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LIQUIDITY DEPENDENCE

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Time-Varying Capital Requirements in a General Equilibrium Model of Liquidity Dependence*

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Abstract

This paper attempts to quantify business cycle effects of bank capital requirements. We use a general equilibrium model in which financing of capital goods production is subject to an agency problem. At the center of this problem is the interaction between entrepreneurs' moral hazard and liquidity provision by banks as analyzed by Holmstrom and Tirole (1998). We impose capital requirements on banks and calibrate the regulation using the Basel II risk-weight formula. Comparing business cycle properties of the model under this procyclical regulation with those under hypothetical countercyclical regulation, we find that output volatility is about 25% larger under procyclical regulation and that this volatility difference implies a 1.7% reduction of the household's welfare. Even with more conservative parameter choices, the volatility and welfare differences under the two regimes remain nonnegligible.

JEL codes: E32, G21, G28

Keywords: Procyclicality, capital requirements, countercyclical regulation

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1 Introduction

Recently, there has been strong interest in understanding the interaction between banking regulation and macroeconomic fluctuations. The new risk-sensitive regulatory capital regime (aka Basel II) has been implemented in most G-10 countries, and both policy-makers (FSF (2009)) and academics (Brunnermeier et al. (2009)) have been advocating for changes to Basel II by explicitly making the regulation on capital requirements countercyclical. In the current Basel II regime, the risk weight associated with each loan is negatively related to the borrower's credit quality. Thus, in good times when overall credit quality improves, capital requirements are reduced. This leads to increases in aggregate lending, amplifying macroeconomic fluctuations. Conversely, when borrowers' credit quality deteriorates in economic downturns, the increases in capital requirements tend to amplify the declines in credit and magnify the effects of the adverse shock to the economy. In policy and academic circles, this phenomenon has been termed the "procyclicality" of bank capital regulation (Borio et al. (2001)).

Several papers study the macroeconomic implications of bank capital requirements. Blum and Hellwig (1995) examine the procyclical effects of fixed capital requirements under Basel I. Using a simple reduced-form macroeconomic framework, they argue that it is likely to amplify macroeconomic fluctuations. Heid (2007) goes one step further by studying the implications of risk-sensitive capital requirements in a similar reduced-form environment. More recently, Zhu (2008) studies the effects of bank capital regulation on banks' behavior by applying the industry model of Cooley and Quadrini (2001) to a banking sector that is subject to risk-sensitive capital requirements. Finally, Repullo and Suarez (2009) use a more simplified micro-founded model to study the role of risk-sensitive capital requirements in credit cycles.

Relative to these previous studies, we examine the business-cycle implications of time-varying capital requirements in a general equilibrium macro model. Using a general equilibrium framework allows us to quantify the impacts of bank capital regulation on macroeconomic variables. In our model, the financing of capital goods production is subject to an agency problem, as in Carlstrom and Fuerst (1997). The financing problem, however, is characterized by entrepreneurs' moral hazard and liquidity provision by financial intermediaries. This framework is proposed by Holmstrom and Tirole (1998) and adapted by Kato (2006) to a DSGE environment. We extend Kato's work in several dimensions so that we can examine the quantitative impacts of bank capital regulation. An alternative approach would be the costly state verification framework developed by Townsend (1979) and popularized in macroeconomics by Bernanke and Gertler (1989), Carlstrom and Fuerst (1997), and Bernanke et al. (1999). We have adopted the moral hazard framework of Holmstrom and Tirole (1998) because, as shown by Kato (2006), the model generates countercyclical liquidity dependence. Firms tend to rely more heavily on lines of credit to finance their liquidity needs during downturns. This countercyclical liquidity dependence underscores the important role banks play in an economy. According to Schuermann (2009), U.S. banks provide approximately 20% of total U.S. lending, but during downturns, market finance becomes scarce, and firms increase their liquidity dependence on banks by drawing down the loan

commitments prearranged with banks.¹ The increase in bank lending will also increase the amount of capital the bank needs to hold to support the expansion of its lending capacity. Our paper tries to quantify the effects of this interaction between countercyclical liquidity dependence and bank capital regulation.

In this paper, we consider three regulatory regimes. The first case assumes that capital requirements do not vary over the business cycle. This mimics the regulation under Basel I. The other two regimes assume that the capital requirement ratio is time-varying. The first one is *procyclical regulation* and corresponds to the Basel II regulation. Under this regime, we let capital requirements increase (decrease) during downturns (booms). The second one is *countercyclical regulation*, which is argued, for example, in FSF (2009) and Brunnermeier et al. (2009). In this regime, we let capital requirements decrease (increase) during downturns (booms).

The model is calibrated by using relevant observable information such as the utilization rate of the credit lines, loss given default, and the default rate. These pieces of information, together with the Basel II risk-weight formula, help us calibrate, among other things, procyclical capital requirements, in a way such that the aggregate-level risk-weight fluctuates in a plausible manner. We also consider hypothetical countercyclical regulation that fluctuates symmetrically with the procyclical case by the same magnitude. Our simulations suggest that regulation can have large effects on the amplification of macroeconomic fluctuations. With our benchmark calibration, output under procyclical regulation responds much more strongly than under countercyclical regulation; the largest difference in output responses amounts to one percentage point. This translates into an almost 26% difference in the standard deviation of output under the two time-varying capital requirements. While this volatility difference narrows to around 12% in more conservative calibrations, the main conclusion that bank capital regulation has quantitatively important business cycle effects still holds. Our main result is driven by the ability of banks to provide lines of credit to firms. In the countercyclical regulation regime, when the availability of lines of credit is more valuable (during downturns), the cost of making those loans is reduced because capital requirements are relaxed. Relaxing capital requirements implies that it is easier for banks to meet the firm's financing needs and, consequently, more positive NPV projects (that would otherwise be abandoned) are implemented. The impacts of the shock on investment and output are thus dampened. In contrast, procyclical regulation has exactly the opposite effects. The effect on household consumption in our model turns out to be less clear-cut, but the consumption path under countercyclical regulation is indeed smoother, thereby implying higher welfare. Specifically, the benchmark calibration implies that welfare under countercyclical regulation is 1.7% higher than under procyclical regulation.

This paper proceeds as follows. In Section 2, we describe our model. In Section 3, we describe the calibration of the model. Section 4 examines business-cycle implications of the procyclical and countercyclical regulatory regimes. In Section 5 we provide some sensitivity analysis with respect to key parameters of the model. Section 6 concludes the paper.

¹There are several papers on the importance of loan commitments for bank risk management and corporate liquidity management. See, for example, Kashyap et al. (2002) and Sufi (2009), respectively.

Table 1: Sequence of Events Within a Period

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1. The aggregate technology shock (ϵ) is realized.
 2. Firms hire labor and rent capital from households and entrepreneurs and produce the consumption good.
 3. Households earn their labor and capital income and make the consumption-saving decision.
 4. The bank uses the resources obtained from the households to provide loans to the entrepreneurs. The optimal contract is described in Subsection 2.2.
 5. The entrepreneurs borrow $i - n$ consumption goods from the bank and place all of them together with their entire net worth n into capital-creation projects.
 6. The idiosyncratic liquidity shocks (ω) are realized. The projects with $\omega \leq \bar{\omega}$ are financed through credit lines. Otherwise, the projects are abandoned and the bank obtains the liquidation value of τi .
 7. Outcomes of the continued projects are realized. The entrepreneurs with successful projects pay back the loan.
 8. The entrepreneurs make the consumption-saving decision.
-
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2 Model

The model structure is similar to that in Kato (2006), who provides an important alternative to Carlstrom and Fuerst (1997) and Bernanke et al. (1999) in modeling the financial frictions in macroeconomic models. The latter two papers embed costly state verification (CSV) into an otherwise-standard RBC model. Instead of CSV, Kato (2006) adopts the financial contract developed by Holmstrom and Tirole (1998), who emphasize the importance of the liquidity provision by financial intermediaries and its interaction with entrepreneurs' moral hazard. We deviate from Kato (2006) in the following two ways. First, we allow for the non-zero liquidation value when the projects are abandoned. The second, which is the focus of our paper, is that we impose capital requirements on financial intermediaries.

2.1 Environment

The economy is populated by four types of agents: a fixed mass η of households, a fixed mass $1 - \eta$ of entrepreneurs, banks, and firms. Both the households and the entrepreneurs supply labor and rent out capital to the firms that produce the consumption good. The entrepreneurs differ from the households with respect to their ability to produce the capital good. The entrepreneurs borrow funds from the banks, which funnel the households' savings. The intermediation is subject to the agency problem of Holmstrom and Tirole (1998). Further, the banks are also constrained by capital requirements. The sequence of events, which is similar to that in Carlstrom and Fuerst (1997), is summarized in Table 2.1.

2.2 Financial Contract

The financial contract starts and ends within a period. The general equilibrium of the economy influences the contract only through the level of net worth n and the price of capital q . These variables are thus treated parametrically in this subsection.

The contract involves two parties, a bank and an entrepreneur. Both parties are risk neutral. Entrepreneurs are endowed with technology that converts the consumption good into the capital good. Let i be the investment size (measured in the consumption good), which yields Ri units of the capital good, when the project is successful.² The success probability is p_j where $j \in \{H, L\}$. The entrepreneur, whose net worth is n , borrows $i - n$ units of the consumption good from the bank.

The project proceeds in three stages (0, 1, and 2). At stage 0, the investment (i) is put in place. At stage 1, the exogenous “liquidity shock,” $\omega \in [0, \infty)$, is realized. The shock determines a per-unit-of-investment cash infusion necessary to continue the project. ω is assumed to be i.i.d. cross-sectionally and over time and distributed according to $\Phi(\omega)$ with density $\phi(\omega)$. Without the cash infusion, the project is abandoned and liquidated. When the project is abandoned, the salvage value, τi , is transferred to the lender.³ The last stage, in which the project is actually undertaken, is subject to moral hazard of the entrepreneur. He can exert effort or shirk. Exerting effort yields the success probability of p_H and no private benefit and shirking results in the lower success probability of $p_L (< p_H)$ and yields a private benefit of Bi .

As Holmstrom and Tirole (1998) show, socially optimal financing in this environment is characterized by the cutoff rule that the project is abandoned if and only if $\omega \geq p_H R \equiv \omega_1$. This level of the liquidity shock is called the first best cutoff.

Capital Requirements. The bank can raise funds through either deposits or equity (E), but issuing equity involves the resource cost $\Gamma = \gamma_0 E$. The linear cost is assumed for analytical convenience. The banks are, by regulation, required to maintain a certain level of equity; the regulator imposes “capital requirements” in terms of the size of equity relative to the total number of loans (L):

$$E = \theta(\Omega)L, \tag{1}$$

where $\theta(\Omega)$ is the capital requirement ratio, which can depend on the exogenous aggregate state Ω .⁴

We will consider three regulatory regimes: (i) a fixed-requirement regime where θ does not vary with the aggregate state, (ii) a procyclical regulation regime, and (iii) a countercyclical regulation regime. In the last two regimes, the requirement ratio varies with Ω . We postulate a simple log-linear relation between θ and Ω , and the elasticity will be calibrated later. Note that our specification of the countercyclical regulation is similar to the proposal by Gordy

²When it fails, the return is zero.

³Kato (2006) assumes that the liquidation value is zero. In contrast, we allow for a positive liquidation value and the parameter τ is calibrated referring to the empirical evidence.

⁴Because equity is more costly than deposit, the constraint always binds in our model.

and Howells (2006) who argue relaxing (tightening) capital requirements when the aggregate economic condition is worse (better) than normal.

Optimal Contract. The optimal contract maximizes the entrepreneur's expected payoffs by choosing (i) the size of the project i , (ii) the return to the entrepreneur, R^e when the project is successful,⁵ and (iii) the cutoff liquidity shock ($\bar{\omega}$). The problem is subject to the bank's break-even constraint and the entrepreneur's incentive compatibility constraint:⁶

$$\max qi p_H R^e \int_0^{\bar{\omega}} \phi(\omega) d\omega, \quad (2)$$

subject to:

$$i - n + qi \int_0^{\bar{\omega}} \omega \phi(\omega) d\omega = qi \int_0^{\bar{\omega}} p_H (R - R^e) \phi(\omega) d\omega + qi(1 - \Phi(\bar{\omega}))\tau - \gamma_0 E, \quad (3)$$

and

$$p_H R^e \geq p_L R^e + B, \quad (4)$$

where Equation (3) is the bank's break-even constraint and Equation (4) is the entrepreneur's incentive compatibility constraint. In (3), the left-hand side represents the total number of loans (i.e., the sum of initial project loans and the credit lines in the middle stage), the first term on the right-hand side gives the return to the bank when the project is successful, the second term gives the liquidation value when the project is terminated, and the last term gives the equity issuance cost.

As Holmstrom and Tirole (1998) show, Equation (4) binds in the optimal contract. The return to the lender is then written as $p_H \left(R - \frac{B}{p_H - p_L} \right) \equiv \omega_0$, which is called pledgeable income. Using Equation (1) and the binding incentive compatibility constraint, Equation (4), in Equation (3) results in:

$$i = \frac{1}{1 - qh(\bar{\omega}, \theta(\Omega))} n, \quad (5)$$

where

$$h(\bar{\omega}, \theta(\Omega)) = \frac{\Phi(\bar{\omega})\omega_0 + (1 - \Phi(\bar{\omega}))\tau}{1 + \gamma_0\theta(\Omega)} - \int_0^{\bar{\omega}} \omega d\Phi(\omega). \quad (6)$$

This expression makes clear that investment is influenced not only by net worth and the price of capital as in Kato (2006) but also by the capital requirement ratio. Using Equation (5) in Equation (2) and maximizing the resulting expression with respect to $\bar{\omega}$ results in the following first-order condition:

$$q \int_0^{\bar{\omega}} \Phi(\omega) d\omega = 1 - \frac{q\tau}{1 + \gamma_0\theta(\Omega)}. \quad (7)$$

⁵This is equivalent to choosing the division of the total return R between the two parties.

⁶Note that a binding capital requirement is a priori imposed below.

We can solve this optimality condition for the cutoff liquidity shock $\bar{\omega}$, given the levels of q and $\theta(\Omega)$. As in Kato (2006), we define the degree of liquidity dependence as follows:

$$\text{Liquidity dependence} \equiv \frac{i \int_0^{\bar{\omega}} \omega d\Phi(\omega)}{ip_H R \Phi(\bar{\omega})} = \frac{\int_0^{\bar{\omega}} \omega d\Phi(\omega)}{\omega_1 \Phi(\bar{\omega})}. \quad (8)$$

This expression captures the dependence on bank's liquidity provision relative to the size of investment.

2.3 Households

The representative household maximizes the discounted sum of their utility derived from consumption (c_t) and leisure (l_t):

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t), \quad (9)$$

where β is the discount factor. As in Carlstrom and Fuerst (1997) and Kato (2006), we assume that the utility function is additively separable in consumption and leisure, and labor supply is indivisible:

$$u(c_t, l_t) = \frac{c_t^{1-\psi}}{1-\psi} + \nu(1-l_t), \quad (10)$$

where ψ is the coefficient of relative risk aversion and ν is a normalizing constant.⁷ The decisions are subject to the following budget constraints:

$$c_t + s_t = r_t k_t + w_t(1-l_t), \quad (11)$$

$$k_{t+1} = (1-\delta)k_t + \frac{1}{q_t} s_t, \quad (12)$$

where s_t is the household saving at the bank, k_t is the capital stock held by the household, w_t and r_t are, respectively, wage and interest rates paid by the firm, and δ is the depreciation rate of the capital stock. The first-order conditions to this problem are written as follows:

$$q_t = \beta E_t \left(\frac{c_t}{c_{t+1}} \right)^\psi \left[r_{t+1} + (1-\delta)q_{t+1} \right], \quad (13)$$

$$-\nu c_t^\psi = w_t. \quad (14)$$

Note that the proportion $\theta(\Omega_t)$ of the household saving s_t is held as “bank equity E ,” and the rest as “deposits.” From the household's standpoint, however, the portfolio choice is irrelevant because either asset yields gross interest of unity. This outcome is supported by the assumption that the financial contract starts and ends within the same period.

⁷Our results below are not sensitive to the choice of the functional form. For instance, we have experimented with cases where the utility function is non-separable or where labor supply is divisible and obtained results similar to those reported below.

2.4 Entrepreneurs

In modeling the behavior of entrepreneurs, we make several assumptions similar to Carlstrom and Fuerst (1997), which are also adopted by Kato (2006). First, they are risk-neutral. Second, they discount the future more heavily ($\beta^e < \beta$) than the households. This latter assumption is to avoid the self-financing equilibrium.⁸ Third, the entrepreneurs supply labor inelastically to the firm. The entrepreneur maximizes the discounted sum of their utility derived from consumption (c_t^e):

$$E_0 \sum_{t=0}^{\infty} (\beta^e)^t c_t^e, \quad (15)$$

subject to

$$n_t = (1 - \delta)q_t z_t + r_t z_t + w_t^e, \quad (16)$$

$$c_t^e + q_t z_{t+1} = \frac{q_t(\omega_1 - \omega_0)\Phi(\bar{\omega}_t)}{1 - qh(\bar{\omega}_t, \theta(\Omega_t))} n_t, \quad (17)$$

$$(18)$$

where z_t is the capital stock held by the entrepreneur, and w_t^e is the wage payment to the entrepreneur. The first-order condition to this problem is:

$$q_t = \beta^e E_t [q_{t+1}(1 - \delta) + r_{t+1}] \frac{q_{t+1}(\omega_1 - \omega_0)\Phi(\bar{\omega}_{t+1})}{1 - qh(\bar{\omega}_{t+1}, \theta(\Omega_{t+1}))}. \quad (19)$$

2.5 Firms

The representative firm produces the consumption good by using the following constant-returns-to-scale technology:

$$Y_t = A_t K_t^\alpha H_t^\iota J_t^{1-\alpha-\iota}, \quad (20)$$

where A is TFP, K is aggregate capital stock, H is labor supply by the household sector, and J is labor supply by the entrepreneurial sector. TFP evolves according to the following AR(1) process:

$$\ln A_{t+1} = \rho \ln A_t + \epsilon_{t+1}. \quad (21)$$

The technology shock ϵ_t is distributed as standard normal $N(0, \sigma_\epsilon)$. Labor and capital rental markets are assumed to be competitive. The firm thus hires two types of labor and rent capital according to: $r_t = \alpha A_t K_t^{\alpha-1} H_t^\iota J_t^{1-\alpha-\iota}$, $w_t = \iota A_t K_t^\alpha H_t^{\iota-1} J_t^{1-\alpha-\iota}$, and $w_t^e = (1 - \alpha - \iota) A_t K_t^\alpha H_t^\iota J_t^{-\alpha-\iota}$.

2.6 General Equilibrium

The following market-clearing conditions close the model:

$$H_t = (1 - \eta)(1 - l_t) \quad (22)$$

⁸See, for example, Carlstrom and Fuerst (1997) and Bernanke et al. (1999).

$$J_t = \eta \tag{23}$$

$$Y_t = (1 - \eta)c_t + \eta c_t^e + \eta i \left(1 + q_t \int_0^{\bar{\omega}_t} \omega d\Phi(\omega) + q_t \frac{\gamma_0 \theta(\Omega_t) \Phi(\bar{\omega}_t) \omega_0 - (1 - \Phi(\bar{\omega}_t)) \tau}{1 + \gamma_0 \theta(\Omega_t)} \right) \tag{24}$$

$$K_{t+1} = (1 - \delta)K_t + \eta i \omega_1 \Phi(\bar{\omega}_t). \tag{25}$$

The first two equations above clear the two labor markets, the third equation clears the market for the consumption good, and the last equation clears the market for the capital good. The last term in Equation (24) properly accounts for the bank’s equity issuance cost net of the liquidation value of the failed projects.

3 Benchmark Calibration

We now discuss benchmark calibration of the model. One period in the model is assumed to be one quarter. The parameter values used in benchmark calibration are summarized in Table 2.

3.1 Parameters Set Externally

The discount factor for the household (β) is set equal to 0.99. The discount factor for the entrepreneur (β^e) needs to be set to a lower value to avoid the self-financing equilibrium and is chosen to be 0.94. This value is commonly used in this literature (e.g., Carlstrom and Fuerst (1997)). The CRRA parameter of the household (ψ) is set to 1.5. The firm’s production technology is Cobb-Douglas, as shown in (20), with the capital share α equal to 0.33, the household’s labor share ι equal to 0.66, and the entrepreneur’s labor share equal to 0.01. These numbers are all in line with the previous literature. The depreciation rate of the capital stock δ is 0.025. The aggregate TFP process (A_t) is assumed to have the persistence parameter ρ equal to 0.95 and the conditional standard deviation σ equal to 0.007. The equity issuance cost is assumed to be equal to 0.20, which is slightly lower than the value reported in Cooley and Quadrini (2001).⁹ Because this is an important parameter that could potentially influence the effects of capital requirements, we will later consider an alternative, lower value. Finally, we follow the literature in assuming that 30% of the population are entrepreneurs and 70% are households.

3.2 Parameters Set Internally

First, the normalizing parameter ν of the labor supply function is chosen to be 3.25, such that the household spends one-third of its time on working, given all other parameter values. We assume that the distribution of liquidity shocks $\Phi(\omega)$ is lognormal with mean equal to

⁹Cooley and Quadrini (2001) use 0.3 for the equity issuance cost. However, we want our calibration to be on the conservative side and thus use 0.2 instead of 0.3.

Table 2: Parameter values for the benchmark economy

Discount factor of households	β	0.99
Discount factor of entrepreneurs	β^e	0.94
Relative risk aversion of households	ψ	1.50
Labor supply parameter	ν	3.25
Capital share	α	0.33
Household labor share	ι	0.66
Depreciation rate	δ	0.025
S.D of liquidity shock	σ_ω	0.42
First best cut-off	ω_1	2.75
Pledgeable income	ω_0	2.04
Recovery rate parameter	τ	0.60
Equity issuance costs	μ	0.20
Level of capital requirements	γ_0	0.08
Elasticity of capital requirements	γ_1	$\{0, \mp 8\}$
Persistence of aggregate TFP shock	ρ	0.95
S.D. of aggregate TFP shock	σ	0.007

Notes: Three regulatory regimes are considered and are distinguished by the elasticity of the capital requirement ratio with respect to aggregate TFP. $\gamma_1 = 0$ corresponds to the fixed requirement regime, $\gamma_1 = -8$ the procyclical regulation regime, and $\gamma_1 = 8$ the countercyclical regulation regime.

one and a standard deviation of σ_ω .¹⁰ We assign σ_ω together with the three parameters, the first-best cut-off ω_1 , the pledgeable return from the investment ω_0 , and the liquidation value parameter τ , to match the following four moments from the data; (i) loss given default (LGD) on bank loans; (ii) probability of default (PD); (iii) utilization rate on lines of credit; and (iv) the ratio of unused commitments to total loans. These four moments are summarized in Table 3.

LGD. First, note that Moody's and S&P have databases with recovery rates for various debt instruments. However, most of the defaults in these two databases are for corporate bonds and not for bank loans. There are various differences between these two instruments,

¹⁰The mean of the distribution is set to one as normalization. In principle, we could use either the steady-state level of the price of capital or the mean as normalization.

and in particular, corporate bonds are unsecured and bank loans are often secured loans at the time of default. This results in significant differences in average recovery rates. Specifically, corporate bonds have significantly lower recovery rates compared to bank loans. We thus make use of the information provided by Araten et al. (2004) to calibrate average LGD. This study was based on the default experience of a single large U.S. bank in the period between 1982 and 1999. Given the large size of this bank's portfolio, we believe that this series is more representative than the information based on a limited number of defaulted bank loans available in the Moody's or S&P databases. The average LGD of this bank over this 18-year period is 39.8%. We target this value in the steady state by associating it with the following concept in the model:

$$\text{LGD} = 1 - \frac{\tau qi}{i - n},$$

where the second term in the right-hand side is the recovery rate of the initial bank loan.

PD. For the empirical default rate, we rely on the default-rate series published by Moody's that covers the period between 1982 and 2004. In Moody's data, the average default rate over the 22-year period is 0.50% per quarter, which is taken to be our target. In the model, the corresponding default rate is simply the probability that the liquidity shock ω is higher than the cutoff value $\bar{\omega}$.

Utilization rate. We use the evidence gathered by Sufi (2009) to calibrate the average ratio of the used amount of the credit line to the committed amount. For a sample of 300 firms with debt outstanding, the average utilization rate is 32.5% over the period 1996 through 2003. This evidence is taken to be our target. In the model, we can define the utilization rate as follows:

$$\text{Utilization rate} = \frac{\int_0^{\bar{\omega}} \omega d\Phi(\omega)}{\bar{\omega}\Phi(\bar{\omega})}.$$

Unused commitments. The ratio of unused commitments to total loans is available on the regulatory filings of all commercial banks. The information is collected as part of the call reports. The sample period for this series is 1990 through 2004. The average ratio of unused commitments over this period amounts to 86%. In the model, this ratio is defined as follows:

$$\text{Ratio of unused commitments} = \frac{qi \int_0^{\bar{\omega}} (\bar{\omega} - \omega) d\Phi(\omega)}{(i - n) + qi \int_0^{\bar{\omega}} \omega d\Phi(\omega)}.$$

Table 3 presents the steady-state performance in matching these four moments. While the model is unable to match these moments exactly, three moments appear reasonably close to their empirical counterparts.

Table 3: Selected moments: data vs. model

Moments	Data (%)	Model (%)
LGD	39.8	40.7
PD	0.5	0.5
Utilization rate of credit lines	32.5	36.2
Ratio of unused commitments over total loans	86.0	86.9

Notes: LGD (loss given default) equals the ratio of the amount of losses to loans outstanding at the time of default. The reported number is an average over 1982 through 1999 for a large U.S. bank, reported by Araten et al. (2004). PD (the probability of default) is from Moody’s default rate series. The reported number is an average over 1982 through 2004. The utilization rate is equal to the ratio of used revolving credits over the committed amount. It is taken from Sufi (2009), who uses a sample of 300 firms with debt outstanding over 1996 through 2003. The ratio of unused commitments to total loans is calculated from the series in call reports, RCFD3423 and RCFD1400, which cover all U.S. commercial banks over 1990 through 2004.

3.3 Capital Requirements

It remains to specify the process for regulatory capital requirements θ . First, we assume that the capital requirement ratio is a simple log-linear function of the exogenous aggregate state (Ω_t). In our model, the only exogenous state variable is TFP and thus $\Omega_t = A_t$. The function is written as:

$$\theta_t = \gamma_0 A_t^{\gamma_1}. \tag{26}$$

where γ_0 and γ_1 are the parameters to be calibrated. As we mentioned above, we consider three regulatory regimes.

Fixed capital requirement regime. In the *fixed capital requirement regime*, we set γ_0 and γ_1 to 0.08 and 0, respectively. In this regime, the capital requirement ratio is fixed independent of the aggregate state, mimicking the regulation under Basel I.

Procyclical regulation regime. In the *procyclical regulation regime*, the capital requirement ratio increases (decreases) when the economy is in a downturn (boom), implying that $\gamma_1 < 0$. This regime mimics the regulation under Basel II. The Basel II regulation requires banks to calculate the risk weight for each loan based on a formula, which is detailed in the Appendix. Roughly speaking, the formula takes PD, LGD, and maturity of the loan and yields the risk weight for that loan. We calculate the average risk weight (i.e., the average capital requirement ratio) by using average values of these three variables. LGD is taken to be 40%, a level consistent with the evidence mentioned before. Average maturity is taken to be 2.5 years. Last, we use the Moody’s default rate series for PD. We then obtain a time

series of the economy-wide risk weight over the period 1982 and 2004. This series fluctuates over time because of the time variations in the default rate series. We calibrate γ_0 and γ_1 to replicate the cyclical features of this series. Specifically, the aggregate risk-weight series has a mean level of 8% and volatility of 0.10 after applying the HP filter with smoothing parameter of 1600. We thus set γ_0 to 0.08. We also obtain $\gamma_1 = -8$ as a value that matches the volatility of the HP-filtered series.

Countercyclical regulation regime. In contrast to the procyclical requirement regime, the *countercyclical regulation regime* imposes a lower (higher) capital requirement ratio when the economy is in a downturn (boom). As a natural benchmark, we consider the case where the cyclicality of the capital requirement ratio is symmetric to the procyclical regime. That is, θ_t fluctuates around the same mean ($\gamma_0 = 0.08$) and the same elasticity with an opposite sign ($\gamma_1 = 8$). In a later section, we examine the sensitivity of our results with respect to smaller elasticities.

3.4 Solving the Model

We solve the model nonlinearly by applying the projections PEA (parameterized expectation algorithm). Specifically, we parameterize the conditional expectations in the two Euler equations (13) and (19) by a tensor product of the Chebyshev polynomials of the three state variables z_t , K_t , and A_t . Given the parameterized values of the expectations, we solve for all endogenous variables. We can then evaluate the conditional expectations and see if they are close to the initially postulated conditional expectations. We iterate on this process until the coefficients of the parameterized functions converge.¹¹

4 Results

This section discusses the quantitative implications of the model under the benchmark calibration. To gain some insights about the effects of the change in capital requirements, we first consider the case where the requirement ratio θ goes down by itself (with no change in aggregate productivity). We then briefly discuss the quantitative properties of the model under the presence of the aggregate productivity shock, holding the capital requirement ratio at 8% (i.e., fixed capital requirement regime). Last, we combine the two cases and compare the economy's responses under different regulatory regimes.

4.1 Responses to a Capital Requirement Shock

In this subsection, we assume that the capital requirement ratio itself follows an AR(1) process with a persistence parameter of 0.95. We assume that capital requirements fall from

¹¹The integrals associated with the aggregate shock is numerically calculated by using the Gauss-Hermite quadrature with 5 nodes. The integrals associated with the liquidity shock is calculated by using Simpson's rule with 51 nodes, since the distribution is truncated by $\bar{\omega}$.

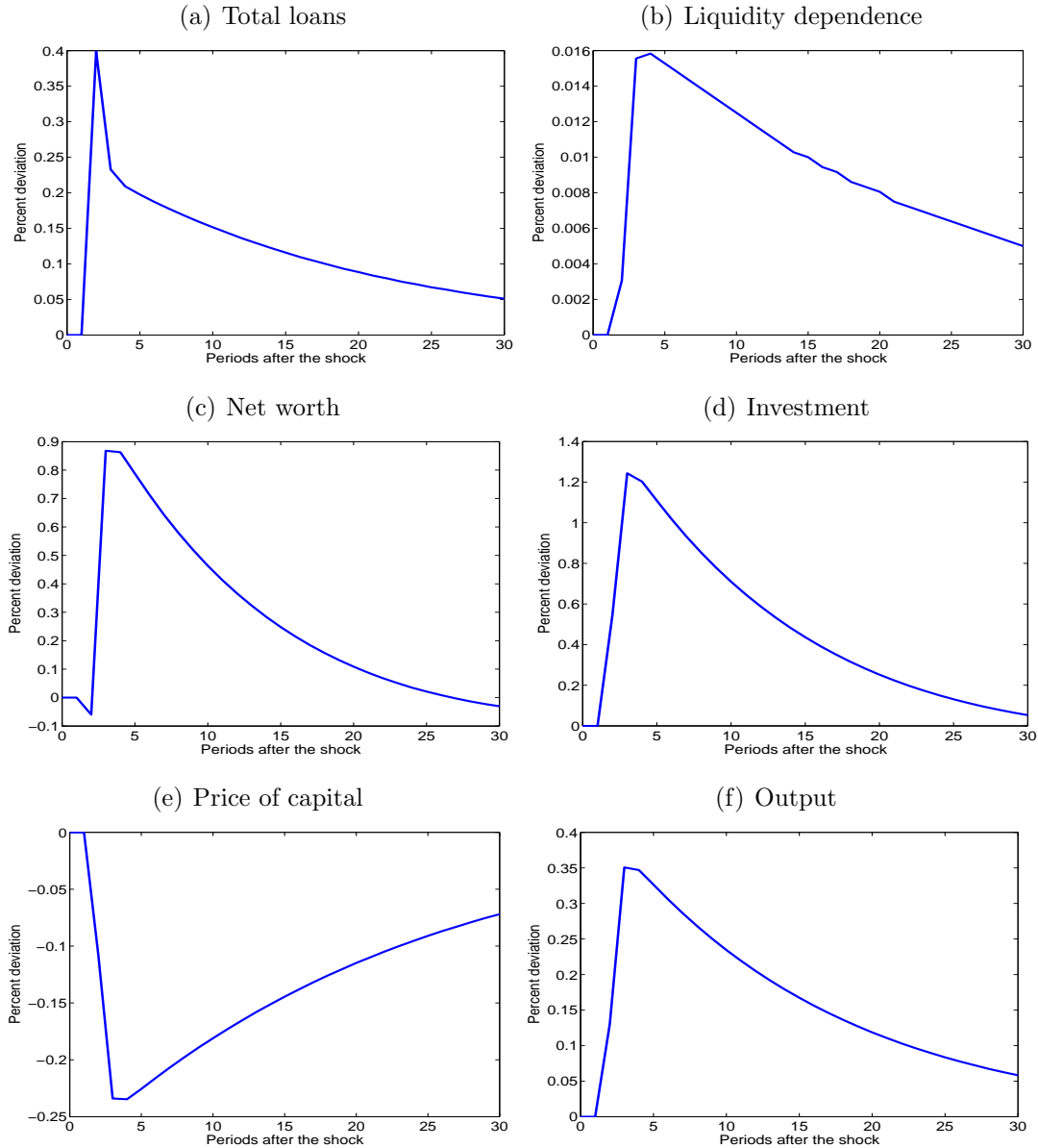


Figure 1: Responses to a Capital Requirement Shock

Notes: Plotted are responses to a decline in the capital requirement ratio. The requirement ratio drops from 8% to 6.7% in the impact period and returns to 8% with a persistence parameter of 0.95.

8% to 6.7% on impact and gradually return to the steady-state level of 8%.¹²

Figure 1 presents the responses of total loans, liquidity dependence, the entrepreneur's net worth, investment, output, and the price of capital.¹³ Due to the drop in the capital

¹²The size of the initial decline equals the size that occurs when the economy is hit by a one-standard-deviation productivity shock and the two variables are linked through Equation (26).

¹³The number of loans is given by the left-hand side of Equation 3. See Equation (8) for the definition of liquidity dependence.

requirement ratio and because equity is more costly than deposits, loan demand increases by about 0.4% relative to its steady-state value (Panel (a)). The liquidity dependence variable slightly increases by 0.016% from its steady-state value (Panel (b)). Note that this increase of liquidity dependence, while small in this experiment, represents the feature of the model that lower capital requirements allow banks to finance projects that would have been terminated otherwise. Further, since lower capital requirements imply a lower cost of funds, it translates into increases in the entrepreneur’s net worth and hence increases in investment (Panels (c) and (d)). The price of capital falls because lower capital requirements increase the supply of capital goods (Panel (e)), since aggregate productivity remains the same. Finally, since capital and labor are complements in consumption goods production, aggregate output increases by 0.35% (Panel (f)). This exercise demonstrates that, in this model, changes in capital requirements cause significant real effects.

4.2 Responses to an Aggregate Productivity Shock

The responses to a one-standard-deviation *negative* aggregate productivity shock are shown in Figure 2. Here, we assume that the capital requirement ratio stays constant at 8%. The responses to an aggregate productivity shock are also analyzed in Kato (2006), and thus we will be brief and emphasize the results particularly relevant to our paper.

In our view, a key feature of this model is the behavior of liquidity provision by banks in the wake of an adverse shock. In particular, observe that the firm’s liquidity dependence *increases* when the negative shock occurs. That is, it is optimal for the bank to increase the liquidity dependence to allow entrepreneurs to better withstand their liquidity needs in bad times. Naturally, aggregate loan demand falls in response to the negative shock since the marginal product of capital falls. However, the increase in liquidity dependence dampens the impact of the productivity shock on output. As emphasized by Kato (2006), this “smoothing” mechanism generates a hump-shaped response in aggregate output.¹⁴

4.3 The Effect of Time-Varying Capital Requirements

We now consider the exercises where the capital requirement ratio is linked with aggregate productivity through Equation (26). Remember that our specification of the capital requirement ratio assumes that it is perfectly correlated (either positively or negatively) with the aggregate productivity series. It is informative to see how the capital requirement ratios behave relative to aggregate output in our economy. Figure 3 compares the two capital requirement series with aggregate output generated under fixed capital requirements.¹⁵ Under the procyclical regulation, which mimics Basel II, the requirement ratio takes its highest value at around 11% and its lowest value at around 6% over the 15-year period we consider

¹⁴Kato (2006) compares output responses in his model and the standard RBC model and shows that the RBC model implies a larger initial response of output. While our model differs from Kato’s in terms of calibration as well as the model itself, we also obtain the hump-shaped response.

¹⁵Output paths under the two time-varying requirement ratios, of course, differ from each other and thus we use here the output path under the fixed requirement ratio.

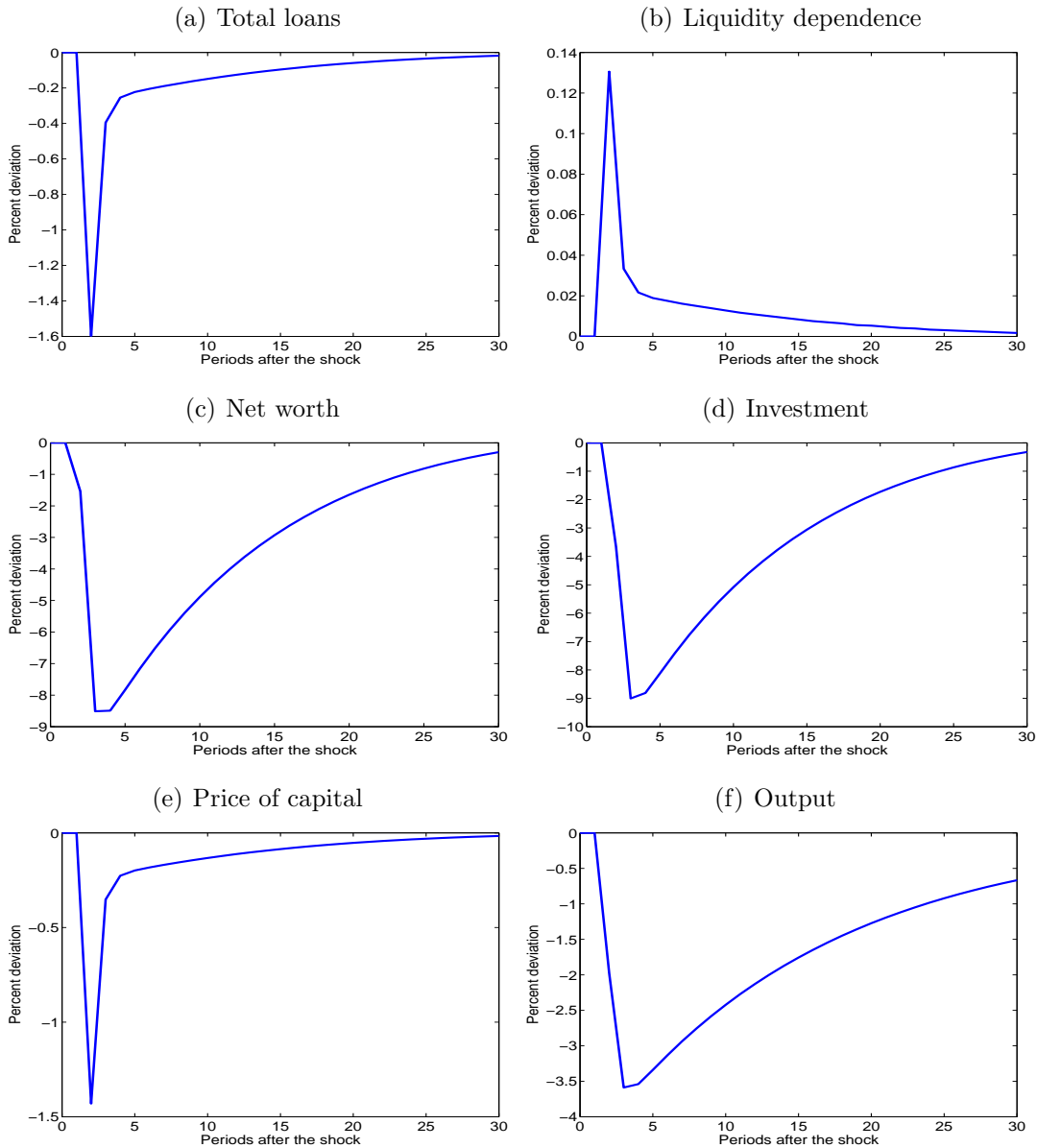


Figure 2: Responses to a Productivity Shock

Notes: Plotted are responses to a one-standard-deviation negative productivity shock. The capital requirement ratio is assumed to be fixed at 8%.

in the figure. The variability of this series appears plausible, since it is obtained using the available empirical evidence in the risk-weight formula of Basel II. The figure also plots our simulated series under the hypothetical countercyclical regulation. As mentioned before, it moves symmetrically within the same range.

Figure 4 shows how differently the economy responds to the negative productivity shock under the three regulatory regimes. The figure plots responses of household consumption and labor supply as well as the same six variables considered before. Panel (a) shows that the

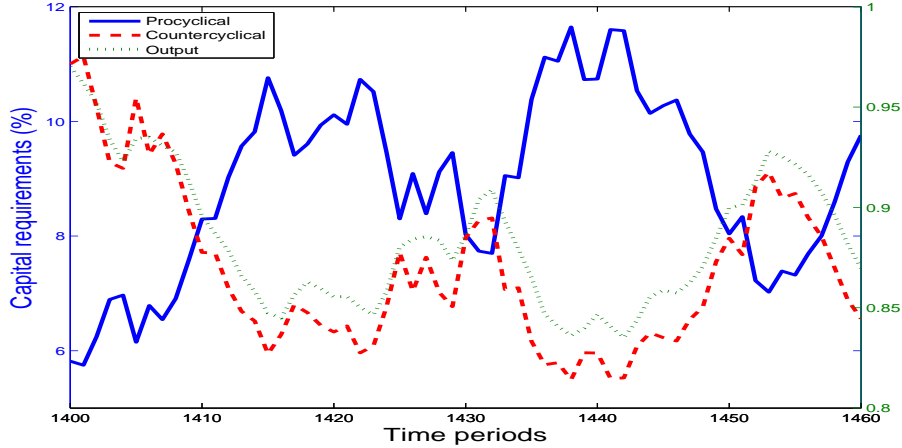


Figure 3: Sample Paths of Capital Requirements and Aggregate Output

Notes: Plotted are simulated series of capital requirements (measured along the left axis) together with the aggregate output series (measured along the right axis). The capital requirement series are simulated with the countercyclical regulation ($\gamma_1 = 8$) or procyclical regulation ($\gamma_1 = -8$). The output series is the one generated under the fixed capital requirement regime.

number of loans falls much more significantly when procyclical regulation is imposed. The largest difference between two time-varying cases is more than one percentage point. Panel (b) shows the differences in liquidity dependence. The entrepreneurs become more dependent of credit lines in bad times, and this effect is considerably more persistent when regulation is countercyclical. As in the case of loan demand, the procyclical capital requirements exacerbate the response of lending to a negative aggregate shock.

The second row of Figure 4 shows the responses of net worth and investment under the three regimes. In line with the larger declines in lending under procyclical regulation, declines in entrepreneurial net worth and investment are also more accentuated in that case. Because equity is more costly than deposits, the increases in capital requirements in bad times raise the costs of external funds to entrepreneurs. Consequently, entrepreneurial profits and thus net worth are reduced by more under procyclical regulation.

The third row presents the responses of output and the price of capital. The output responses are hump-shaped across all cases, and the fall of output is most significant under procyclical regulation. Comparing the two time-varying capital requirement regimes, we can see that the difference in the declines in output amounts to more than one percentage point when the economy is at the trough (i.e., the third quarter after the shock). As for the behavior of the price of capital goods, observe that the pattern of the responses is reversed. That is, declines in the price of capital is smallest in the case of procyclical regulation. It even goes above its steady-state value several periods after the shock. Remember that the higher capital requirement ratio itself raises the price of capital, since it reduces the supply of capital goods. Thus, declines in the price of capital in the face of the negative productivity shock is mitigated under procyclical regulation. The opposite mechanism is at work when

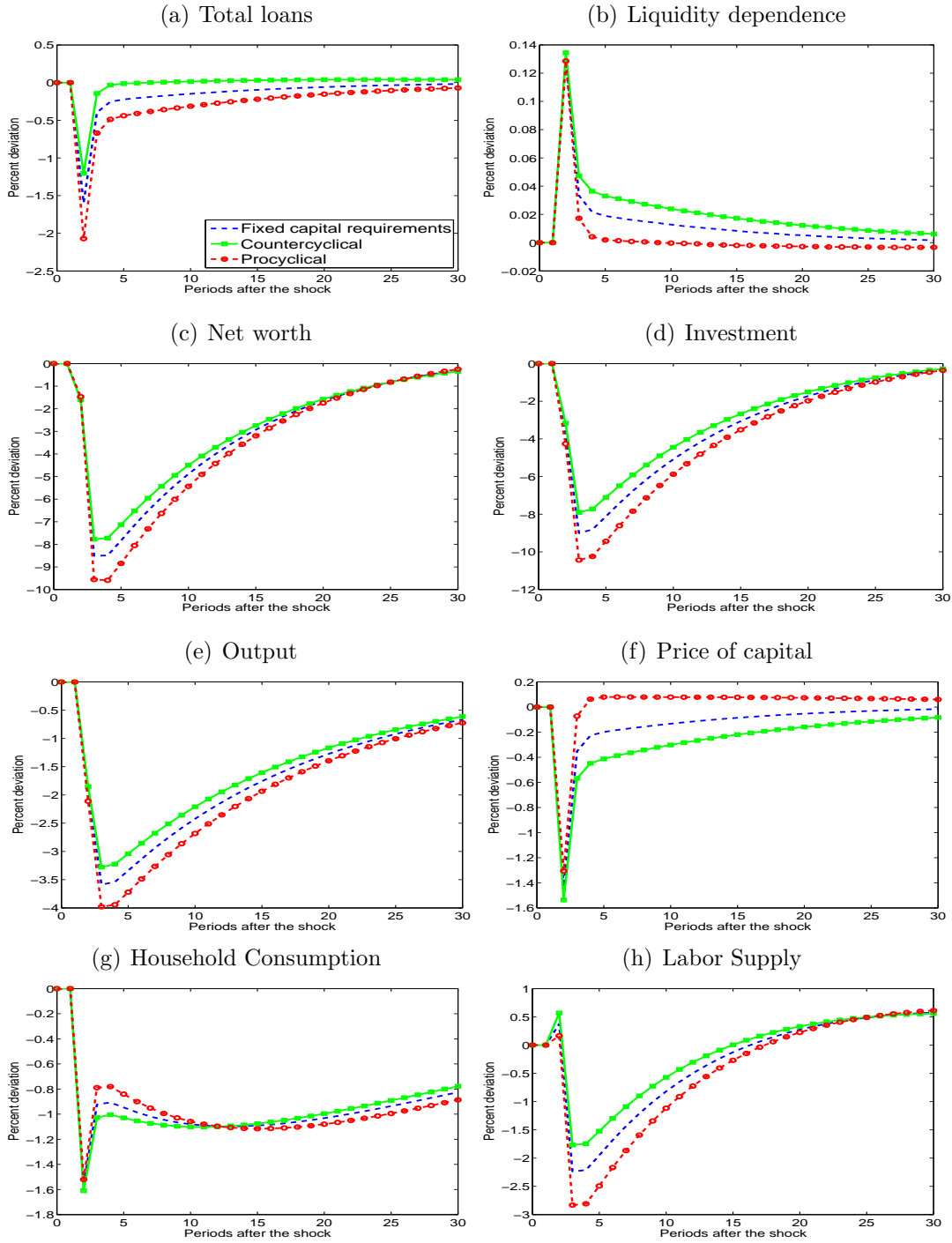


Figure 4: Responses to a Productivity Shock under Three Regulatory Regimes

Notes: Plotted are responses to a one-standard-deviation negative TFP shock under the three regulatory regimes discussed in Subsection 3.3. In Equation (26), regulation is countercyclical when $\gamma_1 = 8$ and procyclical when $\gamma_1 = -8$

regulation is countercyclical, having a negative impact on the price of capital. This behavior of the price of capital has an implication for the behavior of household consumption, which we now discuss.

Panel (g) displays the responses of household consumption and shows that around up to the first 2 years, household consumption is higher under procyclical regulation than under countercyclical regulation. This stems from the behavior of the price of capital; the higher price of capital under procyclical regulation benefits the household, since it means smaller declines in the assets price, supporting household consumption. However, the differences in the behavior of consumption are relatively small. Last, Panel (h) shows that the largest declines in labor supply occur under procyclical regulation. This is in line with the behavior of aggregate output.

Output volatility and welfare. The first row of the upper panel of Table 4 shows output volatilities under the three regimes in terms of standard deviations of the HP filtered data. First, relative to the fixed capital requirement regime, procyclical regulation increases output volatility by about 13%. In the last column, we present the comparison of output volatility in procyclical and (symmetrically) countercyclical regimes. The result shows that output volatility is almost 26% higher under procyclical regulation.

The first row of the lower panel demonstrates the welfare comparison under the different regimes. The second and third columns give the percentage differences of welfare under the two time-varying requirement regimes relative from that under the fixed requirement regime. We calculate welfare by computing a discounted sum of household utility over 200 quarters.¹⁶ These figures translate the volatility differences into household lifetime utility. As we saw in Panel (g) of Figure 4, the effects that the different regimes have on household consumption are not clear-cut; the impact response of consumption is larger under countercyclical regulation than under procyclical regulation. After that, however, consumption does move more smoothly under countercyclical regulation. As the lower panel of Table 4 shows, the latter effect dominates the former, and countercyclical regulation generates higher welfare; it is more than 0.8% higher than under the fixed regulation regime. Compared to the procyclical regulation regime, the welfare gain amounts to 1.7%. The results here, of course, vary with calibrations of the model. The next section discusses the robustness with respect to several important parameters.

5 Sensitivity

As we discussed in Section 3, several parameter choices used in benchmark calibration can have significant implications of our assessment of the different regulatory regimes. Here, we consider two other calibrations, which we think are of highest importance. First, the equity issuance cost μ is set equal to 0.1 instead of 0.2. Because our main results rely on the assumption that equity issuance is more costly than deposits, it is important to see how

¹⁶The figures in the table are based on 500 replications of the simulation.

Table 4: Output Volatility and Welfare

	Fixed capital req.	Countercyclical regulation (a)	Procyclical regulation (b)	Difference (b)/(a)
Output Volatility				
Benchmark	2.02	1.79	2.25	1.26
Lower equity issuance cost	2.02	1.90	2.13	1.12
Lower elasticity	2.02	1.90	2.13	1.12
Welfare				
Benchmark	—	0.83	-0.87	—
Lower equity issuance cost	—	0.36	-0.33	—
Lower elasticity	—	0.40	-0.42	—

Notes: Results are based on 500 replications of 200 observations (after randomization of the initial condition). Output series are logged and HP filtered with smoothing parameter of 1600. Welfare in each replication is calculated as a discounted sum of the household utility over the 200 observations. The levels of welfare are expressed as a percentage difference from the welfare level in the fixed requirement regime. In each panel, the first row gives the results from benchmark calibration. The second row assumes the lower equity issuance cost $\mu = 0.1$. Calibration for the third row reduces the elasticity of capital requirements to -4 (procyclical regulation) and 4 (countercyclical regulation).

sensitive our results are with respect to a lower equity issuance cost. Second, another obvious parameter to change is the elasticity of the capital requirement ratio to the aggregate shock. In Section 3, we have calibrated the elasticity using Moody’s default rate and the Basel II risk-weight formula discussed in the Appendix. It is, however, possible that this procedure overstates the volatility of risk weights over the business cycle. First, in reality, banks can adjust their portfolio towards safer assets during economic downturns, which would attenuate the volatility of capital requirements over time. Second, Moody’s PD is a point-in-time naive estimate of the default probability, but in practice, banks can use more smooth “through-the-cycle” estimates of PDs. Given these two reasons, we reduce the target volatility of capital requirements to 5% from 10%. Accordingly, we use $\gamma_1 = \mp 4$ to simulate procyclical and countercyclical regulations, respectively. Below we discuss only the effects on output volatility and welfare because the pattern of impulse responses remains approximately the same across all cases.

Results. The second and third rows in each panel of Table 4 report the results from the alternative calibrations. As expected, a lower equity issuance cost narrows the volatility difference to 12% from 26% of the benchmark calibration. It also reduces the welfare difference between the two time-varying capital requirement regimes to 0.7% from 1.7%. Similarly, a

lower elasticity reduces the volatility and welfare differences. Interestingly, the size of reduction is slightly more than one-half, implying the presence of some nonlinearity between the elasticity of the capital requirement ratio and output volatility (or welfare). In summary, the volatility and welfare implications of different capital requirements are altered quite significantly with respect to the equity issuance cost and the elasticity of the requirement ratio. Nevertheless, it seems clear that all calibrations considered here imply nonnegligible business cycle effects of capital requirements.

6 Conclusion

In this paper, we have examined the business cycle effects of different capital requirement regimes. Relative to previous studies, our analysis is based on a general equilibrium model where capital goods production is subject to the agency problem studied by Holmstrom and Tirole (1998). Comparing business cycle properties of the model under procyclical and countercyclical regulations, we find that output volatility is almost 26% larger under procyclical regulation. The difference in output volatility translates into the welfare difference of 1.7% under the two regimes. Even with more conservative calibrations, the volatility and welfare differences between the two regimes remain nonnegligible.

Many simplifying assumptions we made allowed us to quantify the macroeconomic effects of bank capital requirements in a general equilibrium model. Our model thus misses several aspects that are considered important in the earlier literature. First, our model lacks a mechanism that generates a precautionary capital buffer (e.g., Repullo and Suarez (2009)) and thus capital requirements are always binding. Second, we a priori assumed the existence of capital requirements. For example, capital requirements can be motivated as a device limiting the bank's moral hazard (e.g., Van den Heuvel (2008)). Extending the model along these dimensions is an important avenue for future research.

7 Appendix

The internal ratings based (IRB) approach uses the probability of default, the loss given default, the exposure at default, and maturity for each exposure to calculate the bank's capital requirements for each loan. For a derivation of the IRB formula, see Gordy (2003). The risk weight is defined as:

$$\text{Risk weight}_t = LGD \times \left[N \left(\frac{N^{-1}(PD_t) + \sqrt{R_t} \times N^{-1}(0.999)}{\sqrt{1 - R_t}} \right) - PD_t \right] \times \left(\frac{1 + (M - 2.5) \times b_t}{1 - 1.5 \times b_t} \right),$$

where $N(\cdot)$ represents the distribution function of standard normal. Moody's default rate is used for PD and LGD is assumed to be 40%. M is average maturity of loans and set equal to 2.5 years. R is called the correlation factor. Lopez (2004) develops the link between R and PD , which is described by the following expression:

$$R_t = 0.12 + 0.12 \times \exp^{-50 \times PD_t}.$$

Finally, there is a parameter, b , which adjusts the maturity of the loan according to its risk as found in various quantitative impact studies conducted by banks as requested by national supervisors and the Basel Committee. This parameter is defined as follows:

$$b_t = [0.11852 - 0.0547 \times \log(PD_t)]^2.$$

References

- ARATEN, M., M. JACOBS JR. AND P. VARSHNEY, “Measuring LGD on Commercial Loans: An 18-Year Internal Study,” *The Risk Management Association Journal* 86 (2004), 96–103.
- BERNANKE, B. AND M. GERTLER, “Agency Costs, Net Worth, and Business Fluctuations,” *American Economic Review* 79 (1989), 14–31.
- BERNANKE, B., M. GERTLER AND S. GILCHRIST, “The Financial Accelerator in a Quantitative Business Cycle Framework,” in J. Taylor and M. Woodford, eds., *Handbook of Macroeconomics* volume 1, chapter 21 (Elsevier, 1999), 1341–1393.
- BLUM, J. AND M. HELLWIG, “The Macroeconomic Implications of Capital Requirements for Banks,” *European Economic Review* 39 (1995), 739–749.
- BORIO, C., C. FURFINE AND P. LOWE, “Procyclicality of the financial system and financial stability: issues and policy options,” BIS Papers No. 1, 2001.
- BRUNNERMEIER, M., A. CROCKETT, C. GOODHART, A. PERSAUD AND H. SHIN, *The Fundamental Principles of Financial Regulation* (International Center For Monetary and Banking Studies, CEPR: Geneva Reports on the World Economy 11 - Preliminary Conference Draft, 2009).
- CARLSTROM, C. AND T. FUERST, “Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis,” *American Economic Review* 87 (December 1997), 893–910.
- COOLEY, T. AND V. QUADRINI, “Financial Markets and Firm Dynamics,” *American Economic Review* 91 (2001), 1286–1310.
- FSF, “Report of the Financial Stability Forum on Addressing Procyclicality in the Financial System,” (2009), available at www.financialstabilityboard.org/publications/r0904a.pdf.
- GORDY, M., “A Risk-Factor Model Foundation for Ratings-Based Bank Capital Rules,” *Journal of Financial Intermediation* 12 (2003), 199–232.
- GORDY, M. AND B. HOWELLS, “Procyclicality in Basel II: Can we treat the disease without killing the patient,” *Journal of Financial Intermediation* 15 (July 2006), 395–417.

- HEID, F., “The Cyclical Effects of the Basel II Capital Requirements,” *Journal of Banking and Finance* 31 (2007), 3885–3900.
- HOLMSTROM, B. AND J. TIROLE, “Private and Public Supply of Liquidity,” *Journal of Political Economy* 106 (February 1998), 1–40.
- KASHYAP, A., R. RAGHURAM AND J. STEIN, “Banks as Liquidity Providers: An Explanation for the Co-existence of Lending and Deposit-Taking,” *Journal of Finance* 57 (2002), 33–74.
- KATO, R., “Liquidity, Infinite Horizons and Macroeconomic Fluctuations,” *European Economic Review* 50 (July 2006), 1105–1130.
- LOPEZ, J., “The empirical relationship between average asset correlation, firm probability of default and asset size,” *Journal of Financial Intermediation* 13 (2004), 265–283.
- REPULLO, R. AND J. SUAREZ, “The Procyclical Effects of Bank Capital Regulation,” Unpublished manuscript, CEMFI, 2009.
- SCHUERMANN, T., “Hearing on Commercial & Industrial and Commercial Real Estate Lending,” (2009), testimony before the Congressional Oversight Panel for the Troubled Asset Relief Program. Available at www.newyorkfed.org/newsevents/speeches/2009/sch090528.html.
- SUFI, A., “Bank Lines of Credit in Corporate Finance: An Empirical Analysis,” *The Review of Financial Studies* 22 (2009), 1057–1088.
- TOWNSEND, R., “Optimal Contracts and Competitive Markets with Costly State Verification,” *Journal of Economic Theory* 21 (1979), 265–93.
- VAN DEN HEUVEL, S., “The Welfare Cost of Bank Capital Requirements,” *Journal of Monetary Economics* 55 (March 2008), 298–320.
- ZHU, H., “Capital Regulation and Banks’ Financial Decisions,” *International Journal of Central Banking* 4 (2008), 165–211.