Capital Adequacy Requirements and Optimal Monetary Policy*

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Abstract

We have two principal additions to the literature. One, we present a model of economy with a leveraged and regulated financial sector. Consistent with prior models, this economy shows the characteristics of a financial accelerator in a state of the world in which banks do not face regulatory capital constraints. More importantly, the model shows the absence of an accelerator when the economy is capital constrained. This is the mechanism through which one can show a state-dependent monetary policy. Two, we use a stylized GMM method to find optimal Taylor rules for this economy. We find rules consistent with a strong pro-inflationary reaction during financial crisis. This produces a debt devaluation that allows an effective 'recapitalization' of the banking sector and a return to the unconstrained world.

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1 Introduction

The ongoing recession/slowdown has led to renewed concern about the role of the financial system in the business cycle. The 'credit crunch' in the United States has focused attention on the determinants and the macroeconomic impact of a decline in bank lending. In this context, the roles of banking regulation and monetary policy are becoming once again hotly contested. According to one hypothesis, the previous 'credit crunch' in the United States was at least partly a consequence of banks' eagerness to meet the 1992 deadline for capital adequacy requirements under the 1988 Basle agreement (Bernanke and Lown, 1991). Though preparation for Basle II is underway and the final Rule is complete, a new 'credit crunch' is transpiring, though this time the reasons may not be the same.

Why does this matter? Indeed, within the new-Keynesian framework now common for the analysis of monetary policy, one typically rules out real impacts of the financial sector. Evidence from both the financial crisis in the late 1980s when banks saw large real-estate related write-down and the current crisis has suggested that a the role of the financial sector may be important in the transmission of real shocks. Similarly, the reactions of central banks to these crises has been strong, and well out of sync with predictions from consensus Taylor rules. Indeed, the monetary authority reactions are discordant with an estimated Taylor rule as well (see Rudebusch, 2006). This of course requires little systematic analysis to observe; the federal reserve has lowered its principal policy rate by more than 3% in less than a year, even in the face of rising inflation, rejecting existing Taylor rules quite strongly. Rationale for this reaction have been suggested as ranging from direct protection of the financial sector to a longer-term view that financial sector stabilization can lead to a return to stable economic conditions.

To provide a potential solution to this question, we turn our attention to the nexus of monetary policy and bank regulation. In particular, we ask how one can evaluate the macroeconomy in an environment where the monetary authority must cope with regulated banking sector. The potential conflict between central bankers and financial supervisors has been noted before. A range of research has found that capital adequacy requirements, while potentially important for financial stability, can also be procyclical.[1] Of course, if monetary policy is intended to promote stable economic growth, its countercyclical bias will run counter to bank regulation. A joint authority now has the advantage (or the problem) that policy decisions must account for both factors.

The presence of a regulated banking sector matters for our purposes here because it provides a potential explanation for the apparent inconsistency in monetary policy during crisis periods. We focus on 'crises' as defined by shocks to bank capital. In a new-Keynesian model of the economy with no financial frictions, bank capital shocks are irrelevant. Bank lending is typically determined completely by available deposits. Thus, capital shocks have no impact on the real economy. In a world with either leverage or some other type of financial sector friction, economic shocks and monetary policy are amplified through the financial sector (Bernanke *et al.*, 1989). Of course, even in this world, the implied optimal policy rules cannot explain

[1] The literature on the procyclicality of adequacy requirements is quite large. Berger and Udell (1994), Blum and Hellwig (1995), Brinkmann and Horvitz (1995), Thakor (1996); recent papers include Goodhard *et al.* (2004), Estrella (2004), Kashyap and Stein (2004), Gordy and Howells (2006).

dramatic reductions in interest rates in the face of inflationary pressures.

In a regulated banking sector, financial sector leverage has legal limits. Thus shocks that impact bank capital pass through to limitations on lending. In most cases, this is similar to the Bernanke *et al.* (1989) world in that economic shocks are magnified by the financial sector, in this case through a leverage effect. However, a sufficiently large shock to bank capital changes the nature of the 'accelerator.' When bank capital falls below a regulatory requirement, lending is capped. Thus, the leverage effect vanishes and monetary policy becomes ineffective at stimulating the real economy until bank capitalization rises again above the constraint. Notice that this produces the nonlinear effect of an increasingly strong monetary policy as banks approach the constraint, due to the fact that leverage is rising. However, once the constraint is reached, monetary policy *cannot* impact lending as banks are legally prevented from expanding lending.

Critically, this implies that monetary policy necessarily changes at this point as well. As such, it makes little sense to estimate a single policy rule across both constrained and unconstrained regimes. So, what does optimal policy look like when the two regimes are considered separately? Cechetti and Li (2008) take an important first step in this direction by looking at two isolated regimes.

To extend the Cechetti and Li (2008) work to fit into the current new-Keynesian synthesis model and to incorporate the possibility of moving between the constrained and unconstrained states of the world, we turn to a revision of a model that explains the efficacy of the monetary policy transmission mechanism in the context of banking sector constraints. To this end, we draw on the financial accelerator model (Bernanke *et al.*, 1999) finding that the economy has a stronger transmission mechanism when banks are lending constrained than when unconstrained. We then incorporate a leveraged financial sector with a capital adequacy threshold and reserve requirements.

In the current crisis, we can see this regulatory constraint as being both a surprise and binding as follows. Briefly, financial institutions, seeking to preserve profitability as the yield curve first flattened, then inverted, developed financial instruments which effectively channeled intermediation outside the traditional banking system. The idea was to fund mortgages and other loans by creating and selling short-term securities with tailored risk characteristics rather than by lending out bank deposits. The fly in the ointment was a lack of proper incentives for careful quality control. Risk spreads have widened and non-conventional mortgage lending has nearly disappeared, now that the true risk characteristics of these loans are better understood. Banks, forced to bring supposedly off-balance-sheet activity back onto their books, are either currently short of capital or fearful that once full loan-losses have been realized, they will be.

We have two principal additions to the literature. One, we present a model of economy with a leveraged and regulated financial sector. Consistent with prior models, this economy shows the characteristics of a financial accelerator in a state of the world in which banks do not face regulatory capital constraints. More importantly, the model shows the absence of an accelerator when the economy is capital constrained. This is the mechanism through which one can show a state-dependent monetary policy. Two, we use a stylized GMM method to find optimal Taylor rules for this economy. We find rules consistent with a strong pro-inflationary reaction during financial crisis. This produces a debt devaluation that allows an effective 'recapitalization' of the banking sector and a return to the unconstrained world.

Our paper proceeds as follows. Section 2 outlines our extension of the Bernanke *et al.* (1999) financial accelerator. We continue in section 3 with a discussion of the setup for our simulation exercises and show some results in section 4. Section 5 provides some discussion and we conclude in section 6.

2 The Benchmark Model

Our benchmark is the financial accelerator model where credit market conditions are relevant. Although there are different ways to rationalize a financial accelerator, theoretically, one natural framework to analyze the current credit market conditions is the "costly state verification" (CSV) model of credit market frictions (see, e.g., Bernanke *et al.*, 1999) which has been extensively used in the literature. In particular, this model and its extensions show that endogenous changes over the business cycle in the costs of auditing the borrower's realized return on capital can add an "external finance premium". This premium over the risk-free rate, in turn, produces a financial accelerator effect or an amplification of the impact of a given shock.

We build a variant of the financial accelerator model with sticky-price features of Bernanke *et al.* (1999), to include a Taylor rule as a modern characterization of monetary policy, and to enhance the structural definition of the banking system. We add a financial intermediary that takes deposits from the households and lends them to the firms to pay for the capital rental bill. We also introduce the regulatory feature of adequacy requirements on the bank's own capital and reserve requirements on deposits. There are a number of reasons behind this choice for the specification of financial frictions. For starters, the Bernanke *et al.* (1999) model shares an important characteristic with the framework of Kyotaki and Moore (1997) in that asset price movements serve to reenforce credit market imperfections, which lead Gomes *et al.* (2003) to discard the Carlstrom and Fuerst (1997) framework[2].

Our model illustrates that an economy with banks that are adequately capitalized but without a buffer (credit-constrained) is often more responsive to monetary relaxation than an unconstrained economy. Similarly crucial is the fact that an undercapitalized banking system is more likely to lead to a credit-constrained outcome or a 'credit crunch'. Financial institutions can become unresponsive as they use rate reductions to increase margins on existing loans to shore up capital rather than to expand lending. The combination of these two features suggests variable impacts of monetary policy above the constraint point and a sharp nonlinearity at the point where credit markets become constrained (see Figure 1, Panel A).

We develop this intuition in a model of monetary policy that incorporates bank regulation along with the financial accelerator. We reformulate slightly the model of the financial accelerator in Bernanke *et al.* (1999) most notably to expand the role of the banking system. The baseline model is essentially a stochastic business cycle model that incorporates monopolistic competition and nominal price rigidities, modified to allow financial intermediation to play a role on financing investment.[3] Bernanke *et al.* (1999) have financial intermediaries taking deposits from households. We allow banks to accumulated capital directly and to take on deposits. Then we impose reserve levels and capital adequacy requirements to capture the essence of the regulatory framework under which the banking system operates.

The model is populated by households, capital producers, wholesale producers, retailers, banks, and the central bank. Households own and operate all the firms. Capital producers determine a price for

[2] Faia and Monacelli (2007) and Walentin (2005) provide an insightful theoretical comparative analysis of the Bernanke *et al.* (1999) and Carlstrom and Fuerst (1997) frameworks.

[3] Often, the literature has focused on the role of financial intermediation to finance the wage bill instead of the investment bill (see, e.g., Carlstrom and Fuerst, 2001). We look at the financing model instead because it emphasizes the impact of financial frictions. The idea is that investment -unlike labor- is an intertemporal decision. Therefore, the financial accelerator model not only has the potential to amplify the effects of a shock, but by constraining capital accumulation it also propagates the effects of the shock over time.

capital. Retailers are distinguished from wholesale producers in order to introduce price inertia in a tractable manner. Wholesale producers themselves are operated through firms or entrepreneurs subject to idiosyncratic shocks and, therefore, exposed to bankruptcy. We also add a banking system that intermediates between the households and the wholesale producer firms. The financial intermediation occurs in an environment where capital returns on defaulting firms are not observable, so loan contracts are designed to reduce the agency costs associated. Funds must be raised from households. Finally, a central bank is added with powers to set both banking regulation as well as monetary policy.

2.1 Description of the Model

Since the model of Bernanke *et al.* (1999) is quite well-known, we refrain from a detailed discussion of their first principles. This section describes the log-linearized version of the model and its variants to make the presentation more compact. For more details, we refer the reader to the original paper or suggest further readings along the way. We specify a stochastic general equilibrium model populated by a continuum of infinitely-lived (and identical) households in the interval $[0, 1]$. Households maximize utility additively separable on consumption and labor. Aggregate consumption evolves according to a standard Euler equation,

$$\widehat{c}_t \approx \mathbb{E}_t\left[\widehat{c}_{t+1}\right] - \sigma\left(\widehat{i}_{t+1} - \mathbb{E}_t\left[\widehat{\pi}_{t+1}\right]\right), \tag{1}$$

where $\sigma > 0$ $(\sigma \neq 1)$ is the elasticity of intertemporal substitution, $\widehat{c}_t$ denotes consumption, $\widehat{i}_{t+1}$ is the nominal interest rate, and $\widehat{\pi}_t \equiv \widehat{p}_t - \widehat{p}_{t-1}$ stands for inflation. The intertemporal elasticity of substitution, σ, regulates the sensitivity of the consumption path to the Fisherian real interest rates, i.e. $\widehat{r}_{t+1} \equiv \widehat{i}_{t+1} - \mathbb{E}_t\left[\widehat{\pi}_{t+1}\right]$. We approximate the labor supply as follows,

$$\widehat{w}_t - \widehat{p}_t \approx \frac{1}{\sigma}\widehat{c}_t + \varphi\widehat{h}_t, \tag{2}$$

where $\varphi > 0$ denotes precisely the inverse of the Frisch elasticity of labor supply, $\widehat{h}_t$ represents labor, $\widehat{w}_t$ are nominal real wages and $\widehat{p}_t$ is the consumption price index (CPI).

Capital accumulation evolves according to a conventional law of motion,

$$\widehat{k}_{t+1} \approx (1-\delta)\,\widehat{k}_t + \delta\widehat{x}_t, \tag{3}$$

where $\widehat{k}_t$ denotes physical capital and $\widehat{x}_t$ stands for investment. Investment dynamics, however, are conditional on our underlying assumptions regarding the costs faced to change the flow of investment. The first equation that we add to our model, as in Bernanke *et al.* (1999), assumes that this adjustment cost is a function of the investment-to-capital ratio (aka, CAC function). Investment dynamics are governed by,

$$\widehat{q}_t \approx \chi\delta\left(\widehat{x}_t - \widehat{k}_t\right), \tag{4}$$

where χ regulates the degree of concavity of the cost function around the steady state. This parameter directly affects the sensitivity of investment to fluctuations in the real value of installed capital (or Tobin's q), $\widehat{q}_t$, through the investment equation.

We also consider two different alternative specifications for this adjustment costs. On one hand, we adopt the Christiano *et al.* (2005) conjecture that the adjustment cost is a function of investment growth instead (aka, IAC function). Accordingly, the investment equation behaves as follows,

$$\widehat{x}_t \approx \frac{1}{1+\beta}\widehat{x}_{t-1} + \frac{\beta}{1+\beta}\mathbb{E}_t\left[\widehat{x}_{t+1}\right] + \frac{1}{\kappa\left(1+\beta\right)}\widehat{q}_t, \tag{5}$$

where κ regulates the degree of concavity of the cost function around the steady state, and where $\beta \in (0,1)$ is the subjective intertemporal discount factor of the households. Implicitly we ought to assume that households make all the investment decisions or, alternatively, that capital producers are fully-owned by the households and operate in competitive markets. The parameter κ directly affects the sensitivity of investment to fluctuations in Tobin's q, but the investment equation in (5) reveals now that investment is both inertial and forward-looking (unlike in the Bernanke *et al.*, 1999, setting). On the other hand, we also consider the simpler case in which there are no adjustment costs. Hence, that would imply,

$$\widehat{q}_t \approx 0. \tag{6}$$

This case is of particular interest because without the asset price fluctuations captured by Tobin's q, the Bernanke *et al.* (1999) loses the characteristic that asset price movements serve to reenforce credit market imperfections. For more details on the derivations of the investment equations, see Martínez-García and Søndergaard (2008).

On the supply-side, besides capital producers, the sector consists of a continuum of wholesale producers and retailers each located in the interval $[0,1]$. The wholesale firms are responsible for manufacturing wholesale goods. In turn, the retailers can be thought as adding a 'brand' name to the wholesale good to introduce differentiation and, consequently, to gain monopolistic power to charge a retail mark-up[4]. Both, wholesale producers and retailers are solely owned by the households.

The wholesale good is the only input used by retailers. For simplicity, we assume that no capital or labor is added to the retail goods. Retailers choose their price to maximize the expected discounted value of their net profits, subject to a demand constraint. Due to Calvo-signals (e.g., Calvo, 1983), in each period only a fraction $1-\alpha$ of the retailers gets to re-optimize. Households do have a taste for all retail varieties, and the elasticity of substitution across varieties is constant at θ. The resulting inflation dynamics aggregating over all retailers are captured by the following process,

$$\widehat{\pi}_t \approx \beta\mathbb{E}_t\left[\widehat{\pi}_{t+1}\right] + \left(\frac{\left(1-\alpha\beta\right)\left(1-\alpha\right)}{\alpha}\right)\left(\widehat{p}_t^w - \widehat{p}_t\right), \tag{7}$$

where, for notational convenience, we denote the relative wholesale price as $\widehat{p}_t^{rw} \equiv \left(\widehat{p}_t^w - \widehat{p}_t\right)$. This equation takes the form of a conventional Phillips curve. In an environment with price rigidity, retailers will, in addition to current marginal costs, take into account expected future marginal costs, giving rise to the

[4]Wholesale producers manufacture wholesale goods in competitive markets and then sell their output to retailers who are monopolistic competitors. Retailers do nothing other than buy goods from entrepreneurs, differentiate them (costlessly), then re-sell them to households. The monopoly power of retailers provides the source of nominal stickiness in the economy; otherwise, retailers play no role.

forward looking term in the Phillips curve. We can summarize the profits from retailers as follows,

$$\widehat{\pi}_t^r \approx \widehat{p}_t + \widehat{y}_t + (1-\theta)\,\widehat{p}_t^{rw}. \tag{8}$$

Naturally, the retailer's profits are rebated lump-sum to the households.

The wholesale producers require homogenous labor and capital to produce wholesale output. All factor markets are perfectly competitive, and each producer relies on the same Cobb-Douglas technology. Naturally, output can be expressed as follows,

$$\widehat{y}_t^w \approx \widehat{a}_t + (1-\psi)\,\widehat{k}_t + \psi\widehat{h}_t, \tag{9}$$

where $\psi \in (0,1)$ is the labor share in the production function, $\widehat{y}_t^w$ denotes the wholesale output and $\widehat{a}_t$ is an aggregate productivity shock. The productivity shock follows an AR(1) process of the following form,

$$\widehat{a}_t = \rho_a \widehat{a}_{t-1} + \varepsilon_t^a, \;\; |\rho_a| < 1, \tag{10}$$

where ε_t^a is a zero mean, uncorrelated and normally-distributed innovation. The parameter ρ_a determines the persistence of the productivity shock.

Since wholesale producers operate in a competitive labor market, the real wages paid to households should be equal to the marginal return on labor. That gives us the following equation for the labor demand,

$$\widehat{w}_t - \widehat{p}_t \approx (\widehat{p}_t^w - \widehat{p}_t) + \left(\widehat{y}_t^w - \widehat{h}_t\right), \tag{11}$$

Combining equations (2) and (10), we can easily derive a labor market equilibrium condition in the following terms,

$$\widehat{y}_t^w - \widehat{h}_t + \widehat{p}_t^{rw} - \frac{1}{\sigma}\widehat{c}_t \approx \varphi\widehat{h}_t. \tag{12}$$

This equilibrium condition allows us to internalize the behavior of real wages, but we still have to account for the cost of capital. Wholesale producers buy the capital stock from capital goods producers at a given price determined by Tobin's q, using both internal funds (or net worth as it is called in Bernanke *et al.*, 1999) and loans from the financial system. After purchasing the capital stock, wholesale producers are hit with an idiosyncratic shocks that affects each entrepreneur's capital holdings. Subsequently, they must utilize capital to produce perfectly substitutable wholesale goods. Accordingly,

$$\mathbb{E}_t\left[\widehat{r}_{t+1}^k - \widehat{\pi}_{t+1}\right] \approx \mathbb{E}_t\left[(1-\epsilon)\left(\widehat{p}_{t+1}^{rw} + \widehat{y}_{t+1}^w - \widehat{k}_{t+1}\right) + \epsilon\widehat{q}_{t+1}\right] - \widehat{q}_t, \tag{13}$$

where the coefficient $(1-\epsilon)$ is obviously related to the steady state of the model, and the inflation rate is defined as follows $\widehat{\pi}_{t+1} \equiv \widehat{p}_{t+1} - \widehat{p}_t$. We treat ϵ as a free parameter rather than a composite of the structural parameters of the model to give more flexibility to the representation. The expected returns on capital net of inflation, $\widehat{r}_{t+1}^k - \widehat{\pi}_{t+1}$, must be approximately equal to the marginal returns on capital from the production function and the cost of buying and re-selling the stock of capital to the capital producers (as captured by Tobin's q). The marginal return on capital, which is defined as $\widehat{p}_{t+1}^{rw} + \widehat{y}_{t+1}^w - \widehat{k}_{t+1}$, would give us the shadow value of renting out capital to other firms that can 'guarantee' that competitive return. Equation (12) gives us an asset pricing characterization of the Tobin's q which is quite instrumental in the model. Thus far, the model is fairly standard and follows Bernanke *et al.* (1999), in particular, closely (although expanded to distinguish between nominal and real variables).

Following the costly state verification framework of Bernanke *et al.* (1999), wholesale producers cannot borrow at the riskless rate. The cost of external financing differs from the risk-free rate because the returns to capital of the wholesale producers are unobservable from the point of view of the financial intermediaries. In order to infer the realized return of the entrepreneur, the bank has to pay a state verification cost. The banks monitor the producers that default, pay the verification cost and seize the remaining capital. In equilibrium, wholesale producers borrow up to the point where the expected return to capital equals the cost of external financing,

$$\mathbb{E}\left[\widehat{r}_{t+1}^{k}-\widehat{\pi}_{t+1}\right] \approx \widehat{i}_{t+1}-\mathbb{E}_{t}\left[\widehat{\pi}_{t+1}\right]+\vartheta\left(\widehat{n}_{t+1}-\widehat{p}_{t}-\widehat{q}_{t}-\widehat{k}_{t+1}\right), \tag{14}$$

which can be decomposed in two terms, the risk-free rate itself and the external financing premium.[5] The parameter ϑ measures the elasticity of the external financing premium to variations in wholesale producer internal funds, measured by its net worth relative to capital expenditures. The higher the producer's stake in the project (i.e. the higher N/PQK), the lower the associated moral hazard. As shown explicitly in Bernanke *et al.* (1999), the premium over the risk-free rate the financial intermediary demands is a negative function of the amount of collateralized net worth. In case producers have sufficient net worth to finance the entire capital stock, agency problems vanish, so the risk-free rate and the return to capital coincide.

Aggregate net worth for the wholesale producers accumulates according to the following equation[6],

$$\widehat{n}_{t+1}-\widehat{i}_{t} \approx \zeta \frac{1}{\beta}\left[\widehat{n}_{t}+\eta\left(\widehat{r}_{t}^{k}-\widehat{i}_{t}\right)-\eta\left(\widehat{p}_{t-1}+\widehat{q}_{t-1}+\widehat{k}_{t}\right)\right], \tag{15}$$

where ζ can be interpreted as a survival rate in the spirit of Bernanke *et al.* (1999). Alternatively, we prefer to think of this parameter as an implicit profit-sharing parameter. Households would, accordingly, receive a constant fraction of that net worth which is not retained in the form of lump-sum dividends. Hence, it is possible to write an approximation for wholesale profits in the following terms,

$$\widehat{\pi}_{t}^{w} \approx \widehat{n}_{t+1}. \tag{16}$$

The parameter η, in turn, represents the fraction of capital over net worth in steady state and is taken also as a free parameter to make our model more flexible. Equation (15) simply tells us that the present discounted value of next period's nominal net worth, where net worth is denoted as $\widehat{n}_{t+1}$, must be approximately equal to the current net worth at the beginning of the period adjusted by taking out the cost of capital and adding the differential between the returns on capital and the risk-free rate.

[5] The key mechanism involves the link between "external finance premium" (the difference between the cost of funds raised externally and the opportunity cost of funds internal to the firm) and the net worth of potential borrowers (defined as the borrowers' liquid assets plus collateral value of illiquid assets less outstanding obligations).

[6] We rewrite the model without the bankruptcy cost and default threshold parameters of Bernanke *et al.* (1999), and we implicitly assume that in a deterministic steady state the costs of bankruptcy must be approximately equal to zero. There are a couple of reasons to do so. First, it allows us to refrain from assumptions about the distribution of idiosyncratic productivity shocks, as well as its parameters. This approach avoids a number of computational difficulties, as in Meier and Müller (2005). Second, the remaining parameters can arise in related frameworks. One particular strand of models we have in mind is that of limited enforcement (e.g. Kiyotaki and Moore 1997). Although the underlying microeconomic assumptions are entirely different, these models give rise to similar financial accelerators.

The standard goods market equilibrium condition is augmented with a term capturing the costs of variable bankruptcy derived from the costly-state verification framework of Bernanke *et al.* (1999),

$$\widehat{y}_t \approx \gamma_c \widehat{c}_t + (1 - \gamma_c - \gamma_{csv}) \widehat{x}_t + \gamma_{csv} \left(\widehat{r}_t^k + \widehat{p}_{t-1} + \widehat{q}_{t-1} + \widehat{k}_t \right), \tag{17}$$

where γ_c denotes the consumption share, $\gamma_x = (1 - \gamma_c - \gamma_{csv})$ is the investment share, and γ_{csv} is the share attributed to the bankruptcy costs in steady state. In this class of models, the consumption share is a function of the elasticity of substitution across varieties, θ, which is a structural parameter, but does not appear anywhere else in the linearization. Therefore, the consumption share can be viewed as a free parameter in itself. The share on the costly state verification costs is taken as a free parameter to ensure that our model is flexible enough; however, we adopt in most of our simulations the assumption that these costs are negligible in steady state, so $\gamma_{csv} = 0$. The costs of state verification are a function of the value of capital at liquidation plus the returns on capital, all of which is appropriated by the bank after the wholesale producers declare bankruptcy (and the banks pay for the verification).

In line with most of the literature, we assume that monetary authorities are willing to smooth changes in the actual short-term nominal interest rate, $\widehat{i}_t$, but do target inflation and output (the dual mandate). Short-term rates, however, may deviate unexpectedly from their target rates for exogenous reasons (out of the control of the monetary authorities). Thus, the monetary policy is determined by the following Taylor-type interest rate rule,

$$\widehat{i}_{t+1} = \rho_i \widehat{i}_t + (1 - \rho_i) \left[\psi_\pi \widehat{\pi}_t + \psi_y \widehat{y}_t \right] + \widehat{m}_t, \tag{18}$$

where ρ_i is the smoothing parameter, ψ_π and ψ_y are the weights on inflation an output for the target rate, and $\widehat{m}_t$ defines the monetary shock in the economy. The monetary policy shock follows an AR(1) process of the following form,

$$\widehat{m}_t = \rho_m \widehat{m}_{t-1} + \varepsilon_t^m, \;\; |\rho_m| < 1, \tag{19}$$

where ε_t^m is a zero mean, uncorrelated, and normally-distributed innovation. The parameter ρ_m determines the persistence of the monetary shock.

Up to this point, we have followed very closely the derivation of the linearized equilibrium conditions in Bernanke *et al.* (1999). The main differences arise because we have implicitly subsumed the role of entrepreneurs operating the wholesale producers into the households. We have adopted the view that entrepreneurial labor is negligible and that the net worth of producers that go bankrupt is rebated directly to the households as dividends rather than consumed by a different agent in the form of an entrepreneur. In that sense, we view wholesale producers strictly as firms whose sole ownership corresponds to the households. We contend that this variations are rather minor and do not affect the principal characteristics of the financial accelerator developed in Bernanke *et al.* (1999).

A More Complex Financing Structure. The Miller-Modigliani theorem asserts that, under perfect capital markets, economic decisions do not depend on financial structure. An obvious implication is that the addition of financial intermediaries to this environment has no consequences for real activity. Here, we attempt to revive the idea that the services provided by financial intermediaries or banks are important determinants of aggregate economic performance. The banking sector in the model of Bernanke *et al.* (1999) is fully described by the equilibrium conditions described up until this point.

The implicit assumption is that banks are perfectly competitive and that the deposits held by households at intermediaries must be equal the total loanable funds supplied to the wholesale producers to finance their capital acquisitions in every period, i.e.

$$\widehat{l}_t \approx \widehat{d}_t,$$

where $\widehat{d}_t$ represents the nominal amount of deposits in the financial intermediaries. While the banks offer deposits and loans, the demand for those deposits has to be met by the households and the demand for those loans by the wholesale producers. Therefore, in this setting, households finance the external funding needs of wholesale producers and all the relevant features in the financial side are summarized in the implicit costly-state verification contract (and how it handles the moral hazard problem posited) as described by Bernanke, *et al.* (1999).

Until now, we have departed from Bernanke, *et al.* (1999) only slightly. Here, however, we propose a non-negligible expansion of the model in which the balance sheet of the banking sector is no longer trivial. First, we need to take into account that the demand for loans from the financial intermediaries is simply equal to the difference between the value of capital acquired and the net worth (internal funds), i.e.

$$\widehat{l}_t \approx \left(\widehat{p}_{t-1} + \widehat{q}_{t-1} + \widehat{k}_t\right) - \widehat{n}_t. \tag{20}$$

Second, we need to take into account that the demand for deposits can be determined by the budget constraint of households, i.e.

$$\frac{PC}{PC+D}\left(\widehat{p}_t + \widehat{c}_t\right) + \frac{D}{PC+D}\widehat{d}_{t+1} \approx \frac{WH}{PC+D}\left(\widehat{w}_t + \widehat{h}_t\right) + \frac{D}{PC+D}\frac{1}{\beta}\left(\widehat{i}_t + \widehat{d}_t\right) + \frac{\Pi^r}{PC+D}\widehat{\pi}^r_t + \frac{\Pi^w}{PC+D}\widehat{\pi}^w_t.$$

We already know from equations (8) and (16) that the dividends received by the households can be expressed in terms of other endogenous variables. As a result, it follows that,

$$\begin{aligned} &\tfrac{PC}{PC+D}\left(\widehat{p}_t + \widehat{c}_t\right) + \tfrac{D}{PC+D}\widehat{d}_{t+1} \approx \tfrac{WH}{PC+D}\left(\widehat{w}_t + \widehat{h}_t\right) + \\ &+ \tfrac{D}{PC+D}\tfrac{1}{\beta}\left(\widehat{i}_t + \widehat{d}_t\right) + \tfrac{\Pi^r}{PC+D}\left[\widehat{p}_t + \widehat{y}_t + (1-\theta)\,\widehat{p}^{rw}_t\right] + \tfrac{\Pi^w}{PC+D}\widehat{n}_{t+1}. \end{aligned}$$

Similarly, using the labor demand equation in (11) it easily follows that,

$$\begin{aligned} &\tfrac{PC}{PC+D}\left(\widehat{p}_t + \widehat{c}_t\right) + \tfrac{D}{PC+D}\widehat{d}_{t+1} \approx \tfrac{WH}{PC+D}\left(\widehat{p}^w_t + \widehat{y}^w_t\right) + \\ &+ \tfrac{D}{PC+D}\tfrac{1}{\beta}\left(\widehat{i}_t + \widehat{d}_t\right) + \tfrac{\Pi^r}{PC+D}\left[\widehat{p}_t + \widehat{y}_t + (1-\theta)\,\widehat{p}^{rw}_t\right] + \tfrac{\Pi^w}{PC+D}\widehat{n}_{t+1}. \end{aligned} \tag{21}$$

These two equations would be sufficient to close the model in Bernanke *et al.* (1999) and to pin down deposits and loans, and it must be the case that they equate.

We are going to introduce, however, two twists on the balance sheet of the banking sector. First, we assume that under normal circumstances, the balance sheet of the central bank adopts a more complex structure, i.e.

$$\widehat{l}_t \approx \frac{B}{L}\widehat{b}_t + \left(1 - \frac{B}{L}\right)(1-\varpi)\,\widehat{d}_t, \tag{22}$$

where $\widehat{b}_t$ denotes the bank capital in nominal terms, $\widehat{d}_t$ is the nominal value of deposits, and ϖ represents the reserve requirement on real deposits. In other words, the total amount of loans must be a combination of bank capital plus the fraction of deposits not subject to reserve requirement. Deposits held at the central bank in the form of reserves do not earn interest.[7] Notice that $\frac{B}{L}$ can be interpreted as the long-run steady state leverage ratio of the banking system. As a result, the regulator can affect the total amount of loans in the economy by manipulating the reserve requirement.

Second, we assume that there is a regulatory lower bound on the leverage ratio of the banking capital such that,

$$\widehat{b}_t \geq c^l \widehat{l}_t$$

This implies that the bank capital has to be above a minimum statutory leverage ratio, c^l. The minimum leverage ratio these days, for instance, is 4%. We make the implicit assumption that $\frac{B}{L} \geq c^l$. One way to interpret this restriction is to say that whenever it is binding, i.e. if

$$\widehat{b}_t \approx c^l \widehat{l}_t, \tag{23}$$

banks will only be able to take on a total amount of deposits that is proportional to the available capital. The expression for the total amount of available deposits in equilibrium is determined as follows,

$$\widehat{d}_t \approx \frac{\left(\frac{1}{c^l} - \frac{B}{L}\right)}{\left(1 - \frac{B}{L}\right)(1 - \varpi)} \widehat{b}_t.$$

Clearly, the regulator can also affect the demand for deposits and the amount of available loans by changing the requirements. Another way to think about the constraint environment is to say that loans are rationed and the amount of deposits is capped too. That's what our previous derivations entail. Replacing this into the equation for the deposit demand it follows that,

$$\begin{aligned} &\tfrac{PC}{PC+D}\left(\widehat{p}_t + \widehat{c}_t\right) + \tfrac{D}{PC+D} \tfrac{\left(\frac{1}{c^l} - \frac{B}{L}\right)}{\left(1-\frac{B}{L}\right)(1-\varpi)} \widehat{b}_{t+1} \approx \tfrac{WH}{PC+D}\left(\widehat{p}^w_t + \widehat{y}^w_t\right) + \\ &+ \tfrac{D}{PC+D} \tfrac{1}{\beta} \left(\widehat{i}_t + \tfrac{\left(\frac{1}{c^l} - \frac{B}{L}\right)}{\left(1-\frac{B}{L}\right)(1-\varpi)} \widehat{b}_t\right) + \tfrac{\Pi^r}{PC+D}\left[\widehat{p}_t + \widehat{y}_t + (1-\theta)\,\widehat{p}^{rw}_t\right] + \tfrac{\Pi^w}{PC+D} \widehat{n}_{t+1}. \end{aligned} \tag{24}$$

We assume that $\widehat{b}_t$, bank reserves, evolve exogenously. The bank capital follows an AR(1) process of the following form,

$$\widehat{b}_t = \beta \widehat{b}_{t-1} + \varepsilon^b_t, \tag{25}$$

where ε^b_t is a zero mean, uncorrelated and normally-distributed innovation. The parameter β, which represents time-preference as well as the inverse of the long-run interest rate, determines the persistence of the bank capital process.We also assume that there is an exogenous probability of becoming constrained which is determined uniquely by the current value of $\widehat{b}_t$ and the distribution shocks.

[7] Currently, reserve requirements held at the Federal Reserve do not pay interest. In 2006, congress gave the Federal Reserve permission to pay interest on reserves, but mandated that this wait until 2011 to take place. The Federal Reserve has requested permission to start this program immediately. The Federal Reserve has argued that paying interest would deter banks from lending out excess reserves and as such would make it easier for the Fed to attain its target rate.

3 Simulation and Estimation

As noted, we make two substantive claims in the paper. One, the model economy has no financial acceleration of the monetary transmission mechanism in the constrained world. Two, monetary policy with a capital threshold implies considerably different actions in the constrained and unconstrained states of the world. We find evidence of these differences in our model and find optimal monetary policy parameters that reflect the patterns of monetary policy evident in the US before and during the current credit crisis.

We proceed here to answer each of these questions. The first can be answered using relatively standard computational tools (e.g. Dynare) and showing results from two isolated economies, one of which is constrained and one unconstrained. For the second question, we will use a version of a simulated generalized methods of moments (S-GMM) approach in order to obtain answers. Essentially we will need to find monetary policy parameters that optimize some loss function with respect to the shocks in the economy and the model that we've specified. This is a problem well suited to the mechanics of S-GMM as one needs to estimate optimal parameters in the absence of information about the economy's behavior under a range of counter-factuals. Using the model, we can simulate the economy under a wide range of parameter possibilities and use S-GMM to yield policy functions in a consistent way.

3.1 Parameters

As our goal here is to comment on the role of monetary policy in the context of banking sector stress, we follow the literature in the choice of parameter values. Labor share is set to 0.64, and quarterly capital depreciation is set to 0.025. Our Calvo-price stickiness parameter is set at 0.75, and inverse labor supply elasticity is set to 3. Each of these parametric choices follows Bernanke, *et al.* (1999) exactly. We also set the discount rate to a quarterly 0.971 and the elasticity of substitution across varities at 1.05. Kydland and Prescott (1982) calibrated the elasticity of intertemporal substitution to 0.66 and Lucas (1990) argued that even 0.5 appears too low for macro data. For comparability, our elasticity of intertemporal substitution is set at 0.5. What we have called the sensititivity to the external finance premium, υ, is fixed at 0.25.

Capital adjustment costs are set at 0.999, and the profit reinvestment rate is set at a constant 0.8. We parameterize our Taylor rule as follows. Interest rate inertia, ρ_i, is set at 0.9. As well, we set steady state nominal bank capital to 0.15.

We follow Bernanke, *et al.* (1999) in imposing a unit root on productivity. The shocks themselves are zero mean, with uncorrelated innovations whose variance is fixed at 0.0066. Perhaps most importantly, we set the leverage maximum to 25, which implies a capital to asset ratio of 0.04. Basle I requirements stipulate that a Tier 1 capital[8] to assets ratio of below 0.04 implies that the institution is 'undercapitalized.' Being 'well capitalized' requires a Tier 1 capital to assets ratio of above 0.06. We use the 0.04 level for the industry as this reflects the point at which financial institutions can be considered in 'distress' from the point of view of the regulator, which in turn menas that monetary policy becomes almost completely ineffective.

Our parameter choices are summarized in Table 1.

[8] Tier 1 capital is defined as common equity, non-cumulative perpetual preferred stock and minority interests in equity accounts of minority shareholders.

3.2 Methodology

Thus, we begin with a standard simulation exercise to answer question 1 by looking at two economies separately. One is the standard unconstrained banking system popularized by Bernanke, *et al.* (1999), modified in the ways discussed above and studied also by many others. The other is the constrained system. In the constrained economy, banks cannot expand lending as capital levels lie below the regulatory threshold. In each of the two economies, the central bank follows a Taylor rule.

The goal of course, is then to understand find Taylor parameters that minimize some objective function. To answer this question, we move to the exercise that looks in form like simulated generalized method of methods (S-GMM). Below, we'll discuss why it is not precisely S-GMM. Of course, the object is to estimate a vector of structural parameters, denoted θ, which minimize a given social loss function. For our case, $\theta \equiv \left\{\psi_\pi^u, \psi_y^u, \psi_\pi^c, \psi_\pi^c; P\right\}$, where P is the vector of all parameters of the specified system (see table 1). A simulated GMM approach minimizes the weighted distance between moments of the data, M^D, and moments produced from a simulation of the model using a vector of parameters, $M^s(\theta; P)$. Thus one wants an estimate of θ to minimize the function,

$$A(\theta) = \left(M^d - M^s(\theta; P)\right) W \left(M^d - M^s(\theta; P)\right)'$$

where W is an appropriate weight matrix.

As there is no clear analytic representation of the mapping of θ to the relevant moments, one can solve this type of minimization problem by simulation. Given vectors θ and P, we can generate full time-paths of economic processes using the steady-state equations in this paper. Using the output of these processes, such as relevant impulse response functions, we can calculate moments, M^d, to estimate the above. In our case our full parameter vector is the set of four Taylor-rule parameters and the remaining parameters of the full system. For the purposes of this analysis, we will take the parameters contained in the vector P as given and estimate the four Taylor-rule parameters using a variant of S-GMM.

We deviate here from S-GMM as follows. Because optimal monetary policy parameter is conditioned on the model of the economy used, in our case, the analog to a moment from the data, M^d, is simply the moments that are generated from the steady-state model. Thus, we can interpret $M^s(\theta; P)$ as the moments that are derived from a given set of shocks, conditional on the model economy. For the moments, we use the absolute value integral of the deviation from steady-state of output and inflation. That is, all deviations from steady state receive equal punishment, whether up or down. Thus a shock to output that causes output to decline, then increase above steady state before returning would receive a value equal to the absolute value of the integral of the impulse response function below steady state plus the absolute value of the integral for the time period above. By assumption, the model produces steady-state values for output and inflation and deviations can be regarded as negative outcomes. Since the baseline in this model is indeed the steady state, we can reduce the equation above to reflect the fact that optimal monetary policy is typically derived by looking at variation from a specified loss function. We can specify that the GMM objective function is now,

$$A(\theta) = (M^s(\theta)) W (M^s(\theta))'.$$

Notice that the M^d have disappeared as these moments are by definition zero. If the moments specified here are $|\pi(\theta) - \pi^*|$ and $|y(\theta) - y^*|$, then we have a pseudo-GMM method of estimation that maps back into a standard view of the loss function as absolute value deviations from optimal levels of π and y. Notice that this corresponds to a mechanism calculation to find the Taylor parameters that lead to the smallest deviations from steady state.

One could in principle also use moments from the data, M^D, and optimize over monetary policy in order to find the parameter vector θ. This corresponds to estimation of the existing historical Taylor rules. The difference between this data approach and ours highlights a methodological distinction. We allow the model to 'speak' on its own, a figurative tying of our hand behind our backs. In that, we are not *fitting* the model to the data, but instead conjecturing a model of the economy and letting it determine a 'best' policy response. We believe that consistent findings in this approach provide greater support for the claims of the model than a direct S-GMM approach. As well, we sidestep difficult questions that would come with a data approach; for example, we do not need to claim knowledge of the precise timing of a bank capital shock.

We compute moments as follows. For each exogenous shock, ε, specified in the full system below, we compute the integral above for $\pi(\theta, \varepsilon)$ and $y(\theta, \varepsilon)$. Beginning with evaluation of two shocks, ε^a and ε^b, to productivity and bank capital, we have four moments to estimate and four output parameters. The weighting matrix, W, is generated using the covariance matrix of shocks derived from a evolution of the system with all shocks allowed to propogate simultaneously. We search over a large number of combinations of θ using grid-search methods. For each of these, we can solve the function above, where the lowest value of $A(\theta)$ yields the optimal set of Taylor rule parameters, two for each state of the world: $(\psi_\pi^u, \psi_y^u, \psi_\pi^c, \psi_\pi^c)$, where the superscripts u, c refer to the unconstrained and constrained states respectively.

Full description of the estimation method is included in the appendix.

4 Findings

4.1 Claim 1: Constrained Economies Have Weaker Transmission Mechanisms

Figure 1 below shows the results from the initial stage of simulation. The chart shows the output and interest rate responses to a productivity shock in each of our two regimes. Recall that our first exercise is one in which the two regimes are fully isolated. The constrained and unconstrained cases in the figure reflect separate economies, each one trapped in a different absorbing state of the aggregate shock. One can think of the difference between the two simply as being a difference in available bank capital for lending. Regardless, one can see much of the intuition behind the joint model in these figues. As placeholders, we specify a set of Taylor rule parameters for use here. We specify $\psi_\pi = 1.5$ and $\psi_y = 0.5$ for both the constrained and unconstrained cases in accord with recent literature.

Consider table 2. To create this table, we estimate a set of 14 impulse response functions for the response of output to a productivity shock. The first two columns consider the constrained case and the latter two columns the unconstrained case. Recall that we have partioned the world into two absorbing states for the time being. Each row defines a steady state ratio of bank capital to loans. One can imagine that steady state value below 0.1 corresponds broadly to what might reasonable be considered the constrained world; a situation in which loans are more than 10 times capital. The high capital to loan ratios may be more appriopriate for the unconstrained case.

Interpreting the magnitudes of the impulse response functions (IRFs) here is difficult given that the world indeed changes between states, thus a characterization of a shock that impacts bank capital and may change the state may not accurately be reflected here. Regardless, the exercise here is to comment principally on differences between the sets of IRFs.

Columns 1 and 3 show the magnitude of initial change in output as a result of a shock to productivity. Columns 2 and 4 show the impact of the policy response from the lowest output point to the highest.

Notice a couple of features. First, the magnitudes in the constrained case are unchanging across specifications of bank capital level. This is a product of the fact that the financial accelerator in the model economy for the constrained world does not function. If it did, the responsiveness of the economy would be a function of bank leverage. This leads to the second point - the accelerator is functioning in the unconstrained world. The magnitude of the economic responses is clearly dependent on bank leverage and increasing with it. When the economy is in a de-leveraged state in the unconstrained world, as seen in the bottom couple of rows, the accelerator begins to function.

4.2 Claim 2: Consistent with U.S. Patterns

To wrap up the claims of the paper, we look for optimal Taylor parameters using the S-GMM method described above and in the appendix. We find optimal parameters in each state of the world as shown in Table 3. The unconstrained parameter fit reasonably well with priors on the behavior of the central bank. Prior literature has led to the conclusion of Taylor rule parameters with magnitudes of the inflation and output of approximately 1.5 and 1.0 respectively; however, with the authority's knowledge of the presence of a constrained world, one may need to consider anew the parameters that would prevail. In particular, notice that the model economy here contains financial sector features that lead to larger output responses to shocks than model with no financial frictions.

The most remarkable feature of the results is the presence of a large negative value for ψ_π^c, the bank's response to movements in the rate of inflation in the constrained state. Of course, a large negative number implies that the central bank will lower interest rates in the face of rising inflation. This is likely to stoke inflation and increase it further, leading to spiraling increasing rates. The only way for the economy to recover from this is for bank capital to rise and return the economy to the unconstrained state in which the central bank will then work in the opposite direction. So, why pursue this path? Lowering the interest rate has the effect, in our model, of devaluing debt. By doing so, this directly increases bank capital. Since the bank has no way to impact the real economy as the accelerator has disappeared, the only way to recover is to impose an inflation-based transfer to the banking sector. We view this as a plausible explanation for the actions of the Federal Reserve to the recent crisis. To the extent that one can view the crisis as a shock to bank capital, the most effective solution, according to the mechanisms in our model, is to lower interest rates and accommodate inflation. This pattern would then be reversed at the point that bank capitalization has returned to the unconstrained state.

In order to test the sensitivity of the results, we reconsider the objective function for only the constrained cases under the condition that the unconstrained case meet conventional wisdom regarding the sensitivity of monetary policy to inflation and output. Thus, we set $\psi_\pi^u = 1.5$ and $\psi_y^u = 0.5$ and look for optimal ψ_π^c, ψ_y^c. Results are available in Table 4. While the magnitude of ψ_π^c is now -1 rather than -2, we consider any negative number quite notable in the context of modern views of monetary policy.

4.3 Sensitivity Tests and Additional Evidence

"Conventional Wisdom"

To test the results of the model, we look at a few exercises. In particular, we wish to evaluate whether the central result of a pro-inflationary central bank maintains across a range of unconstrained monetary policies. We look both at the conventional Taylor Rule of $\psi_{\pi}^{u} = 1.5$ and $\psi_{y}^{u} = 0.5$. Results are in table 4. As such, we reconsider the objective function for only the constrained cases under the condition that the unconstrained case meet conventional wisdom regarding the sensitivity of monetary policy to inflation and output. Thus, we set $\psi_{\pi}^{u} = 1.5$ and $\psi_{y}^{u} = 0.5$ and look for optimal $\psi_{\pi}^{c}, \psi_{y}^{c}$. Results are available in Table 4. While the magnitude of ψ_{π}^{c} is now -1 rather than -2, we consider any negative number quite notable in the context of modern views of monetary policy. Table 5 shows the results of a similar test on varying levels of ψ_{π}^{u} and ψ_{y}^{u}.

Simulated GMM, reprised

One can also use similar methods (S-GMM) to evaluate the model's performance vis-a-vis a range of benchmarks from the data. We look at three moments from the data $\left(M^{d}\right)$: volatility of interest rates, output and the correlation between these two. We then re-evaluate the objective function below to find the optimal monetary policy parameters.

$$A(\theta) = \left(M^{d} - M^{s}(\theta; P)\right) W \left(M^{d} - M^{s}(\theta; P)\right)'$$

Results are in table 5. We find that the patterns using this version of GMM are largely similar to those above. In particular, the key finding of a pro-inflationary response during a constrained environment maintains. Indeed, the model matches the data moments very closely.

5 Discussion

Essential for our analysis, the nonlinearity discussed in this model implies a strong incentive for the joint monetary/regulatory authority to ensure that financial institutions remain above the capital constraint. In times of falling asset values, banks will approach or fall below capital requirements, rendering monetary policy ineffective at stimulating lending. At this point, the monetary/regulatory authority has an incentive to lower capital requirements in order to facilitate monetary intervention (see Figure 1, Panel B). If falling asset values were due to a realization of inaccurate risk measurements, reduced capital levels may simply encourage reckless lending (this is the moral hazard danger).

Consistent with our story, as well as the Ceccheti and Li (2008) intuition, we derive a characterization of the model that implies two regimes for the supply of loans from financial intermediaries that is dependent on the credit supply constraint of the financial system. In one regime, the banking system is unconstrained and depends on own capital as well as deposits to provide the necessary loans to firms for production purposes. In the other regime, the banking system is constrained and depends only on own capital adjusted according to the capital adequacy requirements of the moment. The decision in each period is endogenous, and if the situation is such that the constrained loan supply applies, it can result in a 'credit crunch' where the available funding for productive activities is severely limited.

The fundamental question, then, is how our monetary authority prepares for, and responds to, a 'credit crunch' under such circumstances in the setting of regulatory thresholds. Our model has produced a consistent explanation for the central bank's actions during the crisis.

With this framework in place, there are potentially more open questions that lie beyond the scope of this paper. For example, while the model does a reasonably good job in describing the stylized patterns of the US monetary authority during the recent crisis, it appears to be rejected by the European case. The European Central Bank has held interest rates constant, rejecting the large negative coefficient on ψ_{π}^{c}. Though there are many possible reasons for this, we speculate that this emerges from the differences in mandate. The Federal Reserve has responsibility both for monetary policy and bank regulation of some of the financial system. This produces well-known conflict between counter-cyclical monetary policy and pro-cyclical banking goals. It also produces an incentive to keep banks above regulatory thresholds through the use of monetary policy (see Cechetti and Li, 2008 and neutralization of the capital constraint). Why does this matter here? Two avenues are worth pursuing in future research. One, did the ECB keep rates constant as it saw no direct role within its mandate for financial sector debt deflation? Did the Fed use alternate methods of liquidity provision as a way to provide ad-hoc regulatory tolerance - effectively removing the concern that near-term liquidity problems would decrease asset values sufficiently to lead to a binding capital constraint. By doing so, it attempted to re-open the acceleraztor for monetary policy?

6 Concluding Remarks

We presented a version of the new-Keynesian synthesis model with leveraged and regulated financial sector. Because the financial sector has regulatory constraints, shocks to the economy can lead to an environment in which banks cannot legally expand lending. In such a setting, the financial accelerator, by definition, cannot act. The presence of such a state allows us to estimate optimal monetary policy parameters that are state-dependent. Using a version of S-GMM, we find parameters that stylistically match monetary policy in both states of the world, providing an explanation for the pro-inflationary stance of the monetary authority in the current and past crises.

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Appendix

A S-GMM Computational Procedure

Step 1. Parameterization of the model

Bernanke, *et al.* (1999) provides much of the theoretical framework of the model we are considering. Accordingly, we adopt many of their key assumptions – including most of the parameter values used in their simulation and when appropriate these values are supplemented with well established values from the literature. The detail of which is in our structural parameter list. Our model, however, is a significant extension of the existing literature and we have introduced complexities and parameters which, to our knowledge, have no analogue in existing studies. The values chosen and rationale behind these values can be found in the paper.

Step 2. Determine appropriate grid for examination

As discussed in the paper, we are concerned with minimizing the loss function over possible values for ψ_π^c, ψ_y^c, ψ_π^u, and ψ_y^u (collectively referred to as θ). To do so, we define a range of values for each ψ-parameter and calculate the value of the loss function for each permutation. Regulatory authorities in an unconstrained world respond to deviations from steady state inflation and output. Accordingly, our initial grid allows ψ_π^u and ψ_y^u to range from [0.1:0.1:2.5]. In the constrained world we have fewer *a priori* assumptions about the behavior of regulatory agencies. Accordingly, we allow ψ_π^c and ψ_y^c to range from [-2.5:0.1:2.5].

Step 3. Run unconstrained Dynare process

Conditional on a particular set of ψ_π^u and ψ_y^u values, we use Dynare to solve the DSGE model (in this case the unconstrained process). The details of the Dynare process are, by assumption, familiar to most and as such are omitted here. The Dynare output of interest is the first-order Taylor approximation of the decision and transition functions. For each combination of ψ values, we calculate and store these approximations.

Step 4. Run constrained Dynare process

As Step 3, for a given set of ψ_π^c and ψ_y^c values we obtain the linearized coefficients for the constrained model and store the results.

Step 5. Establish threshold values and transition process

At this point we have two linearized solutions for a set of parameters, θ. We now implement the innovative feature of our model – the incorporation of both states (constrained and unconstrained) into a single policy function. To do so we must specify the mechanism by which policy makers decide how to react to deviations from steady state. In Dynare, the steady state value of each of our variables is normalized to zero and shocks are distributed $N\left(0, \sigma^2\right)$. As such we specify a probabilistic value of a shock to bank capital in steady state that will result in a constrained banking system. The value is uniquely determined by the variance of the shock, σ, and the current distance of bank capital to the regulatory threshold.

Of course, the behavior of the monetary authority and the transition process between the two states is a bit harder to define. For computational simplicity, we assume that the world is considered wholly constrained or wholly unconstrained if, for a given level of bank capital and distribution of shocks, there is less than a 1% possibility that a shock will cause the banking system to change from one regime to the other. Policy makers in this environment have simple policy prescriptions – implement the optimal policy of the current state of the world (be it unconstrained or constrained). However policy makers who operate in an environment where there is a plausible risk to the banking sector do not have such straightforward prescriptions.

Policy makers who have a realistic probability of transitioning from one regime to the other in the next period face a more significant problem – should they blindly continue to implement the policy of the unconstrained/constrained world? Or should they take some other more pro-active action? To account for this ambiguity we assume that policy makers take a measured approach which weights the optimal policy from the constrained and unconstrained worlds according to the probability that a shock, distributed $N\left(0, \sigma^2\right)$, will transition the economy from one state to the other. As the process nears the boundary between states, this average policy reflects an approximation of behavior in a uncertain environment.

Step 6. Run shock process

We now have a process which addresses constrained and unconstrained economies as well as economies which are transitioning between the two states. Next, we evaluate the deviations from steady state, given θ, due to shocks. Specifically we are interested in the response of output and inflation to productivity and bank capital shocks. With the coefficients from the two linearized models we simulate a shock process identical to that performed by Dynare, with the exception of a dynamic coefficient choice. As previously mentioned we weight the coefficients generated in Step 3 and Step 4 by the probability of entering the constrained world, p_c. Thus we simulate the model:

$$y_t = (1 - p_c) * \beta_u y_{t-1} + p_c * \beta_c y_{t-1} + \varepsilon$$

Where y_t are the endogenous variable of interest, β_u and β_c are the linearized coefficients from Step 3 and Step 4, and y_{t-1} is the previous periods endogenous value.

Step 7. Calculate moments for each psi-shock combination

The impulse response functions generated in Step 6 provide the basis for comparison for different θ values. Specifically we calculate moments based on the path of the impulse response functions. We then repeat steps 3-7 for each variant of parameters $\psi^u_{\pi,y}$ and $\psi^c_{\pi,y}$.

Step 8. Select parameter value with minimum moment value

The GMM process minimizes the moments of the loss function such that:

$$A(\theta) = (M^s(\theta;\mu)) W (M^s(\theta;\mu))'.$$

The resultant θ values that produce the minimum distortions from the steady state are then deemed the optimal policy parameters for our dynamic-two state model.

Step 9. Refine grid and repeat

On a course grid we have been able to achieve optimal parameter values, however without a high degree of specificity. Once we achieve a rough estimate of points we refine the grid points and rerun steps 2-8.

B The Complete Log-Linearized Model

As a notational convention, all variables identified with lower-case letters and a caret on top represent a transformation of the corresponding variable in upper-case letters. They are variables in logs and expressed in deviations relative to the their steady state values.

Aggregate Demand Equations.

$$
\begin{aligned}
\widehat{y}_t &\approx \gamma_c \widehat{c}_t + (1-\gamma_c-\gamma_{csv})\,\widehat{x}_t + \gamma_{csv}\left(\widehat{r}^k_t + \widehat{p}_{t-1} + \widehat{q}_{t-1} + \widehat{k}_t\right),\\
\widehat{c}_t &\approx \mathbb{E}_t\left[\widehat{c}_{t+1}\right] - \sigma\left(\widehat{i}_{t+1} - \mathbb{E}_t\left[\widehat{\pi}_{t+1}\right]\right),\\
\mathbb{E}\left[\widehat{r}^k_{t+1}\right] - \widehat{i}_{t+1} &\approx \vartheta\left(\widehat{n}_{t+1} - \widehat{p}_t - \widehat{q}_t - \widehat{k}_{t+1}\right),\\
\mathbb{E}_t\left[\widehat{r}^k_{t+1} - \widehat{\pi}_{t+1}\right] &\approx \mathbb{E}_t\left[(1-\epsilon)\left(\widehat{p}^{rw}_{t+1} + \widehat{y}^w_{t+1} - \widehat{k}_{t+1}\right) + \epsilon\widehat{q}_{t+1}\right] - \widehat{q}_t,\\
\widehat{q}_t &\approx \begin{cases} 0, \text{ if NAC},\\ \chi\delta\left(\widehat{x}_t - \widehat{k}_t\right), \text{ if CAC},\\ \kappa\left(\widehat{x}_t - \widehat{x}_{t-1}\right) - \kappa\beta\mathbb{E}_t\left[\widehat{x}_{t+1} - \widehat{x}_t\right], \text{ if IAC}.\end{cases}
\end{aligned}
$$

Aggregate Supply Equations.

$$
\begin{aligned}
&\widehat{y}^w_t \approx \widehat{a}_t + (1-\psi)\,\widehat{k}_t + \psi\widehat{h}_t,\\
&\widehat{y}^w_t - \widehat{h}_t + \widehat{p}^{rw}_t - \frac{1}{\sigma}\widehat{c}_t \approx \varphi\widehat{h}_t,\\
&\widehat{\pi}_t \approx \beta\mathbb{E}_t\left[\widehat{\pi}_{t+1}\right] + \frac{(1-\alpha\beta)(1-\alpha)}{\alpha}\widehat{p}^{rw}_t,
\end{aligned}
$$

Financial Equations.

$$
\begin{aligned}
&\widehat{l}_t \approx \left(\widehat{p}_{t-1} + \widehat{q}_{t-1} + \widehat{k}_t\right) - \widehat{n}_t,\\
&\left\{\begin{array}{c}
\widehat{l}_t \approx \frac{B}{L}\widehat{b}_t + \left(1-\frac{B}{L}\right)(1-\varpi)\,\widehat{d}_t, \text{ if unconstrained}\\
\frac{PC}{PC+D}\left(\widehat{p}_t + \widehat{c}_t\right) + \frac{D}{PC+D}\widehat{d}_{t+1} \approx \frac{WH}{PC+D}\left(\widehat{p}^w_t + \widehat{y}^w_t\right) +\\
+\frac{D}{PC+D}\frac{1}{\beta}\left(\widehat{i}_t + \widehat{d}_t\right) + \frac{\Pi^r}{PC+D}\left[\widehat{p}_t + \widehat{y}_t + (1-\theta)\,\widehat{p}^{rw}_t\right] + \frac{\Pi^w}{PC+D}\widehat{n}_{t+1}, \text{ if unconstrained}
\end{array}\right.\\
&\left\{\begin{array}{c}
\widehat{l}_t \approx \frac{\widehat{b}_t}{c^l}, \text{ if constrained}\\
\frac{PC}{PC+D}\left(\widehat{p}_t + \widehat{c}_t\right) + \frac{D}{PC+D}\frac{\left(\frac{1}{c^l}-\frac{B}{L}\right)}{\left(1-\frac{B}{L}\right)(1-\varpi)}\widehat{b}_{t+1} \approx \frac{WH}{PC+D}\left(\widehat{p}^w_t + \widehat{y}^w_t\right) +\\
+\frac{D}{PC+D}\frac{1}{\beta}\left(\widehat{i}_t + \frac{\left(\frac{1}{c^l}-\frac{B}{L}\right)}{\left(1-\frac{B}{L}\right)(1-\varpi)}\widehat{b}_t\right) + \frac{\Pi^r}{PC+D}\left[\widehat{p}_t + \widehat{y}_t + (1-\theta)\,\widehat{p}^{rw}_t\right] + \frac{\Pi^w}{PC+D}\widehat{n}_{t+1}, \text{ if constrained.}
\end{array}\right.
\end{aligned}
$$

Evolution of the State Variables.

$$
\begin{aligned}
\widehat{k}_{t+1} &\approx (1-\delta)\,\widehat{k}_t + \delta\widehat{x}_t,\\
\widehat{n}_{t+1} &\approx \zeta\frac{1}{\beta}\left[\widehat{n}_t + \eta\left(\widehat{r}^k_t - \widehat{i}_t\right) - \eta\left(\widehat{p}_{t-1} + \widehat{q}_{t-1} + \widehat{k}_t\right)\right] + \widehat{i}_t,
\end{aligned}
$$

Monetary Policy Rule and Shock Processes.

$$\begin{aligned}
\widehat{i}_{t+1} &= \rho_i \widehat{i}_t + (1-\rho_i)\left[\psi_\pi \widehat{\pi}_t + \psi_y \widehat{y}_t\right] + \widehat{m}_t, \\
\widehat{b}_t &= \beta \widehat{b}_{t-1} + \varepsilon_t^b, \\
\widehat{a}_t &= \rho_a \widehat{a}_{t-1} + \varepsilon_t^a, \ \ |\rho_a| < 1, \\
\widehat{m}_t &= \rho_m \widehat{m}_{t-1} + \varepsilon_t^m, \ \ |\rho_m| < 1,
\end{aligned}$$

Definitions.

$$\begin{aligned}
\widehat{\pi}_t &\equiv \widehat{p}_t - \widehat{p}_{t-1}, \\
\widehat{p}_t^{rw} &\equiv \left(\widehat{p}_t^w - \widehat{p}_t\right).
\end{aligned}$$

Tables and Figures

Figure 1: Independent Simulations

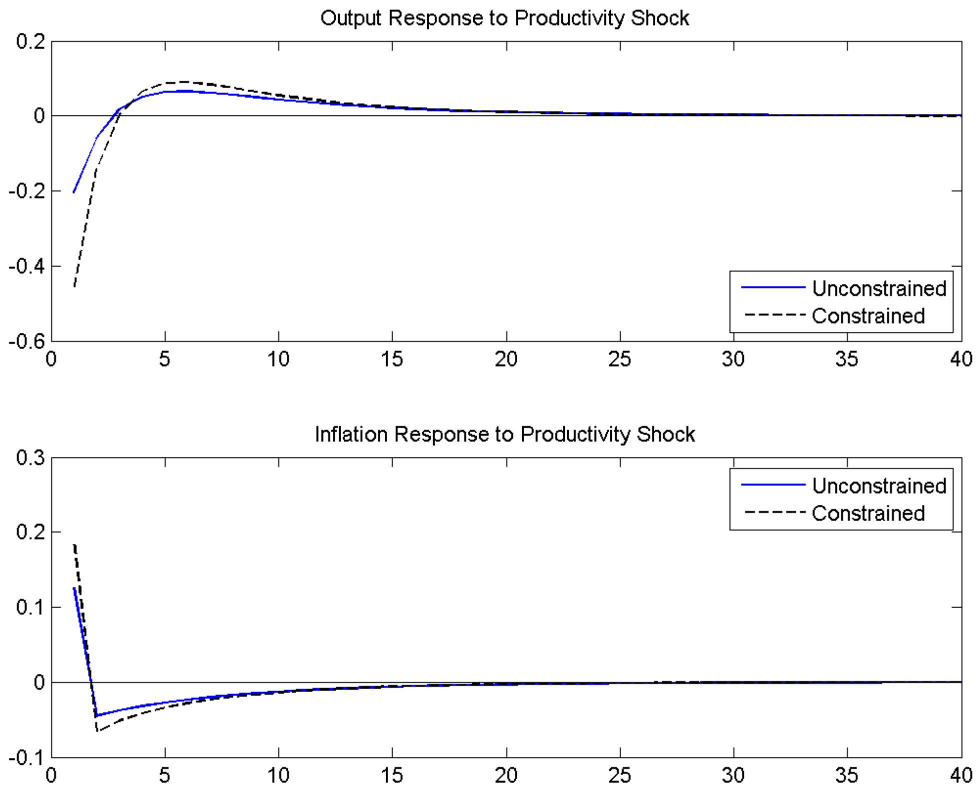

Table 1: Benchmark Calibration

Structural Parameters:			
Discount Factor	β	0.971	
Elasticity of Substitution across Varieties	θ	1.05	
Elasticity of Intertemporal Substitution	σ	0.5	Kydland and Prescott (1982) Lucas (1990)
(Inverse) Elasticity of Labor Supply	φ	3	Bernanke *et al.* (1999)
Sensitivity of External Finance Premium	ϑ	0.1	
$1-\epsilon \equiv \frac{(1-\psi)\frac{P^w}{P}\frac{Y^w}{K}}{(1-\psi)\frac{P^w}{P}\frac{Y^w}{K}+(1-\delta)}$	ϵ	0.7	
Calvo Price Stickiness Parameter	α	0.75	Bernanke *et al.* (1999)
Depreciation Rate	δ	0.025	Bernanke *et al.* (1999)
Capital Adjustment Cost	χ	0.999	
Profit Reinvestment Share	$1-\zeta$	0.99	
Labor Share	ψ	0.64	Bernanke *et al.* (1999)
Fraction of Capital over Net Worth	η	1	
Reserve Requirements on Real Deposits	ϖ	0	
Parameters on the Taylor Rule:			
Interest Rate Inertia	ρ_i	0.9	Bernanke *et al.* (1999)
Weight on Inflation Target, unconstrained	$\psi_{\pi,u}$	1.5	
Weight on Output/Consumption Target, unconstrained	$\psi_{y,u}$	0.5	
Weight on Inflation Target, constrained	$\psi_{\pi,c}$	1.01	
Weight on Output/Consumption Target, constrained	$\psi_{y,c}$	2	
Capital Adequacy Requirement	c	0.04	
Exogenous Shock Parameters:			
Shock Persistence	ρ_a, ρ_m	$1, 0.95$	
Correlation of Innovations		0	
Volatility of Innovations		0.0066	
Steady State Parameters:			
Consumption Share	γ_c	0.7	
Share Attributed to Bankruptcy in Steady State	γ_{csv}	0	
Consumption	C	0.7	
Nominal Bank Capital	B	0.15	
Nominal Bank Loans	L	1.02	
Consumption Price Index	P	0.97	
Nominal Deposits	D	1.01	
Nominal Wage	W	1.02	
Labor Supply	H	0.998	
Nominal Dividends from Retail	Π^r	1.008	
Nominal Dividends from Wholesale	Π^w	1.0003	

This table defines the benchmark parameterization of the structural parameters. The results of the sensitivity analysis for a given parameter are discussed in the paper, but not always reported. They can be obtained directly from the authors upon request.

Table 2: Claim 1

	Constrained		*Unconstrained*	
B/L	*Initial Decline*	*Output Response*	*Inititial Decline*	*Output Response*
0.74	-0.47	0.56	-0.08	0.16
0.49	-0.47	0.56	-0.18	0.26
0.25	-0.47	0.56	-0.22	0.29
0.20	-0.47	0.56	-0.23	0.30
0.10	-0.47	0.56	-0.24	0.31
0.05	-0.47	0.56	-0.24	0.31
0.03	-0.47	0.56	-0.24	0.32

Table 3: Claim 2

$\psi_\pi^u = 2.25,\ \psi_y^u = 0.25,$
$\psi_\pi^c = -1.0,\ \psi_y^c = 0.15.$

Table 4: Sensitivity

$\psi_\pi^u = 1.5,\ \psi_y^u = 0.5$
$\psi_\pi^c = -2.0,\ \psi_y^c = 0.5$

Table 5: S-GMM, reprised

$\psi_\pi^u = 1.0,\ \psi_y^u = 1.0$
$\psi_\pi^c = -2.0,\ \psi_y^c = 1.0$