psi_{2}=0.6$	$\psi_2 = 0.6$	$\psi_2 = 0.6$	$\psi_2 = 0.6$	$\psi_2=0.6$	$\psi_2 = 0.6$	$\psi_2 = 0.6$	$\Psi_{\mu} = -(\Psi_{\pi}/\tau)$ $\Psi_{2} = 0.6$	$\Psi_{\pi} = 1.00$ $\Psi_2 = 1$
					Stand	lard deviati	ons					
Output (Y)	0.0147	0.0140	0.0286	0.0253	0.0254	0.0258	0.0248	0.0241	0.0131	0.0118 0.0101	0.0133	0.0236
Employment (H)	0.0069	0.0072	0.0228	0.019	0.0189	0.0195	0.018	0.0168	0.0073	0.0072	0.0072	0.017
Investment(I)	0.0663	0.038	0.0395	0.0394	0.0398	0.0394	0.0401	0.0407	0.0377	0.0375	0.038	0.0393
Government Spending (G)	0.0158	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152	0.0152
				Relative	standard d	eviations o	$^{\rm CREGUL}/\alpha_{\rm XNC}$	DREGUL				
Macroeconomic variables												
Output (Y)			2.0429	1.8064	1.789	1.832	1.7093	1.6001	0.9338	0.8449	0.9156	1.6879
Consumption (C)			2.2435	1.9471	1.9314	1.9774	1.8441	1.7274	0.9313	0.8476	0.9184	1.7991
Employment (H)			3.1548	2.6215	2.6294	2.6699	2.5084	2.3358	1.0039	0.9922	0.9962	2.3543
Investment (I)			1.0375	1.0352	1.039	1.0354	1.0397	1.0398	0.9911	0.9853	0.9856	1.0337
Government spending (G)			1	1	1	1	1	1	1	1	1	1
Interest rates												
Deposits rate (r)			1.1695	1.1055	1.1042	1.1166	1.0875	1.0656	76997	1.0089	1.0153	1.0764
Lending rate (i)			0.9979	0.9986	0.9982	1.0033	1.0053	1.0587	1.5468	1.6935	1.6649	0.999
Spread $(i-r)$			22.5043	17.8531	18.5194	18.1895	18.1482	17.552	3.7992	2.2263	4.1275	15.5456
Financial variables												
Deposits (D)			0.8766	0.8572	0.8476	0.8557	0.8416	0.83	0.9238	0.9366	0.9028	0.8595
Loans(L)			2.4187	2.005	2.0074	2.0518	1.9369	1.8425	0.9711	0.9673	0.9781	1.8019
Equity (e)			0.1616	0.2018	0.209	0.21	0.2068	0.234	0.16	0.1565	0.1666	0.2465
					Output c	orrelations	$\rho(x, Y)$					
Macroeconomic variables												
Consumption (C)	0.8931	0.9126	0.9817	0.9763	0.9764	0.9773	0.9751	0.9734	0.8995	0.8735	0.9026	0.9726
Employment (H)	0.92	0.6883	0.955	0.9428	0.9464	0.9451	0.9466	0.9486	0.6056	0.4724	0.6316	0.9342
Investment (I)	0.9042	0.7488	0.7136	0.7319	0.7458	0.7286	0.7648	0.7936	0.7372	0.7127	0.7525	0.7421
Government spending (G)	-0.2954	0.0711	0.1034	0.092	0.0835	0.0956	0.0708	0.0487	0.0347	0.0215	0.0336	0.0851
Denosits rate (r)	-0.28	-0 3168	-0.2608	-0.2625	-0.2414	-0.2818	-0.1899	-0.0848	-0.047	-0.0618	-0.0226	-0.264
Lending rate (i)	0.0973	-0.3168	-0.6232	-0.6138	-0.6063	-0.6131	-0.597	-0.5747	-0.5299	-0.4556	-0.52	-0.605
Spread $(i-r)$	-0.25		-0.6175	-0.606	-0.5982	-0.6065	-0.5869	-0.5626	-0.4399	-0.3389	-0.43	-0.5955
Financial variables												
Deposits (D)	0.0941	-0.2135	0.3111	0.1892	0.1738	0.1805	0.1628	0.1536	0.1041	0.04	0.1001	0.123
Loans (L)	0.85	0.4587	0.8983	0.8678	0.8716	0.8734	0.8678	0.8643	0.4025	0.3102	0.4128	0.8462
Equity (e)	0.0162		0.6855	0.7974	0.8016	0.8022	0.792	0.7771	0.7563	0.7673	0.7569	0.8173

 TABLE 2

 Model Simulation Results—All Shocks

Note: All macroeconomic data are from the FRED database by the Federal Reserve Bank of St. Louis. Moments calculated using logged and HP-filtered data.

consistent with the average tier 1 capital holdings by commercial banks in the United States. The required capital-to-assets ratio fluctuates around its steady state value according to the process presented in Equations (2) and (3). In this process the weight parameter is set to $\eta = 0.5$, which implies allowing for equal weights on fluctuations in gross domestic product (GDP) and the volume of credit in determining the changes in requirements along the business cycle. The parameter ψ_2 in Equation (2) is chosen to match a maximum increase in requirements of 2.5 percentage points at the peak of the cycle. In fact, the Basel III accords limit the countercyclical buffer to that amount. The smoothing parameter in the regulation, ψ_1 , is set to allow a change in requirements to last for four periods (a year).⁹

The corporate tax rate on bank profits τ_1 is set to 40% based on the Internal Revenue Service corporate tax schedule.¹⁰

We assume the following parameterization for the central bank's policy rule: The interest rate smoothing parameter is set to $\rho_r = 0.8$. The response to policy targets are set to $\varphi_{\pi} = 1.5$, $\varphi_Y = 0.1$, $\varphi_L = \varphi_Y$, and $\varphi_{\mu} = -0.25\varphi_{\pi}$.

We work with the fiscal rule in Equation (39) where \overline{G} is calibrated to 10% of GDP, the degree of autocorrelation is $\rho_G = 0.9$, and the standard deviation σ_G is chosen to match the volatility of government spending in the data.

Last, the process for borrowers' repayment capacity θ_t in Equation (6) is the following:

$$\ln \left(\theta_{t} \right) = \rho_{\theta} \ln \left(\theta_{t-1} \right) + \left(1 - \rho_{\theta} \right) \ln \left(\left(\frac{Y_{t}}{\overline{Y}} \right)^{\Theta} \right).$$

The autocorrelation or smoothing parameter in the process for θ_t in Equation (41) is set to $\rho_{\theta} = 0.9$. The sensitivity to shocks parameter Θ is set to match the ratio of loan-loss allowances for banks in the United States which was on average 2% of loans (approximately 20% of equity) during the period 1960–2016. This implies that the share of the debt that is repaid fluctuates around a

9. We have also tried as much as possible in all simulations to limit the reduction in requirements to 1.25 percentage points up to $\gamma = .08$. Following Getter (2014), we restrict the fall to be at most the amount of the conservation buffer.

10. According to this schedule the average rate is approximately 40%. The marginal federal tax on the highest bracket is 35%. Even though there are also state and local taxes on corporate income (ranging between 0% and 12%), these are typically deducted from the federal tax payments. See https:// www.putnam.com/literature/pdf/II936.pdf. steady state value of 1, and it reaches a minimum value of 80% of bank equity at the worst possible state of nature.

Finally, the volatility of the financial shock ω is chosen to match the data standard deviation of aggregate credit to the private sector by deposit-taking institutions.

Sensitivity analyses are available from the authors upon request.

V. RESULTS

In this section we use the model to study the "amplifier" or "stabilizer" properties of bank capital requirements under alternative types of interest rate rules followed by the monetary authority. Focusing on the case of recessions, on the one hand, non-performing bank loans will rise so that banks will start trying to recapitalize. Consequently, banks may need to lower the supply of credit which would in turn exacerbate the economic downturn by increasing the cost of working capital for bank-dependent firms who find it costly to switch to other types of lenders. This will exacerbate or amplify the effects of negative shocks. On the other hand, the fact that required capital ratios will be falling during such times might allow for the cost of these recapitalization efforts to be lower than in the case of constant requirements à la Basel I, and act as a stabilizer mechanism.

Thus, we ask two questions: First, whether time-varying capital requirements may mitigate procyclicality and, if so, how. Second, what type of interest rate rule is most effective at mitigating procyclicality.

Given that in the data banks normally hold significant "excess capital" over requirements, in our view it is essential for any model that considers capital requirements and financial accelerator effects to be able to explain this behavior. A model that by construction has capital requirements always binding will likely find accelerator effects as a direct result of that assumption but will not then adequately explain bank behavior, and may then misinterpret the potential effect of anti-cyclical regulation.

In our simulations we calibrate the excess capital to the case of larger banks that tend to hold only a small buffer. Overcompliance and the holding of large buffers is typically associated in the data to smaller banks. Still, the buffer we allow for is large enough for the probability of a binding constraint to be relatively small; that is, the bank tries to minimize the cost associated to

(11)

the capital adequacy regulation. The explanation for this is that for a lower level of excess capital (i.e., one in which the probability of hitting the constraint is positive) it is not guaranteed that the bank will be able to meet the regulatory constraint in every state of nature. Since events when the constraint is not met are costly, the bank builds up enough excess capital to prevent (as much as possible) this from happening.

A. Impulse Response Analysis

Productivity Shocks. In this subsection, we analyze the economy's response to a negative 1% TFP shock under three scenarios: no regulation or non-binding capital requirements ($\gamma_t = 0$), constant capital requirements ($\gamma_t = \overline{\gamma}$), and anti-cyclical requirements à la Basel III (as in Equation (2)). The results are presented in Figure 1.

When capital requirements are not binding, tax-exempt deposits are a cheaper source of financing for banks than equity, so that banks will choose to hold no equity. The model then collapses to a standard dynamic New-Keynesian model with households making consumptionsaving decisions and firms demanding labor and capital from the households and conducting production decisions. Banks are completely redundant in this setting, and since they are perfectly competitive, the interest rate spread (i - r) is zero. As usual in this standard model, after a negative TFP shock, the marginal product of capital and therefore, the interest rate both fall. Employment, capital, investment, and output all fall following the drop in TFP, which is the only source of fluctuations in the model. With price rigidities, the negative supply-side shock generates inflation. The drop in employment and output also induces a fall in consumption. These responses are represented with dotted lines in Figure 1.

With constant capital requirements. Bank equity suffers in response to a negative shock due to the effect of the shock on borrowers' repayment capacity. If capital-to-assets ratios fall below the regulatory minimum as a result of this reduction in equity, banks find themselves needing to pay the costs of violating the capital adequacy regulation or to recapitalize. They do so by retaining earnings up to the point where the constraint on dividends becomes binding. After this, further adjustments to the capital-to-assets ratio have to be achieved by curtailing the supply of loans. The spread and therefore, the interest



FIGURE 1 Impulse Response Functions to a 1% Negative TFP Shock

rate on loans both rise. Thus, credit availability is restricted, and the interest rate spread optimally charged by banks rises relative to a model without capital requirements. This induces borrowers to further lower the demand for labor and capital, which amplifies the standard effects of a negative TFP shock making the recession deeper and more persistent.

These results highlight that the presence of the regulation induces a financial accelerator originated from the supply-side of the credit market. The changes in employment, investment, capital, and consumption are all significantly larger than in the no regulation case (see dashed lines in Figure 1).

With anti-cyclical capital requirements. In an economy with anti-cyclical regulation the required capital-to-assets ratio falls with the negative TFP shock and the associated drop in credit conditions. Then, it is less likely (than with constant requirements) that the regulation will start binding after the negative shock strikes the economy. Therefore, even though there is still some amplification relative to the noregulation economy, it is obvious from Figure 1 that anti-cyclical requirements indeed constitute an effective macroeconomic stabilization tool (relative to constant requirements) as originally intended by the Basel criteria.

A required capital-to-assets ratio that falls from 9.25% to 8% already allows the responses of macroeconomic variables, consumption, investment, employment, capital and output, to all exhibit a smaller amplification relative to the no regulation economy (see solid lines of Figure 1).

Impulse Responses to Government Spending Shocks. The responses to a fiscal consolidation implemented via a 10% negative shock to government spending are presented in Figure 2. In terms of magnitude, the drop in government spending is equivalent to 1% of GDP.

Deflation is generated, which induces the monetary authority to lower the interest rate only slightly. Under no capital regulation, this monetary policy response lowers the cost of investment, so that both investment and capital rise, as a result. The drop in the interest rate lowers the opportunity cost of leisure so that employment drops. The negative effect on output of the reduction in employment seems to dominate that of the increase in capital so that output still drops. In terms of the consequences for the banking sector, the reduced size of working capital imply a drop in the demand for loans



FIGURE 2

faced by banks and a roughly proportional drop in deposits. Since in the unregulated economy banks are not required to hold equity, they start shifting the composition of their portfolios and lowering the more expensive type of financing (equity).

Banks cannot use this same strategy once the regulation is imposed (with constant required capital ratios-dashed lines), so that deposits now fall more markedly, and equity falls but less than in the no regulation case. Just as in the case of productivity shocks, the fiscal contraction creates a recession and makes it harder for firms to pay back their debt, which translates into lower net worth for banks. This reduction in equity makes the regulation constraint bind, which raises the spread and the interest rate on loans. As a result, the cost of hiring labor increases for manufacturers and the negative response of employment is amplified. With a binding regulation implying an increase in the cost of capital, investment still rises but by less than in the unregulated economy. As a result, at the trough the response of output is almost twice as large when the regulation starts to be enforced. With the response of output being larger, the response of inflation is amplified as well. This is how the regulation brings a financial accelerator from the supply-side of the market for credit, alternative to the well-known demand-side accelerator originating from frictions related to the balance sheets of borrowers.

The responses for an economy with anticyclical capital requirements (solid lines) are in between those for the no regulation and the constant requirements case. Intuitively, the recession brought about by the fiscal consolidation makes the required ratio fall. The constraint is still binding as in the case of constant requirements but the shadow value is lower and the interest rate rises by less than before. As a result, the responses of all banking and macroeconomic variables are muted relative to the case of constant capital requirements.

Impulse Responses to Contractionary Monetary Policy. In this section, we study the effects of a monetary tightening implemented by raising the interest rate by 0.25 percentage points. Results are presented in Figure 3.

There is no spread under no regulation so that the increase in the cost for manufacturers of externally financing working capital also rises by this same amount. This induces a decrease in the demand for labor and investment, in the accumulated stock of capital, and in both output and consumption. In the banking sector, both deposits and loans fall.



FIGURE 3 Impulse Response Functions to a Monetary Tightening

FIGURE 4 Impulse Response Functions to a Negative 10% Financial Shock to ω



Just as with the previous two shocks, the presence of the regulation induces a financial accelerator. However, when the regulation is made anti-cyclical, the responses are muted relative to the case of constant γ .

Worthy of note is that in the model monetary tightenings generate deflation only in the first period after the policy shock. Soon after, the policy rate starts to respond to contain deflationary pressures and inflation is actually generated. This could also be explained by the fact that the financial component of the marginal cost of production increases with the initial increase in the policy rate and that generates inflationary pressures.

Impulse Responses to Financial Shocks. In this section, we present the results of subjecting the economy to a one-time 10% increase in firms' demand for loans implemented by raising ω (see Equation (13)) from its steady state value of 1 to 1.1. This shock is intended to provide another avenue through which banks capital constraints might suddenly start binding. These results are presented in Figure 4.

This increase in the demand for loans faced by banks translates into an increase in the latter's own demand for deposits and of the latter's equity holdings. In the unregulated economy, this change in the composition of banks' balance sheets has no impact on deposit interest rates, and with spreads being zero, it has no impact on loan rates either. However, the demands for both labor and capital, and consequently output, still fall. With constant capital requirements, this ends up making the regulation constraint bind, with spreads and loan interest rates rising. As a result, the cost of production rises relative to the no regulation scenario, and the drops in employment, investment, capital, output, consumption, and inflation are all amplified. With procyclical requirements the responses are now amplified even further. The increased demand induces a rise in capital requirement ratios¹¹ and therefore, an increase in the spread and the cost of working capital.

Notice that these results are not only quantitatively, but also qualitatively different from before. Now, the solid lines lie below the dashed ones for all variables.

Impulse Responses to Preference Shocks. In this section, we study the response of the economy to a negative demand-side shock of 20% to ζ . This shock implies a proportional fall in the marginal

11. Since the demand for loans rises drastically by 10%, the index of credit conditions increases.

utility of consumption. The results are presented in Figure 5.

The fall in marginal utility works to optimally shift consumption to the future. As a result, investment rises, labor supply falls so that employment and consumption fall (both because of the lower marginal utility and the decrease in labor income). Even though the increase in investment has a positive impact on the stock of capital, the increase in employment dominates and output still falls. The demand-side shock causes a drop in wages and the rental rate on capital which ultimately leads to an increase in inflation.

Bank equity falls, the constraint becomes binding, the spread rises, and the interest rate on loans increases. The increase in the financial component of marginal cost and therefore of labor and capital induces an attenuation of the positive response of investment and capital, and an amplification of the negative responses of employment, output, and consumption.

Since output is falling, the procyclical required capital-to-assets ratio falls in the case of the Basel III economy. This effect on the requirement makes the constraint less likely to bind so that the increase in the shadow value of the multiplier and the cost of credit are now smaller than in the constant regulation scenario. And this amplifies the responses after the shock. The shadow value of the constraint rises by less than with constant γ ; and the interest rate on loans rises by less. The end result is a less negative response of employment and output, and a more positive response of investment and capital.

B. Simulation Analysis

In this section, we subject the economy to a series of shocks with mean 0 and 1% standard deviation for productivity, 1.25% for government spending, 3.68% for interest rates, 5% for the shocks to the marginal utility of consumption, and 1.15% for the demand for credit. We simulate the response of the economy 500 times for 1,000 periods and average out the responses. The calibration of the volatility of TFP shocks follows the standards in the RBC literature. The volatility of fiscal and monetary shocks is chosen to match the volatilities of government spending and the federal funds rate in the data for the United States. The volatility of preference shocks is chosen to get the volatility of investment to be three times that of output. Finally, the volatility of financial shocks is chosen to match the volatility of credit to the private sector. We calculate RBC moments based on logged and Hodrick-Prescott filtered series. Table 2 presents the results.



FIGURE 5 Impulse Response Functions to a 20% Preference Shock to ζ

From the simulation analysis, it again becomes evident that the presence of the regulation works as an amplifier of fluctuations. While the standard deviation of output in the no regulation scenario is 0.0140, it rises by 100% and 80%, to 0.0286 and 0.0253 for constant and anti-cyclical capital requirements, respectively. Similar patterns arise for the volatilities of employment and investment. This is the case when the central bank uses the benchmark Taylor rule in which interest rates respond only to output and inflation.

The intuition for why the volatility of macroeconomic variables rises with the imposition of the regulation is the same we discussed for the impulse response analysis: Negative shocks (from either the supply or the demand side) hurt the manufacturers' ability to pay back their working capital debt; this lowers payments to banks and reduces their equity; an initially non-binding regulation starts to bind; the cost of financing loans for banks rises; this increase in cost is shifted to borrowers; the cost of credit (and therefore of labor and capital) rises; the demands for labor and capital fall even more than what is justified by the shock alone; and the response of output and consumption are increased over and above those in the economy with no regulation.

Also consistently with the results from the impulse response analysis, making the regulation anti-cyclical means that the economy can start getting closer to exhibiting the properties of the no regulation case. The ratio of standard deviations in the regulated to the unregulated economy always lies above 1 and in between 1.6 and 2.7. This result is obtained with a realistic sensitivity of γ to credit conditions, that is, $\psi_2 = 0.6$ so that the required ratio fluctuates between $\gamma_{min} = 0.08$ and $\gamma_{max} = 0.1175$. This range for γ seems narrow enough to be implemented feasibly in practice by banking regulators.

In terms of the sensitivity of volatility to the type of Taylor rule adopted by the central bank, we can see that the benchmark rule through which interest rates respond to inflation and the output gap, with no response to measures of credit conditions (like the volume of loans or credit spreads) allows the economy to display an output volatility that is 80% higher for output (95% higher for consumption) than in the no regulation scenario. With standard monetary rules, it is not feasible for the regulation to mute fluctuations further than that.

An alternative rule through which interest rates respond only to inflation but not to the output gap does not make a significant difference in terms of stabilization relative to the benchmark Taylor rule. The same is true for a policy rule that responds to the output gap, but not to inflation.

Last, when the policy rate responds to the deviation from steady state of loans volatility is only 70% for output (85% for consumption) higher than that for the economy with no capital regulation. When the policy is allowed to respond to credit spreads, anti-cyclical requirements become a quite powerful stabilization tool and the volatilities of output and consumption are reduced to 93% of those with no regulation. Last, when monetary policy is allowed to respond to both credit and spreads, the economy achieves a volatility in the order of 91% of that without regulation.

To conclude, in the presence of anti-cyclical capital rules, designing monetary policy to respond to credit conditions in financial markets allows the economy to enjoy the benefits of a sounder and more highly capitalized banking sector, without the undesired macroeconomic repercussions of increased volatility (due to the amplification mechanism introduced by capital requirements). The best of both worlds seems to be possible once monetary policy pays attention to developments in credit markets and is not limited to responding only to inflation and GDP fluctuations.

C. Interaction between Regulation and Monetary Policy

In this section, we study the interaction between the two policy tools available to central banks in response to all shocks. We do so by identifying the degree of sensitivity to the volume of credit φ_L and spreads φ_{μ} in the interest rate policy rule that is needed to guarantee that anticyclical bank capital regulation yields what we call a "stabilizer effect." Thus, Figure 6 shows with blue dots the combinations of the sensitivity of capital requirements to credit conditions (ψ_2) and each of the parameters in the Taylor rule that guarantee that the volatilities of output and consumption are at most equal to those that the economy would exhibit if there were no capital requirements.

No response of the Taylor rule to fluctuations in the volume of credit L allows the economy to recover the volatilities of consumption and investment of the no regulation economy.

When the Taylor rule responds to spreads (top set of plots in Figure 6), output and consumption





volatilities can be reduced all the way to their no regulation levels. It takes the sensitivity of interest rates to spreads to be at least $\varphi_{\mu} \leq -0.3$ for any ψ_2 and $\varphi_{\mu} \leq -0.2$ for any $\psi_2 \geq 1.2$.

When the monetary policy rule responds to both credit and spreads (bottom set of plots in Figure 6), $\varphi_{\mu} \leq -0.2$ and $\varphi_L \geq 0$ do the job of returning to the volatilities that would prevail if bank capital was left unregulated.

In conclusion, a slight response of interest rates to spreads is enough for reasonable degrees of cyclicality of the required capital-to-assets ratio to take the economy back to volatility levels similar to those that would prevail under no capital regulation.

D. Welfare Analysis

We conduct welfare comparisons across alternative monetary policy rules based on compensating variations. Given a specific set of Taylor rule and capital regulation parameters, we supply a vector time series for each of the five exogenous shocks via a seeded random number generator. We then compute 200 repeated simulations of pseudo data each of length 700 periods.¹²

With this pseudo data, we can compute welfare as:

(42)
$$V = E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, H_t\right)$$

where C_t and H_t are averages of consumption and labor across the N = 200 simulations.

Then, for any two policy rules A and B, the difference in welfare levels is given by:

(43)

$$\left(V_B - V_A\right) = \ln\left(1 - \Lambda\right) + \frac{\beta}{(1 - \beta)}\ln\left(1 - \Lambda\right)$$

12. See Heer and Maussner (2009) and Woodford (2003) for details on this method.

			Compensating variations Benchmark regime	
Monetary policy	Regulation	Welfare	$\gamma = 0$	Constant y
Benchmark Taylor	$\gamma = 0$	8,680.6		
Benchmark Taylor	$\gamma_t = 0.0925$	8,687.0	-0.1366	
Benchmark Taylor	$\Psi_2 = 0.6$	8,684.7	-0.0847	0.0457
$\varphi_V = 0$	$\psi_2 = 0.6$	8,685.1	-0.0934	0.038
$\phi_{\pi} = 0$	$\psi_2 = 0.6$	8,683.7	-0.0645	0.0635
$\phi_I = \phi_V$	$\psi_2 = 0.6$	8,683.3	-0.0554	0.0715
$\phi_{\mu} = -(\phi_{\pi}/4)$	$\psi_2 = 0.6$	8,680.7	-0.0011	0.1192
$\phi_I = 5\phi_V$	$\psi_2 = 0.6$	8,682.8	-0.0448	0.0808
$\phi_{\mu} = -(\phi_{\pi}/2)$	$\psi_2^2 = 0.6$	8,681.2	-0.0118	0.1098
$\phi_{\mu} = -(\phi_{\pi}/4) - \phi_{I} = \phi_{V}$	$\psi_2 = 0.6$	8,680.6	-0.0003	0.1199
Benchmark Taylor	$\psi_2 = 1$	8,683.7	-0.0641	0.0638

TABLE 3Welfare Calculations

Note: Compensating variations measured in terms of lifetime consumption.

where Λ represents the fraction of lifetime consumption that households under policy rule A would be willing to sacrifice to make them indifferent between monetary rules A and B.

Then we can solve for Λ as:

(44)
$$\Lambda = 1 - \exp\left[(1 - \beta)\left(V_B - V_A\right)\right].$$

Table 3 shows the results of these welfare comparisons, both the welfare levels *V* for each Taylor rule (first column), and the compensating variations Λ with respect to the case of no capital regulation and the case of constant γ (second and third columns, respectively).

These results indicate that (for all monetary policy rules) in the presence of capital requirements, welfare decreases relative to the no regulation economy. This result is not surprising and consistent with the impulse response analysis and simulations results through which it became obvious that capital regulation amplifies shocks and increases volatility relative to an economy with no requirements. The more interesting message that arises from these results however is that the best Taylor rule would be one through which the policy rate reacts to both the volume of credit and interest rate spreads, followed by one that reacts to spreads only and then by one that reacts to credit only. Actually, when interest rates respond to both credit and spreads, consumption falls by only 0.0003% relative to the no regulation economy. Furthermore, it is interesting to see that the standard Taylor rule that responds to both inflation and the output gap does not improve welfare too much relative to the cases in which the interest rate responds only to spreads.

In the last column of Table 3, we compute the compensating variations as compared to an economy with constant capital requirements (à la Basel I). In this case, welfare improves relative to the benchmark regime ($\gamma_t = 0.0925 \ \forall t$) for all monetary policy rules. However, the augmented rules are still better performing. While lifetime consumption rises by 0.04% with the standard Taylor rule, it increases by 0.08% and 0.12% with the credit and spread-augmented rules, respectively.

VI. CONCLUSIONS

In this paper we address the question of which type of monetary policy rule is more desirable in an economy where anti-cyclical bank capital requirements have the potential to induce an undesirable contraction in the supply of credit and tightening of credit spreads. We do so by taking the model in Aliaga-Díaz and Olivero (2012) and extending it with price rigidities and capital requirements à la Basel III that explicitly ask banks to build buffers of equity in good times.

Our results suggest that an anti-cyclical rule for capital requirements could be used to smooth out the business cycles associated with the financial accelerator effect of constant requirements. In other words, anti-cyclical regulations can get the economy closer to exhibiting the volatilities of employment, investment, output, and consumption observed in an environment where banks are left unregulated. These stabilization properties are limited when monetary policy is given by a standard Taylor rule.

However, and even with a very mild cyclicality of capital requirements which restricts γ_t to fall by at most 1.25 percentage points and to increase by at most 2.5 percentage points, a monetary policy rule that responds only slightly to credit spreads can allow the model economy to recover the volatilities of consumption and investment that would prevail under no regulation. In the presence of anti-cyclical capital rules, designing monetary policy to respond to credit conditions allows the economy to enjoy the microeconomic benefits of banks holding higher capital buffers, without the undesired macroeconomic repercussions of increased volatility (due to the amplification mechanism introduced by capital requirements). The best of both worlds seems to be possible once monetary policy pays attention to developments in credit markets and is not limited to responding only to inflation and GDP fluctuations.

In terms of welfare, policy rules that respond to credit spreads also perform best and allow welfare to get back to the levels of an economy in which bank capital is left unregulated. Relative to the case of Basel I (constant requirements), a spread-augmented Taylor rule allows lifetime consumption to increase by 0.12% on average each period. This is a pretty sizable compensating variation for the values that are standard in this type of welfare analysis.

Another result we obtain is that the anticyclical rules on bank capital in Basel III may have only minor impact depending critically on the size of the buffers held by banks. This also has implications for asymmetries in the effects of the regulations across different types of banks. For example, since smaller banks tend to hold larger buffers, the amplification properties of constant requirements would be weaker in economies in which the banking sector is composed of a large number of small banks than in economies where the banking sector is more concentrated.

Introducing heterogeneity at the bank-level in the theoretical model to be able to simulate how the effects differ across sectors is left for future work.

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