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**WORKING PAPER SERIES**

**NO 1222 / JULY 2010**

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**MONETARY POLICY  
AND CAPITAL  
REGULATION IN THE  
US AND EUROPE**

by Ethan Cohen-Cole  
and Jonathan Morse



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# MONETARY POLICY AND CAPITAL REGULATION IN THE US AND EUROPE<sup>1</sup>

by Ethan Cohen-Cole<sup>2</sup>  
and Jonathan Morse<sup>3</sup>



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# CONTENTS

Abstract	4
Non-technical summary	5
1 Introduction	8
2 The benchmark model	10
2.1 Description of the model	11
3 Simulation and estimation	18
3.1 Parameters	19
3.2 Methodology	19
4 Results	21
4.1 Constrained economies have no transmission mechanism	21
4.2 Consistent with U.S. patterns	22
4.3 Consistent with European patterns	22
4.4 Conventional wisdom	23
5 Discussion and implication for regulation	23
6 Concluding remarks	24
References	25
Appendices	27
Tables and figures	31

## Abstract

From the onset of the 2007-2009 crisis, the Federal Reserve and the European Central Bank have aggressively lowered interest rates. Both sets of changes are at odds with an anti-inflationary stance of monetary policy; indeed, as the crisis began in August 2007 inflation expectations were high and rising, particularly in the United States. We have two additions to the literature. One, we present a model economy with a leveraged and regulated financial sector. Two, we find optimal Taylor rules for our economy that are consistent with a strong pro-inflationary reaction during financial crisis while maintaining a standard output-inflation mandate. We have three interpretations of our results. One, because the Federal Reserve has partial control over bank regulation it can exercise regulatory lenience. Two, the Fed's stronger output orientation means that it will potentially respond more quickly when faced with constrained banks. Three, our results support procyclical capital regulation.

*JEL Classification:* E52, E58, G18, G28

*key words:* monetary policy, capital regulation, crisis

From the onset of the 2007-2009 crisis, the Federal Reserve and the European Central Bank have aggressively lowered interest rates. Both sets of changes are at odds with an anti-inflationary stance of monetary policy; indeed, as the crisis began in August 2007 inflation expectations were high and rising, particularly in the United States. We begin by proposing a model of the economy that includes leveraged and regulated financial sector. The result is that the modeled central bank must consider two states of the world: a well-capitalized (unconstrained) one and an under-capitalized (constrained) one. Meshing this with a standard monetary policy stance in which the central bank maintains a mandate on inflation and growth (Fed) or inflation alone (ECB) provides our insights. The key feature of the model will be that banks cannot legally write new loans when undercapitalized. Many current models of monetary policy include a bank lending channel; monetary policy is magnified by the presence of a leveraged banking sector. However, if banks cannot lend when undercapitalized, this implies that monetary policy necessarily changes at the point of capital (in)adequacy. As expected then, the model shows the absence of a bank capital channel when the economy is capital constrained. Based on this model, we find it makes little sense to estimate a single policy (Taylor) rule across both constrained and unconstrained regimes. Thus, we construct empirical estimates of optimal policy when the two regimes are considered separately. Once implemented, our empirical analysis finds rules consistent with the data: a strong pro-inflationary reaction during financial crisis and a standard output-inflation mandate for the central bank.

We have three interpretations of our results. One, because the Federal Reserve has partial control over bank regulation it can exercise regulatory lenience as a part of monetary policy. We explain this below. Two, the Fed's stronger output orientation means that it will potentially respond more quickly when faced with constrained banks and the lack of an accelerator. Three, our results support procyclical capital regulation not because of adequacy concerns, but instead because of the impact on monetary policy.

The most remarkable finding is the presence of a large negative value for Federal Reserve's response to movements in the rate of inflation in the constrained state that qualitatively matches the Federal Reserve actions during the crisis. A large negative number implies that the central bank will counterintuitively 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 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. To the extent that one can view the crisis as a shock to bank capital, the most effective solution 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.

Our principal European result is that the coefficient on the monetary policy sensitivity to interest rates in both states of the world is larger than the US equivalent. We again observe a negative coefficient on the inflation parameter, but it remains close to zero even in the constrained state. This is consistent both with mandate differences and observed policy. A notable feature of the difference between US and European monetary reactions to the crisis was the timing of the reaction. This difference is in part described by the difference in output responsiveness. Another reason lies in the 'distance' to the constrained region. This can be seen as follows. Consider that prior to the crisis, both the US and Europe banks held a given, and equal level of capital. A lower baseline capital requirement in Europe means that the European Central

Bank monetary changes will have an accelerator impact even when US actions are insufficient. Thus for similar levels of shock, the US will necessary enter the constrained state sooner than Europe. Finally, recall that the set of results in based on a calibration that reflects differences in capital thresholds as well as monetary stance. Thus, one can interpret the outcomes as reflective of the combination of monetary stance and regulatory regime. Our interpretation is that the relatively stronger anti-inflationary stance of ECB in the face of a crisis emerges both as a function of its mandate and the fact that it had greater flexibility in exercising monetary policy prior to its banking sector becoming fully constrained. Thus, a relatively smaller change in policy rates could lead to a larger economic effect.

We emphasize two policy implications of our results. One, the Federal Reserve has partial control over bank regulation as well as full control over monetary policy. This permits it to exercise regulatory lenience as a part of monetary policy. It can set an initially higher capital threshold, and lower it in the face of a crisis. This permits some flexibility in times of moderate stress, but also requires the willingness to face inflation risk in times of crisis. Once banks hit the capital threshold, the situation is truly dire. Two, our results our consistent with procyclical capital regulation. However, we reach this conclusion not due to the need to support a stressed financial sector in times of crisis, but rather because the interaction between monetary policy and bank regulation necessitates it.

### **Optimal regulation**

We find a strong incentive for a joint monetary/regulatory authority such as the Federal Reserve 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. We note in the paper that this may in fact lead to lower long run output volatility.

### **Pro-cyclicality**

As has been acknowledged, bank capital follows a cyclical pattern. This cyclicity combined with a fixed capital requirement can lead to excess capital in good times and insufficient capital in bad times. Thus as the economy begins to contract, and banks experience loan losses, they will become less likely to lend as their capital cushions erode. Indeed, regulators may be in a position to shut down institutions that are simply facing cyclical losses, but will soon recover with the rest of the economy. This implies a potential solution of cycle-dependent capital requirements. Our model suggests a second set of reasons for this type of cyclical requirement. In ‘bad’ times as banks becomes capital constrained, not only is their lending impacted, but monetary policy changes as well. As we have demonstrated, because the efficacy of policy changes, the stance of policy necessarily changes as well. Thus, a pro-cyclical regulatory policy has the potential to ameliorate boom-bust monetary policy cycles.

We believe that there are likely many reasons for the differences in ECB and Fed policies over the past two years. Among these are difference in mandate emphasis between the two that lead to stronger anti-inflationary emphasis at the ECB, differences in the timing of impact on the banking sector, and many others. That said, the model presented here is both consistent with both authorities’ actions and is capable of reproducing the stylized features of each. With this framework in place, there are potentially more open questions that lie beyond the scope of this paper. As mentioned, the Federal Reserve has responsibility both for monetary policy and bank regulation of some of the financial system. Indeed, much of the response to the crisis in the United States consisted of extraordinary support to banking institutions; this is largely

equivalent to a relaxation of capital requirements. Thus, to what extent does the ability to change regulatory requirements jointly with monetary policy change the optimization problem? We would hypothesize that this is consistent with current patterns - a relatively higher capital requirement in normal times in the US and stronger monetary policy during times of crisis. However, this is a topic that we leave for future study.



# 1 Introduction

Our paper has two contributions to the literature. One, we construct a model economy with a leveraged and regulated financial sector. It shows financial accelerator characteristics in normal times; that is, in the state of the world in which banks do not face regulatory capital constraints, there is a significant amplification of monetary policy. More importantly, the model shows the absence of an accelerator when the economy is capital constrained. Our second contribution is to calibrate the model to both the US and Europe. We use separate calibrations to find rules appropriate to each environment. We find 1) a stronger anti-inflationary stance for the ECB in normal times. 2) a much stronger willingness by the Federal Reserve to sacrifice inflation risk for output in times of crisis.

We have three interpretations of our results. One, the Federal Reserve has partial control over bank regulation as well as full control over monetary policy. This permits it to exercise regulatory lenience as a part of monetary policy. It can set an initially higher capital threshold, and lower it in the face of a crisis. This permits some flexibility in times of moderate stress, but also requires the willingness to face inflation risk in times of crisis. Once banks hit the capital threshold, the situation is truly dire. Two, a stronger output orientation by the Fed means that it will potentially respond more quickly when faced with constrained banks and the lack of an accelerator. Three, our results are consistent with procyclical capital regulation. However, we reach this conclusion not due to the need to support a stressed financial sector in times of crisis, but rather because of the interaction between monetary policy and bank regulation necessitates it.

Our approach is to incorporate a very simple financial friction into a new-Keynesian synthesis model. The constraint is a regulatory capital minimum for the banking sector.<sup>1</sup> This implies two states of the world: well-capitalized (unconstrained) and under-capitalized (constrained).<sup>2</sup> We mesh this with a standard formulation of monetary policy in which the central bank maintains a mandate on inflation and growth (Fed) or inflation alone (ECB).

Our motivation for this is to assess the implications for monetary policy and bank regulation using only very minor deviations from a synthesis model. We wish to explain patterns of monetary policy from a positive (and normative) perspective without needing to adjust classic, or legislated, views of the role of monetary policy or resorted to other types of financial frictions. Our sole friction is the inability of bank to write new loans when undercapitalized. Of course, in the presence of a bank lending channel, this implies that monetary policy necessarily changes at the point of capital (in)adequacy.

Our conclusion is then that it makes little sense to estimate a single policy rule across both constrained and unconstrained regimes. Thus, we construct empirical estimates of optimal policy when the two regimes are considered separately. We illustrate the motivation for this using a simple diagram (see Figure 1). Notice that the regulatory threshold 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.

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<sup>1</sup>Borio and Zhu (2007) argue that regulatory constraints lead to effective lending limits even if they are not fully eclipsed. The argument is that as banks near the capital limits, the combination of the risk of crossing the threshold and the possibility of government intervention has a similar dampening effect on lending. In our model, lending becomes constrained only at the point of inadequacy.

<sup>2</sup>Cechetti and Li (2008) take an important first step in this direction by looking at two isolated regimes.

Broadly, the recent crisis has highlighted the fact that first-generation new-Keynesian models are not well-equipped to interpret the role of monetary policy under financial stress. They were based on a couple of classic imperfections, such as nominal rigidities and monopolistic competition, to allow for non-trivial market power and price setting. The goal, of course, was to illustrate how demand shifts could impact output, and thus how monetary policy shifting the demand could have real effects. These constructs permitted an extensive literature that could study the basic role of policy. The models, however, omitted details of market imperfections that are central to the study of macroeconomics. This omission is in part responsible for the fact that consensus Taylor rules cannot describe the path of monetary policy (Rudebusch 2006). A new round of (second-generation) new-Keynesian models focuses on the implications of other frictions. Because of the current financial crisis, a number of new papers,<sup>3</sup> this one included, have turned their attention to the role of financial and credit market imperfections by building on work by Bernanke, Gertler and Gilchrist (1999) and Carlstrom and Fuerst (2001). Indeed, there is renewed interest in a real economy link that passes through the banking sector.

The channel through the banking sector is now widely believed to play an important role in the conduct of monetary policy and highlights the importance of banking regulation. 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 Basel agreement (Bernanke and Lown, 1991). This argument as well as the realization that regulation has to date, including Basel I and Basel II, been largely a study in individual bank risk management. As such, policy makers have re-emphasized the need both to incorporate cyclicity into prudential regulation (Borio et al, 2001) as well as to approach regulation from what has been called a macro-prudential perspective (Borio 2003, and many others).

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 the role of the financial sector may be important in the transmission of real shocks. Indeed, the monetary authority reactions are discordant with an estimated Taylor rule (see Rudebusch, 2006). This of course requires little systematic analysis to observe; the Federal Reserve and the European Central Bank have dramatically lowered their respective principal policy rates in less than a year, even in the face of rising inflation. This soundly rejects models that in isolation would assume an anti-inflation stance of policy.

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.<sup>4</sup> Of course, if monetary policy is intended to promote stable economic growth, its countercyclical bias will run counter

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<sup>3</sup>Two recent papers by De Fiore and Tristani (2008) and Curdia and Woodford (2008) make an attempt to characterize monetary policy in a model with financial frictions are important. The former focuses on the specifics of loan contracts to derive implications, while the latter uses a very flexible, but reduced form characterization of frictions. Perhaps more importantly, Curdia and Woodford rely on bank intermediation between households. In this latter model, the linking function allows for a wide variety of characterizations of the link between frictions and monetary policy. Other examples that include financial frictions of various types include Ravenna and Walsh (2006), Faia and Monacelli (2006), Christiano et al., (2006).

<sup>4</sup>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).

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

As noted, 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.<sup>5</sup>

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

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 Kiyotaki and Moore (1997) in that asset price movements serve to reinforce credit market imperfections, which lead Gomes *et al.* (2003) to discard the Carlstrom and Fuerst (1997) framework<sup>6</sup>.

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

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<sup>5</sup>In practice, this threshold may be of relevance both at the true regulatory limit and at points above the threshold in which banks are constrained in the ability to lend due to the relative cost of increases in the capital base is sufficiently high. As has been observed in the crisis of 2007-2008, there is great reluctance amongst banks to issue new equity or cut dividends at precisely the time in which economic conditions may be deteriorating. This can lead to a delay in effort to raise capital until the possibility of a breach of the regulatory limit is imminent. Long before this point, banks can curtail lending (See Borio and Zhu 2007 for a discussion).

<sup>6</sup>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.

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).

Our 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.<sup>7</sup> 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 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,

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

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

$$\hat{w}_t - \hat{p}_t \approx \frac{1}{\sigma} \hat{c}_t + \varphi \hat{h}_t, \quad (2)$$

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<sup>7</sup>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.



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,

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

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,

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

where  $\chi$  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,

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

where  $\kappa$  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  $\kappa$  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,

$$\widehat{q}_t \approx 0. \quad (6)$$

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 reinforce 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<sup>8</sup>. Both,

<sup>8</sup>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,

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  $\theta$ . The resulting inflation dynamics aggregating over all retailers are captured by the following process,

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

where, for notational convenience, we denote the relative wholesale price as  $\hat{p}_t^{rw} \equiv (\hat{p}_t^w - \hat{p}_t)$ . 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 forward looking term in the Phillips curve. We can summarize the profits from retailers as follows,

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

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,

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

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

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_t^a, \quad |\rho_a| < 1, \quad (10)$$

where  $\varepsilon_t^a$  is a zero mean, uncorrelated and normally-distributed innovation. The parameter  $\rho_a$  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,

$$\hat{w}_t - \hat{p}_t \approx (\hat{p}_t^w - \hat{p}_t) + (\hat{y}_t^w - \hat{h}_t), \quad (11)$$

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

$$\hat{y}_t^w - \hat{h}_t + \hat{p}_t^{rw} - \frac{1}{\sigma} \hat{c}_t \approx \varphi \hat{h}_t. \quad (12)$$

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)

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retailers play no role.

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,

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

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  $\epsilon$  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,

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

which can be decomposed in two terms, the risk-free rate itself and the external financing premium.<sup>9</sup> The parameter  $\vartheta$  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.

<sup>9</sup>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).

Aggregate net worth for the wholesale producers accumulates according to the following equation<sup>10</sup>,

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

where  $\zeta$  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,

$$\widehat{\pi}_t^w \approx \widehat{n}_{t+1}. \quad (16)$$

The parameter  $\eta$ , 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.

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),

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

where  $\gamma_c$  denotes the consumption share,  $\gamma_x = (1 - \gamma_c - \gamma_{csv})$  is the investment share, and  $\gamma_{csv}$  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,  $\theta$ , 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,

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

<sup>10</sup>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.



where  $\rho_i$  is the smoothing parameter,  $\psi_\pi$  and  $\psi_y$  are the weights on inflation and 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,

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

where  $\varepsilon_t^m$  is a zero mean, uncorrelated, and normally-distributed innovation. The parameter  $\rho_m$  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 these 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 to 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.

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

Second, we need to take into account that the demand for deposits can be determined by the budget

constraint of households, i.e.

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

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,

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

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

$$\begin{aligned} \frac{PC}{PC+D}(\hat{p}_t + \hat{c}_t) + \frac{D}{PC+D}\hat{d}_{t+1} &\approx \frac{WH}{PC+D}(\hat{p}_t^w + \hat{y}_t^w) + \\ &+ \frac{D}{PC+D}\frac{1}{\beta}(\hat{i}_t + \hat{d}_t) + \frac{\Pi^r}{PC+D}[\hat{p}_t + \hat{y}_t + (1-\theta)\hat{p}_t^{rw}] + \frac{\Pi^w}{PC+D}\hat{n}_{t+1}. \end{aligned} \quad (21)$$

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.

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

where  $\hat{b}_t$  denotes the bank capital in nominal terms,  $\hat{d}_t$  is the nominal value of deposits, and  $\varpi$  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.<sup>11</sup> 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,

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

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

$$\hat{b}_t \approx c^l \hat{l}_t, \quad (23)$$

banks will only be able to take on a total amount of deposits that is proportional to the available capital.

<sup>11</sup>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.

The expression for the total amount of available deposits in equilibrium is determined as follows,

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

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,

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

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

$$\widehat{b}_t = \beta \widehat{b}_{t-1} + \varepsilon_t^b, \quad (25)$$

where  $\varepsilon_t^b$  is a zero mean, uncorrelated and normally-distributed innovation. The parameter  $\beta$ , 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.

### 3 Simulation and Estimation

The principal contribution of our model is to add a ‘constrained’ state of nature. In this constrained state, the model economy has no financial acceleration of the monetary transmission mechanism. We begin by illustrating this phenomenon empirically. The impact of this constraint is than monetary policy both during and prior to the constrained state will necessarily be different that policy in a world in which this state is encountered with probability zero. We thus illustrate how monetary policy differs across the two states of the world and compare it to optimal Taylor rules for economies that are fully unconstrained.

Finally, we calibrate our model, separately, to match US and European economies. Our hypothesis is that the presence of a capital constraint should be reflected in the monetary policy stances of the respective authorities both before and during the current crisis.

We begin by using relatively standard computational tools to show results from two isolated economies, one of which is constrained and one unconstrained. For the second question, as well as the calibration to the two economies, we will use simulated generalized methods of moments (S-GMM) 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 have 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 counterfactuals. 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. A range of parameters will apply to our baseline model and will be appropriate to the US and Europe. We begin by setting labor share 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 varieties to 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 sensitivity to the external finance premium,  $\nu$ , 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,  $\rho_i$ , 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.

Recall that our goals are to show that the model has implications for monetary policy across states of the world and to calibrate to the US and European economies. Because none of these variables will differ across the two economies, nor impact the transition across states of the world, the precise value will not impact the stylized conclusions of the paper.

For a small set of parameters, we will specify differences across the US and Europe. In the US, we set the leverage maximum to 25, which implies a Tier 1 capital to asset ratio of 0.04. Basel I requirements stipulate that a Tier 1 capital<sup>12</sup> 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 means that monetary policy becomes almost completely ineffective. Though regulation vary across Europe, European bank leverage has been somewhat higher than that in the US. We set the minimum capital to asset ratio to 0.025. We provide some sensitivity analysis around this value below.

Finally, we parameterize the shock process for capital. The variance of the capital shock is set to 0.012 in the US and to 0.0081 in Europe. To obtain these values, we use Bankscope to extract the time series of quarterly aggregate industry capital ratio from 1999 Q1 to 2009 Q4.

Our parameter choices are summarized in Table 1.

### 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.

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<sup>12</sup>Tier 1 capital is defined as common equity, non-cumulative perpetual preferred stock and minority interests in equity accounts of minority shareholders.

The goal of course, is then to find Taylor parameters that minimize some objective function. To answer this question, we use simulated generalized method of moments (S-GMM). The object is to estimate a vector of structural parameters, denoted  $\theta$ , which minimize a given social loss function. For our case,  $\theta \equiv \{\psi_\pi^u, \psi_y^u, \psi_\pi^c, \psi_\pi^c; P\}$ , 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  $\theta$  to minimize the function,

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

where  $W$  is an appropriate weight matrix.

As there is no clear analytic representation of the mapping of  $\theta$  to the relevant moments, one can solve this type of minimization problem by simulation. Given vectors  $\theta$  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.

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. 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 S-GMM method of estimation that maps back into a standard view of the loss function as absolute value deviations from optimal levels of  $\pi$  and  $y$ . Notice that this corresponds to a mechanism 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  $\theta$ . 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 support for the claims of the model. 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,  $\varepsilon$ , 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,  $\varepsilon^a$  and  $\varepsilon^b$ , 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 propagate simultaneously. We search over a large number of combinations of  $\theta$  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 Results

### 4.1 Constrained Economies Have No Transmission Mechanism

Figure 4 below shows the results from the initial stage of simulation using a US calibration. 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 as being a difference in available bank capital for lending. Regardless, one can see much of the intuition behind the joint model in these figures. 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 (see Rudebusch 2006). We return to this set of unconstrained parameters in the sensitivity tests below.

Consider table 2. To create this table, we estimate a set of 12 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. 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. Recall that we have partitioned the world into two absorbing states for the time being. Each row defines a steady state ratio of bank capital to loans.

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. Even in the cases where there is ample capital, setting the model to the ‘constrained’ state shuts down the transmission mechanism.<sup>13</sup>

<sup>13</sup>Interpreting the magnitudes of the impulse response functions (IRFs) here is difficult given that the world indeed changes

## 4.2 Consistent with U.S. Patterns

Here we look for optimal Taylor parameters using the S-GMM method described above and in the appendix. Because similar exercise to evaluate optimal Taylor rules do not account for the presence of a constrained economy, our results may differ. In particular, the existing literature effectively includes averaged results for Taylor parameters, indeed, this could explain why central bank actions appear to have deviated so strongly from consensus rules during the crisis. When a constrained state exist, monetary authorities have to include its presence as a potential factor when determining policy, even during normal times. As such, higher capital volatility, and thus risk of crisis, could lead to precautionary monetary policy.

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  $\psi_{\pi}^c$ , 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. 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.

## 4.3 Consistent with European Patterns

We repeat the above exercise using a European parameterization. As mention above, most of the parameters of this economy will remain as above. Again, we look for optimal Taylor parameters using the S-GMM method described above and in the appendix. We report the optimal parameters in each state of the world as shown in Table 3, panel B.

Our principal result is that the coefficient on the monetary policy sensitivity to interest rates in both states of the world is larger than the US equivalent. While in some parameterizations, we again observe a negative coefficient on the inflation parameter, it remains close to zero even in the constrained state. This is consistent both with mandate differences and observed policy.

One notable feature of the difference between US and European monetary reactions to the crisis was the timing of the reaction. This difference is in part described by the difference in output responsiveness.

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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 table is instructive in understanding the difference in transmission mechanisms between the two states of the world.

Another reason lies in the ‘distance’ to the constrained region. This can be seen as follows. Consider that prior to the crisis, both the US and Europe banks held a given, and equal level of capital. A lower baseline capital requirement in Europe means that the European Central Bank monetary changes will have an accelerator impact even when US actions are insufficient. This impact is apparent in figure 1. Thus for similar levels of shock, the US will necessary enter the constrained state sooner than Europe.

Finally, recall that the set of results in based on a calibration that reflects differences in capital thresholds as well as monetary stance. Thus, one can interpret the outcomes as reflective of the combination of monetary stance and regulatory regime. Our interpretation is that the relatively stronger anti-inflationary stance of ECB in the face of a crisis emerges both as a function of its mandate and the fact that it had greater flexibility is exercising monetary policy prior to its banking sector becoming fully constrained. Thus, a relatively smaller change in policy rates could lead to a larger economic effect.

#### 4.4 Conventional Wisdom

As mentioned, our results differ slightly from conventional wisdom, both in the presence of an pro-inflationary response to the constrained state, and in a small degree of difference in the normal, unconstrained, state of the world. To assess whether our results are robust, we re-run our S-GMM estimation with the added constraint that the unconstrained parameter are fixed at standard level. This would be tantamount the unreasonable assumption of a myopic central banker. Nonetheless, the process is instructive in understanding the mechanisms present in our model economy.

Effectively, for each of the US and Europe, we will evaluate the degree to which the our results in normal times are impacted on the margin by the presence of a constrained state.

For the United States, we look at the conventional Taylor Rule of  $\psi_{\pi}^u = 1.5$  and  $\psi_y^u = 0.5$ . For Europe we use  $\psi_{\pi}^u = 2.0$  and  $\psi_y^u = 0.25$ , reflecting a stronger anti-inflationary stance and a very mild pro-output one. After setting  $\psi_{\pi}^u, \psi_y^u$  to these levels, we look for optimal  $\psi_{\pi}^c, \psi_y^c$ . Results for this exercise are in table 4.

In the US case, we notice that the magnitude of  $\psi_{\pi}^c$  is largely the same as the baseline case:  $-2.25$  rather than  $-2.00$ . As we pre-specify the unconstrained inflation parameter to be 1.5, the strength of the pro-inflation reaction in times of crisis is slightly diminished. This is reasonable given the structure of our economy. A central banker that ignores the presence of a constrained state is not very hawkish in regular times. This means that, to maintain time-consistent, once in crisis, the future has, on average, more inflation than our baseline case. As such, the central banker does not need to flood the economy to quite the degree as before.

In the European case, we find a similar effect, though of different magnitudes. Indeed, once we set the unconstrained case to 2.00, the constrained case increases to the same level. In this context, there is no change between states of the world: the central bank continues to follow its anti-inflation mandate regardless of the state of the financial sector. This is consistent with both the ECB mandate as well as its arms-length relationship with the banking sector.

## 5 Discussion and Implication for Regulation

### Optimal regulation

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*). In fact, doing so may lead to lower output volatility in the long run. Figure 5 shows the result of an exercise that consider the decision of a joint authority that must set monetary policy each period as well as may make a one-time adjustment to the capital adequacy threshold. In each simulation, the central bank is allowed to lower the threshold a single time. Doing so provides uniform benefits. Beginning with a threshold of 0.1, we look at the output volatility in an economy for each of a number of possibilities. As should be clear, output volatility falls uniformly with decreased threshold. Of course this model does not include the associated risk of low capitalization on risk taking or the spillover effects of bank failures on the economy; nonetheless, it provides some insight into the tradeoffs faced by a joint authority in the management of a crisis. There appear to be relatively large gains from lowering regulatory requirements both on the efficacy of monetary policy and on output volatility.

Effectively, our explanation rests on the logic that the central bank has an incentive to restore the functioning of the financial sector. Even if this leads to a short-run inflation cost, the long-run output benefits are sufficiently large to offset. In particular, this is true even without an explicit targeting of financial stability itself.

### **Pro-cyclicality**

As has been acknowledged, bank capital follows a cyclical pattern. This cyclicity combined with a fixed capital requirement can lead to excess capital in good times and insufficient capital in bad times. Thus as the economy begins to contract, and banks experience loan losses, they will become less likely to lend as their capital cushions erode. Indeed, regulators may be in a position to shut down institutions that are simply facing cyclical losses, but will soon recover with the rest of the economy. This implies a potential solution of cycle-dependent capital requirements.

Our model suggests a second set of reasons for this type of cyclical requirement. In ‘bad’ times as banks becomes capital constrained, not only is their lending impacted, but monetary policy changes as well. As we have demonstrated, because the efficacy of policy changes, the stance of policy necessarily changes as well. Thus, a pro-cyclical regulatory policy has the potential to ameliorate boom-bust monetary policy cycles.

## **6 Concluding Remarks**

We believe that there are likely many reasons for the differences in ECB and Fed policies over the past two years. Among these are difference in mandate emphasis between the two that lead to stronger anti-inflationary emphasis at the ECB, differences in the timing of impact on the banking sector, and many others. That said, the model presented here is both consistent with both authorities’ actions and is capable of reproducing the stylized features of each. With this framework in place, there are potentially more open questions that lie beyond the scope of this paper. As mentioned, the Federal Reserve has responsibility both for monetary policy and bank regulation of some of the financial system. Indeed, much of the response to the crisis in the United States consisted of extraordinary support to banking institutions; this is largely

equivalent to a relaxation of capital requirements. Thus, to what extent does the ability to change regulatory requirements jointly with monetary policy change the optimization problem? We would hypothesize that this is consistent with current patterns - a relatively higher capital requirement in normal times in the US and stronger monetary policy during times of crisis. However, this is a topic that we leave for future study.

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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  $\psi_\pi^c$ ,  $\psi_y^c$ ,  $\psi_\pi^u$ , and  $\psi_y^u$  (collectively referred to as  $\theta$ ). To do so, we define a range of values for each  $\psi$ -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  $\psi_\pi^u$  and  $\psi_y^u$  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  $\psi_\pi^c$  and  $\psi_y^c$  to range from [-2.5:0.1:2.5].

### Step 3. Run unconstrained Dynare process

Conditional on a particular set of  $\psi_\pi^u$  and  $\psi_y^u$  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  $\psi$  values, we calculate and store these approximations.

### Step 4. Run constrained Dynare process

As Step 3, for a given set of  $\psi_\pi^c$  and  $\psi_y^c$  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,  $\theta$ . 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  $N(0, \sigma^2)$ . 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,  $\sigma$ , 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  $N(0, \sigma^2)$ , 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  $\theta$ , 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,  $\beta_u$  and  $\beta_c$  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  $\theta$  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  $\psi_{\pi,y}^u$  and  $\psi_{\pi,y}^c$ .

**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  $\theta$  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.

**Step 10.** Verify existence and uniqueness of equilibrium

Uniqueness: Note that our GMM method is global. That is, we do not use any search or optimization techniques to find the optimal  $\theta$ ; as a result, we can minimize the moment function without concern that there exists alternate, smaller values. We cannot rule out the presence of solutions that lie between the grid points of our search.

Existence: We verify empirically the presence of equilibrium, by ensuring that with each optimization there exists at least one valid parameter combination.

## 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.

$$\begin{aligned}\hat{y}_t &\approx \frac{C}{Y}\hat{c}_t + \frac{X}{Y}\hat{x}_t + \frac{G}{Y}\hat{g}_t. \\ \hat{c}_t &\approx \mathbb{E}_t[\hat{c}_{t+1}] - \sigma(\hat{i}_t - \mathbb{E}_t[\hat{\pi}_{t+1}]), \\ \mathbb{E}[\hat{r}_{t+1}^k] - \hat{i}_{t+1} &\approx \vartheta(\hat{n}_{t+1} - \hat{p}_t - \hat{q}_t - \hat{k}_{t+1}), \\ \mathbb{E}_t[\hat{r}_{t+1}^k - \hat{\pi}_{t+1}] &\approx \mathbb{E}_t[(1 - \epsilon)(\hat{p}_{t+1}^{rw} + \hat{y}_{t+1}^w - \hat{k}_{t+1}) + \epsilon\hat{q}_{t+1}] - \hat{q}_t, \\ \hat{q}_t &\approx \begin{cases} 0, & \text{if NAC,} \\ \chi\delta(\hat{x}_t - \hat{k}_t), & \text{if CAC,} \\ \kappa(\hat{x}_t - \hat{x}_{t-1}) - \kappa\beta\mathbb{E}_t[\hat{x}_{t+1} - \hat{x}_t], & \text{if IAC.} \end{cases}\end{aligned}$$

### Aggregate Supply Equations.

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

### Financial Equations.

$$\begin{aligned}\hat{l}_t &\approx \frac{PQK}{L}(\hat{p}_{t-1} + \hat{q}_{t-1} + \hat{k}_t) - \frac{N}{L}\hat{n}_t, \\ \left\{ \begin{array}{l} \hat{l}_t \approx \frac{B}{L}\hat{b}_t + (1 - \frac{B}{L})\hat{d}_t, \text{ unconstrained} \\ \hat{l}_t \approx c^a\hat{b}_t + (1 - a^a)(1 - c^a)\hat{b}_t, \hat{d}_t \approx (1 - a^a)(1 - c^a)\hat{b}_t, \text{ constrained} \end{array} \right. \\ \frac{PC}{PC+D}(\hat{p}_t + \hat{c}_t) + \frac{D}{PC+D}\hat{d}_{t+1} &\approx \frac{WH}{PC+D}(\hat{w}_t + \hat{h}_t) + \frac{I^b D}{PC+D}(\hat{i}_t + \hat{d}_t) + \frac{\Pi^r}{PC+D}\hat{\pi}_t^r + \frac{\Pi^w}{PC+D}\hat{\pi}_t^w, \\ \hat{w}_t - \hat{p}_t &\approx \hat{p}_t^{rw} + (\hat{y}_t^w - \hat{h}_t), \\ \hat{\pi}_t^r &\approx \hat{p}_t + \hat{y}_t + (1 - \theta)\hat{p}_t^{rw}, \\ \hat{\pi}_t^w &\approx \hat{n}_{t+1}.\end{aligned}$$

### Evolution of the State Variables.

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

### Monetary Policy Rule and Shock Processes.

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

### Definitions.

$$\widehat{\pi}_t \equiv \widehat{p}_t - \widehat{p}_{t-1}.$$

**FIGURE 1: STYLIZED MONETARY POLICY EFFICACY**

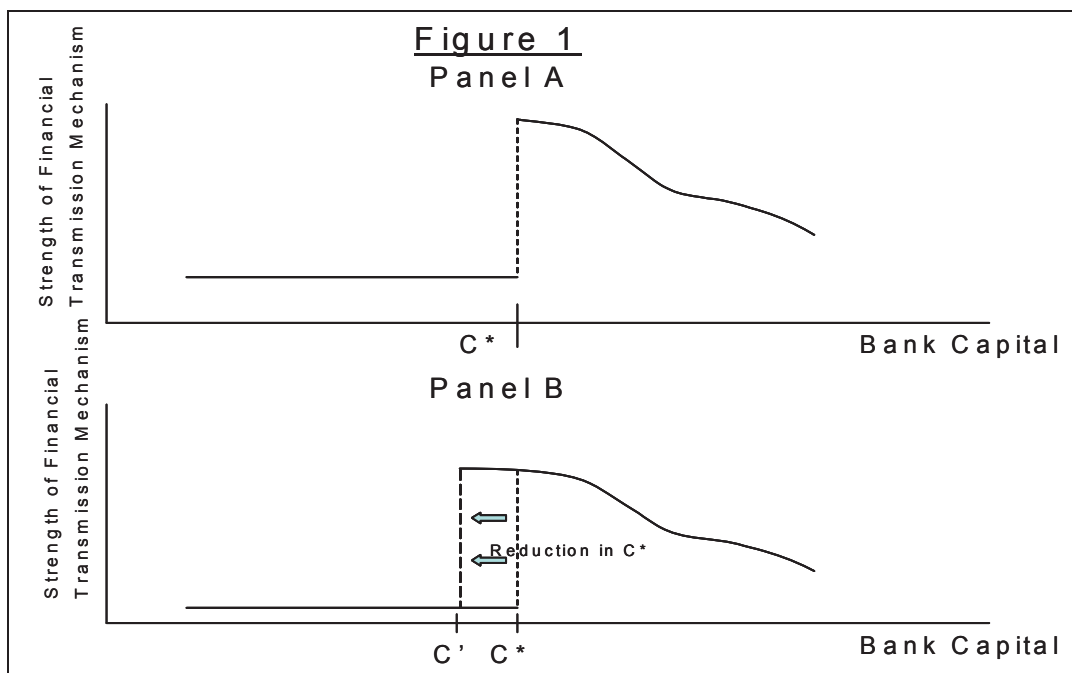


Figure 1 shows the stylized relationship between the strength of the accelerator and the capitalization of the banking sector. The marked point on the capitalization axis represents the crossover between the constrained and unconstrained states of the world. Panel A shows the economy with a given capital threshold. Panel B illustrates the impact given a shift the adequacy threshold. Notice that the accelerator remains even for lower levels of capital.



**FIGURE 2: FED AND ECB POLICY RATES 1999-2009**

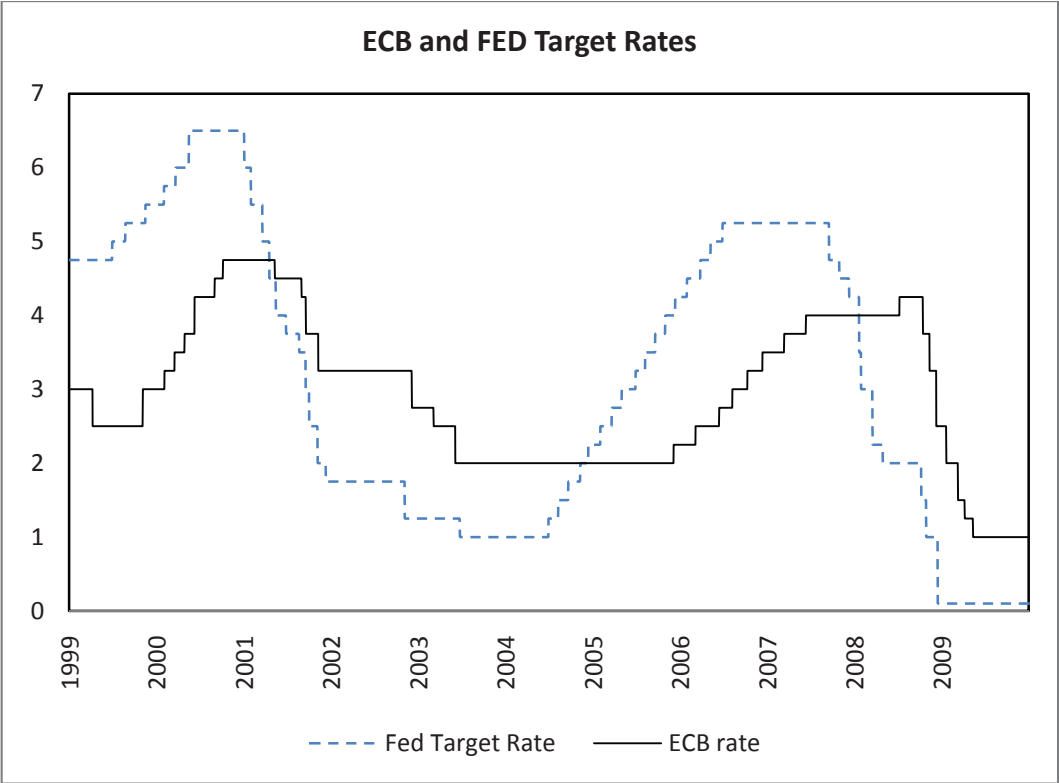


Figure 2 shows the US Federal Reserve and European Central Bank policy rates for the time period from 1999-2009.

### FIGURE 3: TAYLOR RULE RESIDUALS

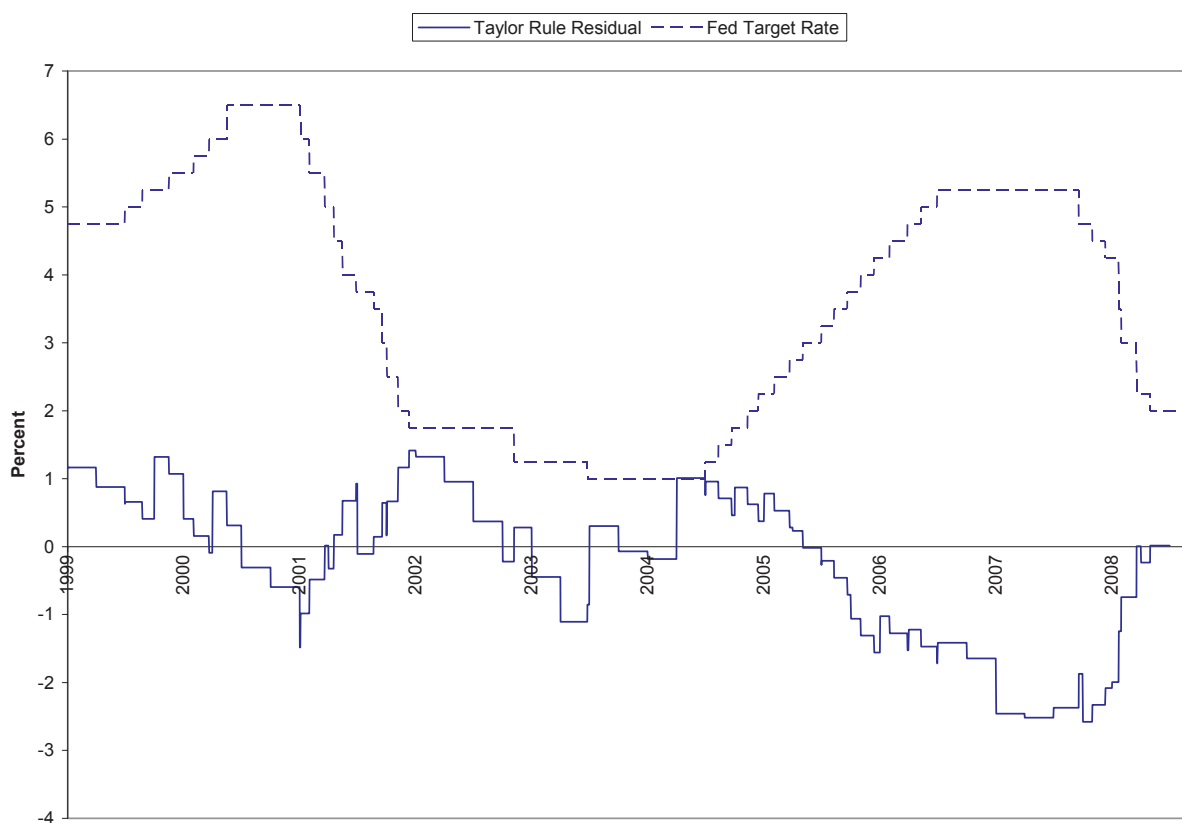


Figure 3 shows the residuals from a consensus Taylor rule. We use Rudebusch (2006):  
 $i_t = 2.04 + 1.39\pi_t + .92y_t$ .

## FIGURE 4: INDEPENDENT SIMULATIONS

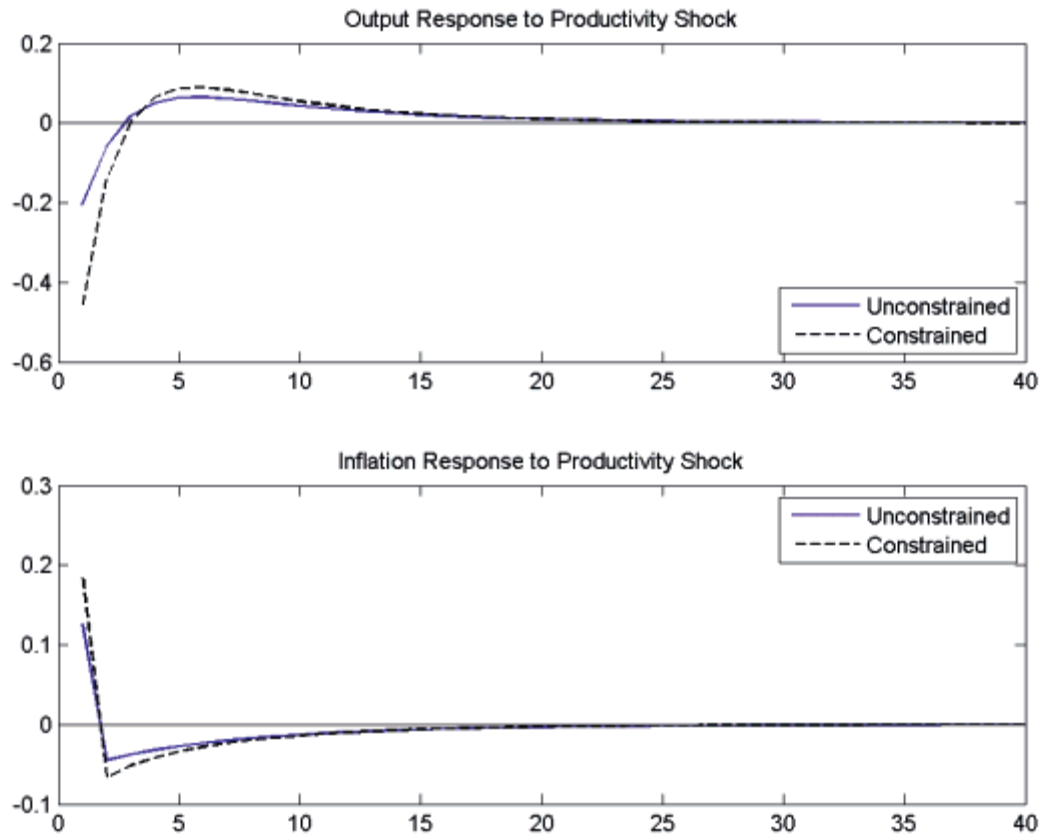


Figure 4 shows the simulated output and inflation responses to a one standard deviation productivity shock. The solid line in each panel shows the response in the unconstrained state and the dotted line the response in the constrained state. Each of these use the parameterization shown in the paper as well as US capital adequacy information.

**FIGURE 5: MONETARY POLICY UNDER VARYING CAPITAL REGIMES**

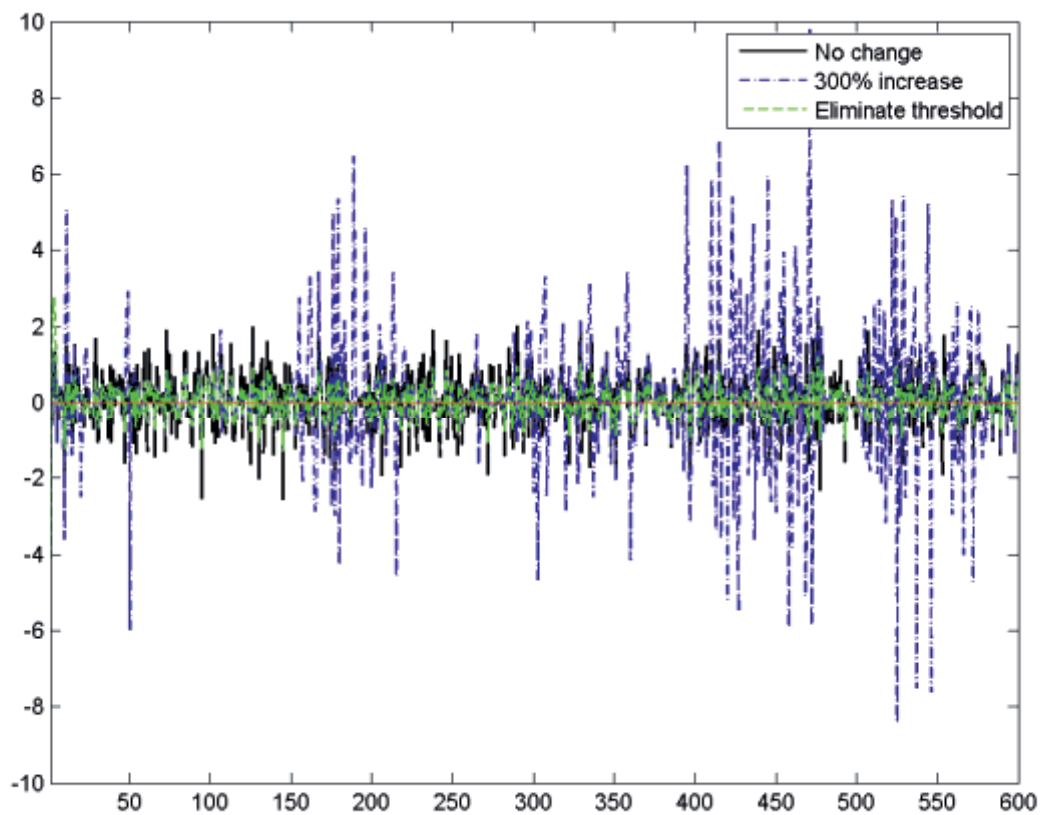


Figure 5 shows a 600 period time series generated by the model economy. We show three output series. The black (solid) line shows a baseline case in which the capital adequacy requirement does not change. The blue (long-dash) line shows a large increase in the requirement, an effective tightening of standards. The green (short-dash) line shows eliminating the threshold altogether.

**Table 1: Benchmark Calibration**

Structural Parameters:				
Discount Factor	$\beta$	0.971	0.971	
Elasticity of Substitution across Varieties	$\vartheta$	1.05	1.05	
Elasticity of Intertemporal Substitution	$\sigma$	0.5	0.5	
(Inverse) Elasticity of Labor Supply	$\phi$	3	3	Bernanke et al. (1999)
Sensitivity of External Finance Premium	$\theta$	0.25	0.25	
$1-\varepsilon \equiv (((1-\psi)(P^w/P)(Y^w/K))/((1-\psi)(P^w/P)(Y^w/K)+(1-\delta)))$	$\varepsilon$	0.7	0.7	
Calvo Price Stickiness Parameter	$\alpha$	0.75	0.75	Bernanke et al. (1999)
Depreciation Rate	$\delta$	0.025	0.025	Bernanke et al. (1999)
Capital Adjustment Cost	$\chi$	0.999	0.999	
Profit Reinvestment Share	$1-\zeta$	0.99	0.98	
Labor Share	$\psi$	0.64	0.64	Bernanke et al. (1999)
Parameters on the Taylor Rule:				
Interest Rate Inertia	$\rho_i$	0.9	0.9	Bernanke et al. (1999)
Exogenous Shock Parameters:				
Shock Persistence	$\rho_a, \rho_g, \rho_y$	1, 0.95, 1	1, 0.95, 1	
Correlation of Innovations		0	0	
Volatility of Innovations		0.0081	0.0081	
Steady State Parameters:				
Consumption	C	0.7	0.7	
Nominal Bank Capital	B	0.25	0.25	
Nominal Bank Loans	L	1.02	1.02	
Consumption Price Index	P	0.97	0.97	
Nominal Deposits	D	1.01	1.01	
Nominal Wage	W	1.02	1.02	
Labor Supply	H	0.998	0.998	
Nominal Dividends from Retail	$\Pi^r$	1.008	1.008	
Nominal Dividends from Wholesale	$\Pi^w$	1.0003	1.0003	
Output	Y	0.99	0.99	
Investment	X	0.1	0.1	
Government Expenditures	G	0.2	0.2	
Entrepreneurial Net Worth	N	0.5	0.5	
Return to Capital	$R^k$	1.004	1.004	
Nominal Riskless Return from Deposits	$I^b$	1.01	1.01	
Real Cost of Capital	Q	0.999	0.999	
Capital	K	1	1	
Nominal Short Term Interest Rate	I	1.01	1.01	

Notes: 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 1b: Capital Parameters**

Capital Adequacy Requirement	$c^{US}$	0.04	0.025
Volatility of Bank Capital Innovations	$\sigma_b^{US}$	0.012	0.0081

Notes: This table defines capital adequacy parameters for the US and Europe as a whole. US capital adequacy requirements are taken as the lower bound of the 'leverage requirement' put in place by FDICIA. European lower bounds are approximate. On average, large European banks showed much lower capital levels as a function of total assets than US banks prior to the current crisis. We use .02 as an approximation of the lower end of the range. Volatility of capital is based on author's calculations using Bankscope quarterly tier 1 capital numbers for the largest US and European banks from 1999-2009.

**Table 2a: Financial Accelerator in 'normal' times (US)**

<i>B</i>	Constrained		Unconstrained	
	<i>Initial Decline</i>	<i>Output Response</i>	<i>Initial Decline</i>	<i>Output Response</i>
0.25	-0.0470	0.0563	-0.0136	0.0197
0.5	-0.0470	0.0563	-0.0130	0.0194
0.75	-0.0470	0.0563	-0.0103	0.0171
1.02	-0.0470	0.0563	-0.0470	0.0563
1.25	-0.0470	0.0563	NA	NA
1.5	-0.0470	0.0563	NA	NA

Notes: For each of 7 initial capital asset ratios, Table 2 shows the initial economic response to a productivity shock plus the ex-post output increase after monetary intervention. Both numbers are percentages of GDP. Output response is measured from trough to peak. The two columns show the same simulations for a constrained economy and for an unconstrained economy. Notice that the constrained economy shows no difference in shock response as a function of bank leverage. That is, there is no accelerator operating.

**Table 2b: Financial Accelerator in 'normal' times (EU)**

<i>B</i>	Constrained		Unconstrained	
	<i>Initial Decline</i>	<i>Output Response</i>	<i>Initial Decline</i>	<i>Output Response</i>
0.25	-0.0470	0.0563	-0.0297	0.0388
0.5	-0.0470	0.0563	-0.0257	0.0348
0.75	-0.0470	0.0563	-0.0169	0.0261
1.02	-0.0470	0.0563	-0.0470	0.0563
1.25	-0.0470	0.0563	-1.1424	1.2956
1.5	-0.0470	0.0563	-5.3117	6.4876

Notes: For each of 7 initial capital asset ratios, Table 2 shows the initial economic response to a productivity shock plus the ex-post output increase after monetary intervention. Both numbers are percentages of GDP. Output response is measured from trough to peak. The two columns show the same simulations for a constrained economy and for an unconstrained economy. Notice that the constrained economy shows no difference in shock response as a function of bank leverage. That is, there is no accelerator operating.

**Table 3: Optimal Taylor Rule Parameters**

	<i>US</i>	<i>EU</i>
$\psi_{\pi}^u$	1.00	2.50
$\psi_y^u$	0.50	0.25
$\psi_{\pi}^c$	-2.00	0.50
$\psi_y^c$	0.25	0.25

Notes: Table 3 shows the optimal Taylor rule parameters from a simulated GMM calibration of the model economy above. Full information on the calibration and S-GMM estimation process are in the appendix. Superscripts identify the state of the economy. We use a coarse grid of optimal parameters in  $\frac{1}{4}$  point intervals. Subscript identify the parameter of interest (inflation and output). Column 1 shows the US parameters and Column 2 the European equivalents. Recall that all parameters in calibration are identical with the exception of the parameters described in Table 1. These capital parameters are in Table 1b. Superscripts identify the state of the economy. Subscripts identify the parameter of interest (inflation and output).

**Table 4: Conventional Wisdom**

	<i>US</i>	<i>EU</i>
$\psi_{\pi}^u$	1.50	2.00
$\psi_y^u$	0.50	0.25
$\psi_{\pi}^c$	-2.25	2.00
$\psi_y^c$	0.25	0.25

Notes: Table 4 shows the optimal Taylor rule parameters from a simulated GMM calibration of the model economy above. This table varies the exercise from Table 3 by imposing a priori Taylor rule parameters for normal times. The literature has found that Taylor rules for the US and Europe are approximately described by those in the table above. Full information on the calibration and S-GMM estimation process are in the appendix. Superscripts identify the state of the economy. Subscript identify the parameter of interest (inflation and output). Column 1 shows the US parameters and Column 2 the European equivalents. Recall that all parameters in calibration are identical with the exception of the description of the banking sector. These capital parameters are in Table 1b. Superscripts identify the state of the economy. Subscripts identify the parameter of interest (inflation and output).



