

A Static Capital Buffer is Hard To Beat*

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Abstract

In a model with endogenous risk taking, deposit insurance and limited liability may lead banks to make risky loans that are socially inefficient. Capital requirements can prevent excessive risk taking at the cost of reducing liquidity-producing bank deposits. The optimal Ramsey rule raises capital requirements: (1) during downturns caused by TFP shocks; (2) during expansions caused by investment-specific shocks; and (3) during increases in market volatility of no consequence for the business cycle. Rules that respond to cyclical conditions fail to prevent excessive risk taking, whereas a static capital buffer performs nearly as well as the Ramsey rule.

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First, do no harm, Hippocrates (5th century BCE)

Mind the cliff, Wile E. Coyote (20th century CE)

1 Introduction

A protracted period of low returns on safe assets followed in the wake of the global financial crisis, and this trend is expected to continue for the foreseeable future. These low returns have raised concerns that financial intermediaries will be tempted to reach for higher yields by taking excessive (or socially inefficient) risks. The risk-taking behavior that we have in mind is epitomized by the emergence of NINJA loans in the subprime mortgage market leading up to the Great Recession and by the booming of leveraged loans in its aftermath. We formalize these concerns by developing a dynamic macroeconomic model in which limited liability and deposit insurance provide incentives for a bank to shift from safe assets to risky assets in its portfolio of loans. A risky asset’s return has high upside potential, but its expected return is lower than that of a safe asset; risky assets are therefore socially inefficient. In our model, a sudden fall in the returns on safe assets can trigger an extended period of excessive risk taking, with major consequences for consumption, business investment and household welfare.

Prudential policy can curb these risk-taking incentives by raising bank capital requirements; indeed, very high capital requirements will force a bank to keep enough “skin in the game” to eliminate the incentives entirely. But capital requirements will reduce bank deposits, which provide liquidity services to households. An all-knowing Ramsey planner – faced with aggregate and sectoral shocks – would maximize the utility of deposits by setting capital requirements just short of triggering a risk-taking episode; triggering a risk-taking episode would lower household utility by a discrete amount. A less-informed planner in the real world might be tempted to zip up to the cliff’s edge without actually going over. But this well-meaning planner runs the risk of a Wile E. Coyote moment, and may be better advised to exercise caution, or do no harm.

In this paper, we will explore this policy tradeoff both theoretically and quantitatively. First, we show how a Ramsey planner would respond to individual macroeconomic shocks, or a change in the volatility of returns in financial markets. We provide examples in which a Ramsey planner would raise capital requirements: (1) during a downturn caused by a TFP shock; (2) during an expansion caused by an investment specific shock; or (3) during an increase in the volatility of financial market returns.

But as suggested above, in a more realistic setting the economy is hit by many shocks simultaneously, and the full Ramsey policy would require too much information to be implementable. To study this more realistic case, we calculate the dynamic Ramsey policy for capital requirements when the economy is bombarded by a full constellation of shocks, and we study the ability of simple policy rules to mimic it. Of particular interest will be the Basel III guidance for setting the countercyclical capital buffer (CCyB).

Our DSGE model combines key elements of the literature on financial frictions and macroeconomic stability. Following Van den Heuvel (2008), banks can lend to safe firms or risky firms. Both kinds of firms are subject to aggregate TFP shocks, but a risky firm is also exposed to an idiosyncratic shock with negative expected value; as mentioned above risky loans are socially inefficient. The only reason a profit maximizing bank would fund a risky firm is that limited liability shields it from downside risk; if the return on safe loans is expected to fall, the bank may take a flier on a risky loan.

Banks fund their lending by issuing deposits and equity to households. Deposits are the cheaper source of funding since they provide liquidity services, and in addition, government deposit insurance makes them the safe asset. Capital requirements increase funding costs and make banks keep more skin in the game. This effect reduces their temptation to take excessive risks. Van den Heuvel's model does not allow for aggregate economic fluctuations or changes in market volatility; our model does.

As noted above, real world policy makers do not have the information necessary to implement the full Ramsey policy when the economy is hit by many shocks at once. Accordingly, we extend the existing literature by considering simple policy rules that try to mimic the Ramsey policy by responding to just one or two endogenous variables. To this end, we use the simulated method of moments to calibrate our model's dynamic structure, which in turn allows us to calculate Ramsey dynamic capital requirements when the model economy is driven by a full constellation of shocks. We generate model data in that stochastic environment, and we regress the Ramsey capital requirements on candidate sets of endogenous variables.

Some simple rules capture the optimal capital requirements rather well; that is, they have an R-square statistic close to 1, at least for some calibrations. However, most of these rules fall into the risk-taking trap from time to time, and we can calculate the frequency of these episodes. Slightly elevated static capital requirements (or "buffers") avoid the Wile E. Coyote moments, and they do about as well as any implementable policy rule on deposits.

The Basel III guidance for the implementation of the CCyB linked increases in capital requirements to periods of rapid credit expansion (or increases in the credit-to-GDP ratio). Basel III called for national authorities to devise guides of their own, but also asked them

to use a common guide that would raise capital requirements when the credit-to-GDP ratio rose relative to its long-run trend.¹ That common guide — which we will call the “Basel rule” — sounds both sensible and implementable in practice. But in our model, the Basel rule does not come close to mimicking the Ramsey policy; other simple rules and small static buffers can do much better.

Related Literature

Our analysis contributes to a rich literature on capital requirements. Our paper is the first to calculate Ramsey policy in a more realistic situation in which a constellation of shocks bombards the economy at the same time. Real world policy makers would not have the information necessary to implement the Ramsey policy in this environment; so, we ask whether simple policy rules, or small capital buffers, can mimic the Ramsey policy. In this focused literature review, we describe other characteristics of our work in the context of various strands of the literature.

Several influential contributions to the literature emphasize risks arising from high leverage and the volume of bank credit. Our work offers a complementary perspective that emphasizes the composition of bank credit: we study the way in which banks reallocate their loan portfolios (between safe and risky assets) in response to shocks that move asset returns.

The papers by Begenau (2020), Collard et al. (2017), and Martinez-Miera and Suarez (2014) share the risk-shifting framework of our model. Their contributions are complementary to our paper. Begenau (2020) — arguably the closest analysis to our own — develops a quantitative business-cycle model that encompasses the basic risk-shifting mechanism of Van den Heuvel (2008). She focuses on the optimal level of static capital requirements in the steady state. Our focus is on optimal cyclical capital requirements. And indeed, as will be explained below, we find it difficult to quantify the optimal steady state. Martinez-Miera and Suarez (2014) develop a model with systemic risk and frictions in the market for bank equity. They analyze how optimal capital requirements change over time when the systemic risk materializes (leading to a sharp drop in bank capital) and during calm periods when the stock of bank capital grows. By contrast, our model has a frictionless equity market and our focus is on how aggregate business-cycle and volatility shocks influence optimal capital requirements. Collard et al. (2017) concentrate on interactions of optimal monetary and prudential policies, in a setting that keeps bank failures off the equilibrium path. We abstract from monetary policy but allow for business-cycle fluctuations and risk-taking on the equilibrium path.

The rich stochastic structure included in our analysis does not provide support for the cyclical nature of optimal capital requirements, as prescribed by say Basel III. Other contribu-

¹The guidelines can be found [here](#).

tions to the literature do. A simple theoretical justification for raising capital requirements during economic expansions is offered, for instance, by Malherbe (2020). This justification involves five ingredients: (1) deposit insurance, (2) default costs covered by deposit insurance and not internalized by the banks, (3) banks that do not internalize the fact that their lending decisions affect the marginal product of capital, (4) idiosyncratic financial shocks that can drive banks into default, even abstracting from aggregate shocks, and (5) a focus on total factor productivity (TFP) shocks. In this framework, the implicit subsidy of deposit insurance leads to excessive amounts of lending. As productivity expands, earnings increase and lead to an inflow of bank capital that can fuel a credit boom. Risk averse planners would curb lending in an expansion. The planners would accumulate precautionary savings to cover default costs and would internalize the effects on the marginal product of capital. Accordingly, they would want to push up capital requirements in a TFP driven boom, curbing the expansion of credit relative to bank capital.

Our framework differs from Malherbe's in four key ways, leading us to alternative policy conclusions. First, the composition of credit chosen by banks drives bank default, as opposed to financial shocks unrelated to the portfolio choices of banks. In turn, we show that these portfolio choices depend on the particular shocks that underlie economic fluctuations as does the optimal response of capital requirements. Second, bank deposits provide liquidity services that households value in our model. This introduces starker policy tradeoffs since changes in capital requirements induce banks to change their demand for deposits, with consequences for household utility. Third, our model isolates the importance of endogenous portfolio choices by letting banks distribute their profits or losses to shareholders in frictionless financial markets. Fourth, the optimal policy would match the Basel III counter-cyclical guidance if we focused on investment-specific shocks, but not if we considered other shocks or combinations of shocks.

Starker cyclical predictions for optimal capital requirements are also offered by Davydiuk (2017). In a setting closely related to Malherbe (2020), and encompassing his five key assumptions, Davydiuk boosts the inefficiency associated with increased lending in an expansion through the extensive margin. In her setting, credit expansions are bound to finance firms with progressively lower productivity. As banks do not internalize the subsidy related to deposit insurance covering default costs, they make inefficient lending decisions. A Ramsey planner that internalizes the subsidy lowers the amount of lending and boosts aggregate productivity by lending to more efficient firms. The new mechanism of Davydiuk (2017) seems plausible, however, her paper does not provide direct empirical support for the assumed productivity changes through the extensive margin. Other papers, for instance Mian et al. (2020), do not find a significant correlation between changes in the ratio of

business-debt to GDP and subsequent economic growth.²

Schularick and Taylor (2012), Jordà et al. (2017), and Mian et al. (2017) present empirical evidence that is often cited in support of Basel-III style counter-cyclical regulation. However, the causal connections behind their observed correlations is harder to assess. Gomes et al. (2018) develop a partial-equilibrium model that shares our emphasis on risks arising from endogenous changes in the composition of bank credit. Their model decouples the macro economy from the financial side and banking-sector activities. Nonetheless, although credit expansions have no causal effect on output by construction, they predict output declines in their model. More specifically, Gomes et al. (2018) show that their model can replicate the empirical evidence presented by Schularick and Taylor (2012), Jordà et al. (2017), and Mian et al. (2017).

In our model, changes in the composition of bank credit can lead to nonlinear default dynamics, and they play a crucial role in influencing the optimal choice of capital requirements. Elenev et al. (2021) also highlight nonlinear interactions as a key new ingredient in their analysis. In their complementary exploration, these interactions involve financial constraints and the possibility of default in the production and intermediation sectors, whereas the composition of bank credit is fixed. Nonetheless, the tightening of those constraints can lead to large welfare losses which influence the optimal choice of capital requirements. Default decisions are also central to the analysis of Mendicino et al. (2018). In their rich model, households who borrow can also default. Their focus is on the optimal level of static capital requirements, and on a particular family of simple and implementable cyclical rules. By contrast, the starker nature of our model allows us to calculate optimal cyclical capital requirements, which we then use to assess the relative performance of a broad family of implementable cyclical rules.

Finally, other contributions (including Angeloni and Faia (2013), Gertler and Kiyotaki (2015), Faria-e-Castro (2019), and Gertler et al. (2020)) show how leverage can increase financial fragility and the risk of bank runs. We make our formal analysis stark by setting aside bank runs but recognize that the possibility of bank runs is a reality.

The rest of the paper proceeds as follows. Section 2 describes the model. Section 3 discusses the model's calibration, including the choice of steady-state capital requirements. Section 4 describes our numerical methods for the model solutions. Section 5 discusses the Ramsey policy we take as optimal. Section 6 presents the responses to different shocks and discusses the Ramsey policy for capital requirements. Section 7 considers some simple implementable rules. And Section 8 concludes.

²Mian et al. (2017) find that increases in household debt (as opposed to business debt) relative to GDP predict a subsequent slowdown in economic growth.

2 The Model

Our model extends a standard RBC model to include banks that enjoy limited liability and government deposit insurance. These are the main features that allow for excessive, or socially inefficient, risk taking, and of course the RBC framework allows for macroeconomic shocks that cause business cycles. Our model consists of households, banks, non-financial firms, and a government whose sole purpose is to provide bank deposit insurance. Banks are at the heart of our model, but the exposition is smoother if we begin with the less exciting firms and households.

But first, a note on notation: There are measure one continua of households, banks and non-financial firms. In what follows, small letters denote individual households, banks or firms; capital letters represent aggregate values. Safe firms (defined below) carry a superscript s ; risky firms carry a superscript r .

2.1 Non-Financial Firms

Non-financial firms are competitive and earn zero profits. There are goods producing firms and capital producing firms. We begin with the former.

2.1.1 Goods Producing Firms:

Firms live for just two periods. A firm born in period t , obtains a bank loan, l_t^f , to buy the capital, k_{t+1} , that it will use for production in period $t + 1$; so,

$$l_t^f = Q_t k_{t+1}, \tag{1}$$

where Q_t is the price of capital (or the price of investment). The ex-post return on the loan is $R_{t+1} l_t^f = R_{t+1} Q_t k_{t+1}$, where we shall soon see that R_{t+1} is the rate of return on capital ownership. So, these bank loans might be better described as equity positions.

There is a continuum of firms of measure 1. But the firms come in two types: “safe” firms face only aggregate shocks, while “risky” firms face both aggregate shocks and idiosyncratic shocks.

In period $t + 1$, a safe firm hires labor, h_{t+1}^s , to produce

$$y_{t+1}^s = A_{t+1} (k_{t+1}^s)^\alpha (h_{t+1}^s)^{1-\alpha}, \tag{2}$$

where A_{t+1} is an aggregate TFP shock. When a safe firm takes the loan in period t , it knows that the firm will hire the optimal h_{t+1}^s next period. So, the safe firm chooses $l_t^{f,s}$ and k_{t+1}^s in period t , and then h_{t+1}^s in period $t + 1$, to

$$\max_{l_t^{f,s}, k_{t+1}^s} E_t \left\{ \max_{h_{t+1}^s} \left[y_{t+1}^s + (1 - \delta)Q_{t+1}k_{t+1}^s - W_{t+1}h_{t+1}^s - R_{t+1}^s l_t^{f,s} \right] \right\} \quad (3)$$

where δ is the capital depreciation rate, and W_{t+1} is the real wage rate. This maximization is subject to (1) and (2). The first order conditions for this maximization problem imply

$$E_t R_{t+1}^s = \alpha E_t \left\{ \frac{A_{t+1}}{Q_t} \left(\frac{h_{t+1}^s}{k_{t+1}^s} \right)^{1-\alpha} + (1 - \delta) \frac{Q_{t+1}}{Q_t} \right\}, \quad (4)$$

where the first term within the brackets is the rental rate on a unit of capital, and the second term is the capital gain on a non-depreciated unit of capital.

A risky firm employs the technology $y_{t+1}^r = A_{t+1} (k_{t+1}^r)^\alpha (h_{t+1}^r)^{1-\alpha} + \varepsilon_{t+1} k_{t+1}^r$, where ε_{t+1} is an idiosyncratic shock that follows a Normal distribution G with a negative mean, $-\xi$, and standard deviation τ :³

$$\begin{aligned} \text{PDF of } \varepsilon_{t+1}, \quad g(\varepsilon_{t+1}) &= \frac{1}{\sqrt{2\pi\tau^2}} e^{-\frac{(\varepsilon_{t+1} + \xi)^2}{2\tau^2}} \\ \text{CDF of } \varepsilon_{t+1}, \quad G(\varepsilon_{t+1}) &= \frac{1}{2} \left[1 + \text{erf} \left(\frac{\varepsilon_{t+1} + \xi}{\tau\sqrt{2}} \right) \right] \end{aligned} \quad (5)$$

The risky firm chooses $l_t^{f,r}$ and k_{t+1}^r , and then h_{t+1}^r , to

$$\max_{l_t^{f,r}, k_{t+1}^r} E_t \left\{ \max_{h_{t+1}^r} \left[y_{t+1}^r + (1 - \delta)Q_{t+1}k_{t+1}^r - W_{t+1}h_{t+1}^r - R_{t+1}^r l_t^{f,r} \right] \right\} \quad (6)$$

subject to the analogous constraints. The first order conditions for this maximization, the zero profit condition for firms, and equation (8) below, imply

$$E_t R_{t+1}^r = E_t R_{t+1}^s - \frac{\xi}{Q_t}. \quad (7)$$

So the idiosyncratic shock lowers the expected value, and increases the variance, of the return on a loan to a risky firm. Risky loans are socially inefficient, or in our language, excessively risky.

Note finally that the marginal product of labor for safe and risky firms is $(1 - \alpha)A(k_{t+1}^i/h_{t+1}^i)^\alpha$ where i denotes the type of firm ($i \in \{s, r\}$). Labor is mobile across firms, and both types of firms face the same real wage rate. So, the first order conditions for labor in period $t + 1$ imply the capital labor ratios equalize across sectors.

³ $\text{erf}(x) = \frac{1}{\sqrt{\pi}} \int_{-x}^x e^{-v^2} dv = \frac{2}{\sqrt{\pi}} \int_0^x e^{-v^2} dv.$

$$k_{t+1}^r/h_{t+1}^r = k_{t+1}^s/h_{t+1}^s. \quad (8)$$

The Appendix provides details on aggregation across firms; there we show that there is a representative safe firm that produces

$$Y_{t+1}^s = A_{t+1}(K_{t+1}^s)^\alpha(H_{t+1}^s)^{1-\alpha}, \quad (9)$$

and also a representative risky firm that produces

$$Y_{t+1}^r = A_{t+1}(K_{t+1}^r)^\alpha(H_{t+1}^r)^{1-\alpha} - \xi K_{t+1}^r. \quad (10)$$

2.1.2 Capital Producing Firms

At the end of period t , goods producing firms sell their capital to competitive capital producing firms. Letting I_t^g denote gross investment, the evolution of capital follows

$$I_t = \eta_t \left[1 - \frac{\phi}{2} \left(\frac{I_t^g}{I_{t-1}^g} - 1 \right)^2 \right] I_t^g, \quad (11)$$

where η_t is an investment specific technology shock, and ϕ is a measure of the severity of investment adjustment costs. The aggregate capital stock evolves according to

$$K_{t+1}^s + K_{t+1}^r = I_t + (1 - \delta)(K_t^s + K_t^r). \quad (12)$$

The capital producing firms are owned by households, and solve the problem

$$\max_{I_{t+i}^g} E_t \sum_{i=0}^{\infty} \psi_t \left\{ Q_{t+i} \eta_{t+i} \left[1 - \frac{\phi}{2} \left(\frac{I_{t+i}^g}{I_{t+i-1}^g} - 1 \right)^2 \right] I_{t+i}^g - I_{t+i}^g \right\}, \quad (13)$$

where $\psi_t = \beta \frac{\lambda_{ct+i}}{\lambda_{ct}}$ is the stochastic discount factor of the households, which are described next.

2.2 Households

The representative household's problem is

$$\max_{C_t, D_t, E_t^s, E_t^r} E \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t - \kappa C_{t-1})^{1-\varsigma_c} - 1}{1 - \varsigma_c} + \varsigma_0 \frac{D_t^{1-\varsigma_d} - 1}{1 - \varsigma_d} \right], \quad (14)$$

subject to

$$\begin{aligned}
C_t + D_t + E_t^s + E_t^r &= W_t + R_{t-1}^d D_{t-1} + R_t^{e,s} E_{t-1}^s + R_t^{e,r} E_{t-1}^r - T_t, & (15) \\
E_t^s &\geq 0, \\
E_t^r &\geq 0.
\end{aligned}$$

Households value consumption, C_t , and value the liquidity services of bank deposits, D_t ; $0 < \kappa < 1$ is the habit persistence parameter, $\varsigma_c > 0$ captures the intertemporal elasticity of substitution, $\varsigma_0 > 0$ governs the utility weight on deposits relative to consumption, and $\varsigma_d > 0$ is the inverse elasticity of households demand for deposits with respect to changes in the interest rate. We put deposits in the utility function in lieu of modeling a particular transactions technology. And for simplicity, we assume that households supply labor inelastically and have normalized the supply of labor to be one.⁴ Household assets include deposits, D_t , which pay a gross real rate R_t^d , and two types of bank equity: E_t^s is equity in a “safe” bank, which lends to a safe firm and pays $R_{t+1}^{e,s}$ next period; E_t^r is equity in a “risky” bank, which lends to a risky firm and pays $R_{t+1}^{e,r}$. The returns on equity are of course not known when the household invests. By contrast, the return on deposits is known, and deposits are protected by deposit insurance; deposits are the safe asset in our model. Finally, households pay lump sum taxes, T_t , to fund the government’s deposit insurance program.

The household’s first order conditions include:

$$C : (C_t - \kappa C_{t-1})^{-\varsigma_c} - \beta \kappa E_t (C_{t+1} - \kappa C_t)^{-\varsigma_c} - \lambda_{ct} = 0, \quad (16)$$

$$D : \varsigma_0 D_t^{-\varsigma_d} - \lambda_{ct} + E_t \beta \lambda_{ct+1} R_t^d = 0, \quad (17)$$

$$E^s : -\lambda_{ct} + E_t \beta \lambda_{ct+1} R_{t+1}^{e,s} + \zeta_t^s = 0, \quad (18)$$

$$E^r : -\lambda_{ct} + E_t \beta \lambda_{ct+1} R_{t+1}^{e,r} + \zeta_t^r = 0, \quad (19)$$

where λ_{ct} , ζ_t^s and ζ_t^r are the Lagrangian multipliers for the budget constraint and the two non-negativity constraints.

If households did not value deposits for their liquidity services ($\varsigma_0 = 0$), (17) would be the standard RBC Euler equation, and R_t^d would be the standard CAPM rate. But households do value deposits in our model, and R_t^d is below the CAPM rate. Equity is not a safe asset, and it does not provide liquidity services. So, deposits will be the cheaper source of funding for banks. This fact will play an important role in what follows.

⁴While the total supply of labor is fixed, its distribution across safe and risky firms is market determined.

2.3 Banks

Banks are at the heart of our model. First, we set the stage by describing their incentives to take excessive risk. Second, we discuss the banking sector in some detail.

2.3.1 Incentives to Take Excessive Risk and Capital Requirements

We saw from the section on firms that $E_t R_{t+1}^r < E_t R_{t+1}^s$. So, why would a profit maximizing bank ever invest in a risky firm? Limited liability and government deposit insurance are the culprits here. Limited liability shields the bank from downside risk. Moreover, deposit insurance actually subsidizes risk taking; it makes bank deposits the safe asset, lowering the cost of issuing deposits, and allowing the bank to expand its portfolio of safe or risky loans. In what follows, we will see that if the expected return on investment in a safe firm falls, due say to a negative TFP shock, the bank may be tempted to take a flier on the risky firm.

As we will see, capital requirements are a potential remedy for excessive risk taking. In what follows, we will consider a requirement that says equity finance cannot fall below a fraction γ_t of the bank's loans. A high γ_t requires the bank and its equity holders to keep more skin in the game, and it shrinks the bank's portfolio since equity finance is more expensive than deposit finance.

2.3.2 The Banking Sector

A measure one continuum of perfectly competitive banks start operating each period, and they live for two periods. In the first period, a bank issues equity and deposits to households, and uses the proceeds to make loans to firms; in the second period, the bank receives the return on its investments and liquidates its assets and liabilities.

More specifically, in period t , the bank creates a loan portfolio by directing a fraction σ_t of its loans to a risky firm; the remainder of its loans go to a safe firm.⁵ Since $R_{t+1}^r = R_{t+1}^s + \frac{\varepsilon_{t+1}}{Q_t}$, the ex-post return on the portfolio will be $R_{t+1}^s + \sigma_t \frac{\varepsilon_{t+1}}{Q_t}$. Note that $nw_{t+1} \equiv \left(R_{t+1}^s + \sigma_t \frac{\varepsilon_{t+1}}{Q_t} \right) l_t - R_t^d d_t$ is the bank's net worth in period $t+1$, where l_t is the total amount of loans. If nw_{t+1} is positive, the bank pays its depositors and distributes the rest to its equity holders. If it is negative, the bank declares bankruptcy; its depositors are protected by deposit insurance, but its equity holders get nothing.

The bank's objective is to maximize the expected return of its equity holders, whose stochastic discount factor is $\psi_{t,t+i}$. Let ε_{t+1}^* be the realization of the idiosyncratic shock

⁵Our assumption that a bank only deals with one safe and one risky firm comes at no loss of generality because all the safe firms are identical, and diversification among the risky firms does not take full advantage of the bank's limited liability. See Collard et al (2017) for a more formal exposition of this result.

below which the bank's net worth is negative; that is, $\left(R_{t+1}^s + \sigma_t \frac{\varepsilon_{t+1}^*}{Q_t}\right) l_t - R_t^d d_t = 0$. Since the distributions of aggregate and idiosyncratic shocks are independent of each other, we can nest expectations with respect to the idiosyncratic shock within the expectation of the aggregate and idiosyncratic shocks, and the representative bank's maximization problem can be written as:

$$\max_{l_t, d_t, e_t, \sigma_t} E_t \left\{ \psi_t \left[\int_{\varepsilon_{t+1}^*}^{\infty} n w_{t+1} dG(\varepsilon_{t+1}) \right] \right\} - e_t \quad (20)$$

subject to

$$\begin{aligned} l_t &= e_t + d_t \\ e_t &\geq \gamma_t l_t \\ l_t &\geq 0 \\ \underline{\sigma} &\leq \sigma_t \leq \bar{\sigma} \end{aligned} \quad (21)$$

where e_t is equity issued to households. The first constraint is the bank's balance sheet, and the second is the bank's capital requirement. The third constraint rules out short selling; its role will be discussed in Section 4. The fourth imposes limits on the fraction of a bank's portfolio that can go to safe or risky loans. In our calibrations, $\bar{\sigma}$ is set equal to 0.99 and $\underline{\sigma}$ is set equal to 0.01; so, banks can get very close to totally safe or totally risky portfolios if they so choose.⁶

The bank's first order conditions can be found in the Appendix. They are not particularly elucidating. In the next subsection, we discuss the bank's basic tradeoff when it decides how risky to make its portfolio of loans.

2.3.3 The Bank's Dividends, and Its Choice of σ_t .

In the Appendix, we derive the bank's expected (discounted) dividend function,

$$\Omega(\sigma_t; l_t, d_t, e_t) = E_t [\psi_t l_t (\omega_1 + \omega_2)], \quad (22)$$

⁶These limits on σ_t are necessary for the numerical methods that follow.

where

$$\omega_1 \equiv \left(R_{t+1}^s - R_t^d (1 - \gamma_t) - \frac{\xi \sigma_t}{Q_t} \right) (1 - G(\varepsilon_{t+1}^*)) \quad (23)$$

$$\omega_2 \equiv \left(\frac{\sigma_t}{Q_t} \right) \frac{\tau}{\sqrt{2\pi}} e^{-\left(\frac{\varepsilon_{t+1}^* + \xi}{\tau \sqrt{2}} \right)^2} \quad (24)$$

and where $1 - G(\varepsilon_{t+1}^*)$ is the probability that the bank will not default.

The first component, ω_1 , is the return on a loan portfolio with a fraction σ_t going to a risky firm; $-\xi$ is the (negative) expected value of the idiosyncratic shock. The second component, ω_2 , is a bonus attributable to the bank's limited liability; the higher is the standard deviation of the idiosyncratic shock, τ , the higher is the upside potential for a risky loan, while the downside risk is protected by limited liability.

Increasing σ_t makes the portfolio more risky. More risk decreases the ex-post return on the bank's portfolio, but it increases the bonus from limited liability. This is the tradeoff that a bank faces.

2.4 The Government

The government provides deposit insurance, and collects taxes to pay for it. Given the Ricardian nature of the model, a lump sum tax, T_t , can balance the budget each period without distorting private decision making. In the Appendix, we show the tax necessary to support the insurance scheme is

$$T_t = \frac{\sigma_{t-1} L_{t-1}}{Q_{t-1}} \frac{\tau}{\sqrt{2\pi}} e^{-\left(\frac{R_{t-1}^d (1 - \gamma_{t-1}) Q_{t-1} - R_t^s Q_{t-1} + \xi \sigma_{t-1}}{\sigma_{t-1} \sqrt{2\tau}} \right)^2} - \frac{1}{2} \left(R_t^s L_{t-1} - \frac{\sigma_{t-1} \xi}{Q_{t-1}} L_{t-1} - R_{t-1}^d D_{t-1} \right) \left[1 + \operatorname{erf} \left(\frac{R_{t-1}^d (1 - \gamma_{t-1}) Q_{t-1} - R_t^s Q_{t-1} + \xi \sigma_{t-1}}{\sigma_{t-1} \sqrt{2\tau}} \right) \right], \quad (25)$$

where L_t is the aggregate amount of loans provided by the banking sector. As might be expected, more risk taking (a higher σ_{t-1}) and/or a higher variance (τ) of the idiosyncratic shock increases the taxes required to protect deposits.

2.5 Analytical Characterization of Equilibrium

We are able to derive some analytical results that enhance our understanding of the model's equilibrium, and how to calculate it. More generally, we will require numerical methods.

2.5.1 Two Propositions and a Corollary

As discussed in the section on households, deposits are a cheaper source of bank funding than equity. So, a bank will fund as much of its loans by issuing deposits as is allowed by the capital requirements. We formalize this argument and prove the following proposition in the Appendix.

Proposition 1. *In equilibrium, capital requirements always bind; that is, $e_t = \gamma_t l_t$.*

The next proposition, and its corollary, show that we need only consider two values of the bank's portfolio risk parameter, σ_t , when we derive the model's equilibrium. The proposition is established in the Appendix.

Proposition 2. *The expected dividends function of banks, $\Omega(\sigma_t; l_t, d_t, e_t)$, is convex in σ_t . This result holds for arbitrary (and not necessarily continuous) distributions of the idiosyncratic shock.*

Corollary. *There are no equilibria with $\underline{\sigma} < \sigma_t < \bar{\sigma}$.*

The intuition for this proposition and its corollary is as follows: If σ_t is high enough, the bank will be bankrupt for low values of ε_t anyway, so it might as well take on as much risk as possible to maximize the portfolio's upside potential for high values of ε_t . If σ_t is low enough, the bank will not be bankrupt even for low values of ε_t , and the value of limited liability is negated; the bank might as well take on the minimum risk to raise the expected value of its portfolio.

Note also that a risky bank seeks to maximize its exposure to the idiosyncratic shock ε_t . Limited liability incentivizes banks to “fail big.” So, a risky bank would not want to diversify its loan portfolio by lending to more than one risky firm.⁷

2.5.2 Equilibrium and Aggregation

We consider a competitive equilibrium in which each bank takes aggregate prices as given. The Appendix lists all the equilibrium conditions of our model. In this subsection, we only present the equilibrium conditions that are not already included in the preceding subsections. We let μ_t denote the fraction of banks with risky portfolios (banks that choose $\sigma_t = \bar{\sigma}$) at date t ; the remaining fraction $1 - \mu_t$ are safe banks ($\sigma_t = \underline{\sigma}$).

⁷In reality, bank regulators would not allow a bank to lend to a single firm. But our result really says that risky banks seek exposure to a single idiosyncratic shock ε_t . To circumvent regulation, for example, a bank may hold a seemingly diversified portfolio of MBS with all the loans exposed to the risk of a decrease in house prices. These incentives seem relevant for the literature on securitization surveyed by Gorton and Metrick (2013).

The fraction μ_t is endogenously determined by equity positions of households: we have $\mu_t = \frac{E_t^r}{E_t^r + E_t^s}$. At any point in time, the economy may be in a safe equilibrium (with $\mu_t = 0$), a risky equilibrium (with $\mu_t = 1$), or a mixed equilibrium (with $0 < \mu_t < 1$).

Each bank within a group (safe or risky) is alike and solves the same maximization problem in which it chooses l_t^i, d_t^i, e_t^i according to its type $i \in \{s, r\}$. The aggregate loans to the (representative) safe firm come from two sources: 1) from all safe banks (of measure $1 - \mu_t$) that allocate $1 - \underline{\sigma}$ share of their loan portfolio to safe projects and 2) from all risky banks (of measure μ_t) that allocate $1 - \bar{\sigma}$ share of their loan portfolio to safe projects. Therefore, the equilibrium restrictions linking our bank-level and firm-level variables representing loans are

$$Q_t K_{t+1}^s = (1 - \underline{\sigma})(1 - \mu_t) l_t^s + (1 - \bar{\sigma}) \mu_t l_t^r. \quad (26)$$

Similarly,

$$Q_t K_{t+1}^r = \underline{\sigma}(1 - \mu_t) l_t^s + \bar{\sigma} \mu_t l_t^r. \quad (27)$$

The aggregate bank loans are linked to the individual bank loans by: $L_t^r = \mu_t l_t^r$ and $L_t^s = (1 - \mu_t) l_t^s$. Therefore, we can describe the latter two equations by using aggregate loans

$$Q_t K_{t+1}^s = (1 - \underline{\sigma}) L_t^s + (1 - \bar{\sigma}) L_t^r, \quad (28)$$

$$Q_t K_{t+1}^r = \underline{\sigma} L_t^s + \bar{\sigma} L_t^r. \quad (29)$$

The equity positions taken by households, in turn, determine the equity positions of individual banks: $E_t^r = \mu_t e_t^r$ and $E_t^s = (1 - \mu_t) e_t^s$. The returns on the equity positions taken by households at date t are linked to the dividends paid by banks at date $t + 1$. We have:

$$E_t^r R_{t+1}^{e,r} = (\omega_1^r + \omega_2^r) L_t^r, \quad (30)$$

$$E_t^s R_{t+1}^{e,s} = (\omega_1^s + \omega_2^s) L_t^s, \quad (31)$$

where we use that $\max[nw_{t+1}^r, 0]$ is linear in loans; ω_1 and ω_2 were defined in equations (23) and (24). Deposits held by households are issued by (safe and risky) banks: $D_t = D_t^s + D_t^r$ where $D_t^s = L_t^s - E_t^s$ and $D_t^r = L_t^r - E_t^r$.

The equilibrium restrictions linking our aggregate and individual firm-specific variables are straightforward, but cumbersome in terms of notation. We state the restrictions in the Appendix. The market-clearing conditions for labor, capital, and goods are

$$H_t^s + H_t^r = 1, \quad (32)$$

$$K_t^s + K_t^r = K_t, \quad (33)$$

and

$$Y_t^s + Y_t^r = C_t + I_t^g. \tag{34}$$

3 Calibration and Steady-State Capital Requirements

Our calibrated parameters are reported in Table 1. We use standard values for the discount factor β , the capital share α , the intertemporal elasticity of substitution ρ_c , and the depreciation rate δ .

Some parameters that govern the attractiveness of excessively risky loans are specific to our model. To choose these parameters in an empirically relevant way, we rely on a definition of excessive risk that was agreed upon by three regulators of U.S. depository institutions — the Office of the Comptroller of the Currency, the Board of Governors of the Federal Reserve, and the Federal Deposit Insurance Corporation. In March of 2013, these regulators issued guidance on leveraged lending with the aim of ensuring that financial institutions did not “unnecessarily heighten risks by originating poorly underwritten loans.”⁸ This guidance established a bright line that loans to firms with a debt-to-EBITDA ratio of 6 or above would raise supervisory concerns.⁹

We choose τ , the standard deviation of the risky firm’s idiosyncratic shock, to match the variance of returns on a risky project in our model to the variance of returns from lending to a firm with a debt-to-EBITDA ratio of 6. In each case, we focus on variances conditional on starting from the non-stochastic steady state of our model. The Appendix provides the details of our procedure. Given τ , we fix the value of ξ , the average penalty from financing risky projects, so that a 10% steady-state capital requirement prevents lending to risky firms. We note that our choice of 10% is consistent with the static values of capital requirements proposed by Basel III; it also lies within a span of values usually considered in the literature on optimal capital regulation.

Why do we not try to calculate an optimal steady-state capital requirement? We show in the Appendix that alternative choices of τ and ξ would support a wide range of steady-state capital requirements. This suggests that a model like ours is not suitable for any attempt to pin down the optimal steady-state value.

To match the data on interest rate spreads, we introduce costs of banking in our quantitative model. We assume that these costs are linked to the provision of loans. In particular, each period the bank incurs an additional cost, fl_t , that is paid out of its current profits.¹⁰

⁸The inter agency guidance on leveraged lending can be found [here](#).

⁹EBITDA is earnings before interest, taxes, depreciation, and amortization.

¹⁰Allowing for these banking costs serves to calibrate the steady-state equilibrium of our model; but it has no effect on the equilibrium dynamics we discuss in subsequent sections, because labor supply is inelastic in

And when a bank defaults, the household has to pay a higher tax to the deposit insurance fund to cover this cost of banking. The Appendix provides further details on the implications of this cost for the lump sum tax, T_t , and on the first order conditions for the optimization problem of banks. We choose f to make the average spread between the safe loan rate and the deposit rate equal to 2.26 percent per annum; we take this value from Collard et al. (2017). The parameter ς_0 measures the utility of deposits in the steady state. We set the value of ς_0 to make the interest rate on bank deposits equal to 0.86% per quarter, a value we borrow from an estimate in Begenau (2020). Finally, our setup for investment adjustment costs mimics the one used by Altig et al. (2011). We pick the value of ϕ consistent with the broad range from their analysis and related literature.

4 Numerical Methods

Occasionally binding nonnegativity constraints on bank loans complicate the solution of our model. To address these complications, we rely on the OccBin toolkit developed by Guerrieri and Iacoviello (2015); they also provide an extensive discussion of the accuracy of their solution. Their algorithm can be applied to models with a large number of state variables, such as ours.

So why did we complicate matters by imposing nonnegativity constraints on loans? We needed to rule out the short-selling of assets (or negative loans). To see why, suppose banks are in the safe equilibrium; in this case, risky loans are overpriced compared to safe loans (because expected returns on risky loans are relatively lower in the safe equilibrium); absent short-selling restrictions, each bank would want to short risky loans. Similar reasoning applies to the risky equilibrium, in which the banks in our model would short safe loans. In either of these cases, arbitrageurs would force the expected returns on safe and risky loans to equality. And this would result in the mixed equilibrium (described in Section 2.5.2) in which $0 < \mu_t < 1$.

5 The Ramsey Policy and Its Numerical Derivation

To compute optimal capital requirements, we focus on the Ramsey problem, conditional on the restrictions of the decentralized equilibrium. The Ramsey program selects the path of capital requirements that maximizes the conditional expectation of the household's utility as of time zero. More precisely, following a dual approach, the Ramsey planner chooses the sequence of capital requirements $\{\gamma_t^*\}_{t=0}^\infty$ to maximize the household utility function, (14),

our model. For this reason, we have suppressed this factor in the equations above.

subject to the equilibrium conditions implied by the optimality conditions of households, firms and banks, and the market clearing conditions. The non-negativity and short-selling restrictions that we noted above complicate this Ramsey problem. We proceed by proposing a natural candidate for the solution and then verifying that the proposed solution does indeed maximize the objective function, (14).

Our proposed solution is to consider the sequence of capital requirements $\{\gamma_t^*\}_{t=0}^\infty$ that is set at the lowest level necessary to prevent risk taking – given the realizations of the shocks – at any date t . This sequence dominates any alternative path $\{\gamma_t^A\}_{t=0}^\infty$ in which $\gamma_t^A = \gamma_t^*$ for $t \neq t_k$ and $\gamma_t^A = \gamma_t^* + \Delta$ for $t = t_k$ and some $\Delta \neq 0$. When $\Delta > 0$, $\{\gamma_t^A\}_{t=0}^\infty$ is welfare dominated by $\{\gamma_t^*\}_{t=0}^\infty$ because a higher capital requirement in period t_k leads to welfare losses from the reduced amount of liquidity services without altering risk-taking incentives. This holds for any t_k and does not depend on the size of $\Delta > 0$. When $\Delta < 0$, banks switch to funding socially inefficient risky projects in period t_k under $\{\gamma_t^A\}_{t=0}^\infty$. The decrease in the capital requirement involves an output loss of ξK from making risky loans, but it may increase the liquidity services that enter into household utility. The trade-off between these two considerations determines the impact on welfare. For a small decrease in capital requirements (i.e. negative values of Δ close to zero), the former consideration is more important. Why? Since banks jump to the risky equilibrium, the lower capital requirement entails a discrete drop in welfare, arising from the drop in output. By contrast, the welfare gain (or loss) associated with liquidity provision is a second order change.

Our reasoning above establishes that the Ramsey planner’s objective function has a local maximum along the path $\{\gamma_t^*\}_{t=0}^\infty$. To show that this is indeed a global maximum, we must check the welfare effect of a large decrease in capital requirements; in this case, liquidity considerations will not be of second order. To see how liquidity considerations compare to the welfare loss associated with inefficient risk taking, we compare (numerically) the welfare measure under our candidate for optimal policy to welfare under an alternative policy that maximizes the benefit of liquidity provision under the risk-taking regime. All the equilibria under the risk-taking regime have the same level of expected output; so, we only need to consider the policy that maximizes liquidity provision. The gains from liquidity services are maximized when $\gamma_{t_k}^A = 0$. Therefore, we need to compare conditional welfare under $\{\gamma_t^*\}_{t=0}^\infty$ to the alternatives that let the capital requirement go down to zero, in some periods.

To check quantitatively if setting capital requirements to zero becomes optimal in response to shocks, we use a variant of the OccBin algorithm. We consider a horizon J and construct all possible combinations of periods from 1 to J in which capital requirements are hardwired to go to zero whenever a switch to the risk-taking regime is made, but are set

to the lowest possible levels necessary to prevent risk-taking $\{\gamma_t^*\}_{t=0}^\infty$ otherwise.¹¹ Then, for each combination, we calculate the conditional welfare and compare it against the conditional welfare of keeping capital requirements at $\{\gamma_t^*\}_{t=0}^\infty$. We verify that the proposed path of $\{\gamma_t^*\}_{t=0}^\infty$ that makes capital requirements just large enough to prevent excessive risk-taking incentives is, in fact, globally optimal in our parameterization.

6 Optimal Dynamic Capital Requirements

In this section, we show how a Ramsey planner would set capital requirement ratios, γ_t , in response to various shocks that can cause excessive risk taking. All of the shocks we consider in this section follow exogenously set AR(1) processes, which are specified below.¹² We take two steps in preparation for our discussion here. First, we ask what might trigger a risk-taking episode in the first place. And second, we show how exogenous shocks to the Planner's policy instrument – capital requirements – would affect financing decisions and real allocations.¹³

6.1 What Triggers an Excessive Risk-Taking Episode?

The answer to this question is rather complex because the banker's maximization problem has so many moving parts. We give a detailed answer in the Appendix; here we offer a simpler explanation that focuses on the main forces at work.

Consider the expected dividends for safe and risky firms, $\Omega_t^s \equiv \Omega(\underline{\sigma}; l_t, d_t, e_t)$ and $\Omega_t^r \equiv \Omega(\bar{\sigma}; l_t, d_t, e_t)$ respectively. Anything that would make $\Omega_t^r - \Omega_t^s$ go positive will trigger a risk-taking episode. Equation (22) specifies $\Omega(\sigma_t; l_t, d_t, e_t)$ for all values of σ_t , where it will be recalled that

$$\varepsilon_{t+1}^* = -\frac{Q_t}{\sigma_t} [R_{t+1}^s - R_t^d (1 - \gamma_t)] \quad (35)$$

is the realization of a bank's idiosyncratic shock below which its net worth is negative, and $G(\varepsilon_{t+1}^*)$ is the probability that the bank will fail. Implicit in the formulation of the banker's problem, (20), is the fact that $G'(\varepsilon_{t+1}^*) > 0$ and $G(\varepsilon_{t+1}^*) \rightarrow 0$ as $\varepsilon_{t+1}^* \rightarrow -\infty$.

For purely expositional purposes, we will in this subsection suppose that $\underline{\sigma} = 0$ and $\bar{\sigma} = 1$. With these simplifications, (22) implies

¹¹For each of our checks, we recompute the path of the minimum capital requirements that prevent risk as this path also depends on the evolution of the endogenous variables in the regime with excessive risk taking.

¹²The rest of the parameter settings are given in Table 1, except that here we set $\varphi = 100$ and $\kappa = 0$.

¹³For the purposes of this section, we have set the steady-state capital requirement at 10.1 percent, 0.1 percent higher than is necessary to avoid excessive risk taking in the steady state. This facilitates our numerical solution methods.

$$\Omega_t^s = E_t [\psi_t l_t^s (R_{t+1}^s - R_t^d (1 - \gamma_t))] \quad \text{and} \quad (36)$$

$$\Omega_t^r = E_t \left[\psi_t l_t^r \left(\left(R_{t+1}^s - R_t^d (1 - \gamma_t) - \frac{\xi}{Q_t} \right) (1 - G(\varepsilon_{t+1}^*)) + \frac{\tau}{Q_t \sqrt{2\pi}} e^{-\left(\frac{\varepsilon_{t+1}^* + \xi}{\tau \sqrt{2}} \right)^2} \right) \right], \quad (37)$$

where $\psi_t \equiv \beta \frac{\lambda_{ct+1}}{\lambda_{ct}}$ is the household's stochastic discount factor, and where it will be recalled that

$$R_{t+1}^s = \alpha \left\{ \frac{A_{t+1}}{Q_t} \left(\frac{H_{t+1}^s}{K_{t+1}^s} \right)^{1-\alpha} + (1 - \delta) \frac{Q_{t+1}}{Q_t} \right\}. \quad (38)$$

What might turn $\Omega_t^r - \Omega_t^s$ positive, triggering a risk-taking episode? The obvious culprit is the interest rate spread $R_{t+1}^s - R_t^d (1 - \gamma_t)$. An expected narrowing of this spread will decrease Ω_t^s more than Ω_t^r since $1 - G(\varepsilon_{t+1}^*)$ is less than one in the risk-taking regime. Moreover, a narrowing of the spread has a secondary effect on Ω_t^r that is a little more subtle: (35) implies that ε_{t+1}^* will rise. The presence of ε_{t+1}^* (instead of $-\infty$) in the bank's expected profits, (20), represents the value of limited liability to banks. Idiosyncratic shocks below this cut-off point cannot lower the bank's profits. An increase in ε_{t+1}^* would enhance the value of the shield of limited liability and increase Ω_t^r .¹⁴ Note finally that if a risk-taking episode is triggered, there will be a jump in σ , and therefore a further jump in ε_{t+1}^* .

So, what might narrow the interest rate spread and provoke a risk-taking episode? There are a number of possibilities. Perhaps the most obvious would be a fall in the expected return on safe assets; for example, an expected fall in TFP could trigger a risk-taking episode. Two parameters in (37) are also of interest. An increase in the standard deviation of the idiosyncratic shock, τ , will raise Ω_t^r since it increases the upside potential of the risky asset (while the downside potential is unchanged because of limited liability). The second parameter is the expected value of the risky firm's idiosyncratic shock, $-\xi$; ξ is the average penalty for investing in the risky asset. A fall in this parameter would also raise Ω_t^r .

Note also that a loosening of the capital requirement, γ_t , would decrease the interest rate spread and could trigger a risk-taking episode. A loosening of the capital requirement allows the bank to fund more of its loans with deposits; this reduces the cost of banking and allows the bank to keep less skin in the game. The bank expands its lending and switches to risky loans. And note finally that a dynamic capital requirement could hold $\Omega_t^r - \Omega_t^s$ constant at

¹⁴It is hard to see these results in (37) without investigating a number of special cases, some involving the absolute value of $\varepsilon_{t+1}^* + \xi$. These special cases are relegated to the Appendix.

its steady-state value; banks would never leave the safe equilibrium. As seen in Section 5, this option is the Ramsey planner’s policy.

The intuitive exposition just given relied upon two simplifying assumptions – one made explicit, and the other implicit – that must now be undone. The explicit assumption was that $\underline{\sigma} = 0$ and $\bar{\sigma} = 1$. In the numerical analysis that follows, $\underline{\sigma}$ is set equal to 0.01 and $\bar{\sigma}$ is set equal to 0.99; in equilibrium, there must be both safe and risky loans (and firms). The implicit assumption was that a bank could observe both Ω_t^r and Ω_t^s , and then choose its loan portfolio accordingly. But, we cannot have both Ω_t^r and Ω_t^s in equilibrium. If we are in a safe equilibrium, we have Ω_t^s , and Ω_t^r is an off-equilibrium object; during a risk-taking episode, we have Ω_t^r , and Ω_t^s is an off-equilibrium object.

However, there is an equilibrium interest rate spread – whose evolution is closely related to $\Omega_t^r - \Omega_t^s$ – that we can track:

$$S_t \equiv E_t [R_{t+1}^{e,r} - R_{t+1}^{e,s}]. \quad (39)$$

S_t is the expected spread between the returns on risky and safe equity. Because of our minimum scale assumptions, a small amount of risky loans will be extended in the safe regime, and conversely, a small amount of safe loans will be extended in the risky regime; so, the returns on equity are equilibrium objects. In a risk-taking episode, S_t turns positive. Once the episode is over, the spread turns negative.¹⁵

6.2 Capital Requirement Shocks

The next two sections illustrate the transmission mechanism for capital requirement policy. And in particular, we show that increases and decreases in capital requirements have asymmetric effects on bank decision making and economic outcomes.

¹⁵There is a simple relationship between S_t and $\Omega_t^r - \Omega_t^s$ when computing Ω_t^r and Ω_t^s conditional on, respectively, the risky and safe loans actually extended (rather than the *desired* amount of loans). In that case, $S_t \equiv E_t [R_{t+1}^{e,r} - R_{t+1}^{e,s}] = \frac{\Omega_t^r}{E_t^r} - \frac{\Omega_t^s}{E_t^s}$. The thought experiment by which a banker compares the expected dividends for a desired level of loans is intuitive, but we solve the model by referring to the Lagrange multipliers on the non-negativity constraints for safe and risky loans. When extending safe loans leads to higher expected dividends, a banker would want to short-sell risky loans, turning the corresponding Lagrange multiplier positive; analogously, when extending risky loans leads to higher expected dividends, a banker would want to short-sell safe loans. These two conditions allow us to determine which regime applies in any period more easily than attempting to construct $\frac{\Omega_t^r}{E_t^r}$ and $\frac{\Omega_t^s}{E_t^s}$, whose computation requires taking a stand on the entire path of future actions.

6.2.1 An Increase in Capital Requirements

Figure 1 shows the effects of a one percent increase in the capital requirement ratio, γ_t ; this shock has a persistence parameter of 0.9. An increase in the capital requirement forces a bank to shift its funding mix from deposits to equity; this shift increases the cost of funding a given amount of loans since deposits have liquidity value, and they will be held by the households at a lower rate of return. The shock does make the bank safer by requiring it to keep more skin in the game.

Note that the Modigliani-Miller Theorem does not hold in our model, since once again deposits are valued for their transactions services. So, even though the economy stays in a safe equilibrium, tighter capital requirements can have real effects on the macroeconomy.

More precisely, an increase in the capital requirement acts like a tax hike on banks. Households, who own the banks, are effectively poorer. They cut back on consumption, and since labor is inelastically supplied, their savings increase correspondingly. But under our calibration, the movements in consumption, investment and output are tiny, as can be seen in Figure 1. The real side of the economy is hardly affected.

There are first order effects in the financial sector, and they can affect household utility. First and foremost, the increase in equity funding reduces the bank's demand for deposits, and the deposit rate falls. Moreover, the increase in household savings pushes up the supply of deposits, which reinforces the decrease in the deposit rate. Deposits make up close to 90 percent of bank funding in our calibration. Somewhat paradoxically, the increase in capital requirements, and the subsequent fall in the deposit rate, end up *reducing* the cost of banking.¹⁶ However, the large drop in deposits, coupled with the (almost imperceptible) fall in consumption, decreases household utility, as can be seen in the last panel in Figure 1.¹⁷

Over time, these movements reverse themselves. The capital requirement falls, and deposits recover. The capital stock falls, increasing the marginal product of capital and R^s , which pushes Ω^s up relative to Ω^r . The economy reverts to its steady state.

6.2.2 A Decrease in Capital Requirements

The dashed lines in Figure 2 show the response to a 1 percent decrease in the capital requirement, with an auto-regressive coefficient of 0.9. Deposits rise and bank equity falls, as the lower capital requirement allows banks to switch to the cheaper source of funding. As

¹⁶Begenau (2020) also finds that an increase in capital requirements can reduce the cost of bank funding and increase lending.

¹⁷Welfare is calculated as the present discounted value of utility at a given point in time; it moves as the state variable change.

explained in Section 6.1, a loosening of the capital requirement immediately triggers a risk-taking episode. On average, risky firms produce less output since a risky firm’s idiosyncratic shock has a negative expected value; so, output and income fall substantially.¹⁸ Consumption and investment also fall. In subsequent periods, the demand for capital falls, as does its price, Q_t . The fall in Q_t , coupled with the jump in σ_t , increases the cut-off point ε_{t+1}^* discussed in Section 6.1, making risky loans more attractive; Ω_t^r and $R_{t+1}^{e,r}$ rise. The spread S_t immediately goes positive. These events are pictured in Panels 5 and 7.

Over time, the capital requirement rises and the process described above reverses itself. When S_t falls to zero, σ_t jumps back to its lower bound, and the economy jumps back to a safe equilibrium. Capital is more productive in a safe equilibrium, since lending to the inefficient risky firms is almost eliminated. This creates a jump in the price of capital, Q_t , and a jump in the return on safe loans, as can be seen in (38); the expected return on safe equity spikes. Gradually, the economy returns to its steady state.

Takeaways:

Positive and negative shocks to the capital requirement have asymmetric effects on the economy, and they are not the mirror images found in linear models. Loosening capital requirements triggers an excessive risk-taking episode, and consumption and output fall. For comparison, the solid lines in Figure 2, repeat the responses shown in Figure 1; the responses of consumption and output are so small as to be imperceptible with the re-scaling of the axes. Loosening capital requirements produces a major disruption on the real side of the economy; for a tightening of capital requirements, what happens in the financial sector stays in the financial sector.

6.3 TFP Shock

TFP shocks have played a major role in RBC modeling. Figure 3 illustrates the effects of a contractionary TFP shock; A_t falls by 1.5 percent (or one standard deviation), and has a persistence parameter of 0.95. In each panel, the dashed line shows what would happen if γ_t were to be held constant at its steady-state value; the solid line shows what would happen if the Ramsey planner set the path of γ_t .

We begin with the case of fixed capital requirements. Since the shock is auto-correlated, today’s TFP shock lowers the expected marginal productivity of capital for the next period, and thus the expected return on safe assets. As explained in Section 6.1, this triggers a risk-taking episode. $R_{t+1}^{e,s}$ falls and the spread S_t jumps positive. Risky firms produce less output on average; so, output and income fall substantially, as does consumption. As output and the

¹⁸Put another way, some of the risky loans fail, destroying bank equity and increasing the taxes necessary to insure deposits. So, output and income fall.

marginal productivity of capital fall, the demand for capital falls, lowering the investment price, Q_t . For use in Section 7 below, we also track the credit-to-GDP ratio. It falls, as under our calibration, bank loans decrease more quickly than GDP.

Over time, the TFP shock dissipates and the process described above reverses itself. Among other things, the falling capital stock raises the marginal productivity of capital and the return on safe assets, and also the price of investment. S_t falls, and jumps negative after σ_t drops to its lower bound, and the economy jumps back to a safe equilibrium. The credit-to-GDP ratio rises, and then midway starts to fall.

Next, we turn to the Ramsey planner’s solution, shown by the solid lines in Figure 3. The Planner’s policy is to set capital requirements just tight enough to keep safe loans attractive; as we have seen, any higher would unnecessarily deprive households of the deposits that they value. γ_t jumps on impact, and falls back to its steady-state value as the TFP shock dissipates.

While the Planner’s policy avoids risk-taking episodes, it cannot undo the damage done by the TFP shock itself. The shock lowers the household’s net worth, and they respond by decreasing consumption and increasing savings/investment. All this is familiar from the RBC literature. Indeed, absent the possibility of excessive risk taking, our model has no banking frictions; in essence, it reduces to the standard RBC model in which there is no role for macroeconomic policy. It may be interesting to note that the gap between the paths of consumption in the third panel is largely determined by the size ξ , the expected loss on risky loans; ξ is a measure of the economic inefficiency in our model.

Takeaways:

A one standard deviation shock to TFP causes a 1.5 percent decrease in output. However, the optimal capital requirement needs only a modest adjustment, an increase from 10 percent to 10.15 percent. Note also that after a few quarters, the path of the investment price, Q_t , in the inefficient solution (inversely) tracks the path in the Planner’s solution rather closely. After its initial fall, the credit-to-GDP ratio rises and then falls midway through the cycle; optimal capital requirements do not follow the guidance laid out by the Basel III accords.

6.4 An Expansionary Investment Technology Shock

Here we study a positive η_t shock in the equation for net investment, (11). The shock has a persistence parameter of 0.8, and we calibrate the size of the shock to increase output by 1% at its peak, roughly on a par with the TFP shock described previously. Figure 4 illustrates the effects of this shock. Once again, the dashed lines show what would happen if the capital requirement were kept at its steady-state value, while the solid lines represent

the Ramsey solution.

This shock was not considered in Section 6.1, but its effects are readily translatable to the discussion there. A positive shock to investment in period t increases the supply of capital next period, K_{t+1} , lowering the expected marginal product of capital and the expected return on the safe asset. The expected return on safe equity falls, and a risk-taking episode is begun, even though the shock itself is expansionary.

Note that the expected return on safe equity only drops for one period. To see why, note that the decrease in the marginal product of capital causes the price of capital, Q_{t+1} , to fall, and this raises the return on safe loans in period $t+2$. However, the damage is already done; the risk-taking episode has already been triggered, as documented by the jump in S_t . The risky firms produce less output on average, and output and consumption fall. From here on, the story is much the same as before. The investment shock decays over time and the process gradually reverses itself. Note that there is an upward spike in the expected return on safe loans when the economy jumps back to a safe equilibrium.

The solid lines illustrate what would happen if the Ramsey planner set the path of γ_t . The Planner raises the capital requirement just enough to offset the switch to excessive risk taking. Consumption and investment rise more in this case since there are no bankruptcies and equity losses to lower household income.

Takeaways:

In this example, the Planner raises capital requirements as the economy goes into a boom period, which may be thought to be in line with Basel III's cyclical buffers; however, the credit-to-GDP ratio falls initially. Once again, this ratio subsequently rises, and then falls midway through the cycle. The optimal adjustment in the capital requirement is again small; γ_t only rises from 10% to a little over 10.2%. But the distance between the solid and dashed lines is substantial. Note that the path followed by the investment price, Q_t , in the inefficient solution (inversely) tracks the Planner's solution, but rather loosely.

6.5 A Volatility Shock

In the steady state, the standard deviation of the idiosyncratic shock, τ , affecting risky firms is 5.5%. Our volatility shock increases the standard deviation by 15 basis points, after which it follows an AR(1) process (with persistence parameter 0.8) back to 5.5%. As explained in Section 6.1, an increase in volatility raises the expected return on risky loans, since it enhances the upside potential of risky loans while the downside risk is protected by limited liability.

Figure 5 illustrates the economic consequences of this volatility shock. As before, the

dashed lines show what would happen if γ_t were to be held constant. The shock is big enough to entice banks to switch to risky loans, some of which will fail, increasing taxes and destroying bank equity. The story that follows is by now familiar. Consumption and savings/investment fall. Eventually, the shock dissipates and the falling capital stock raises R^s enough to make safe loans attractive again. As the solid lines illustrate, the Ramsey planner would increase capital requirements just enough to eliminate the excessive risk taking. Under the Ramsey policy, there is no change in the expected return on safe equity or on S_t ; the shock has absolutely no effect outside of financial markets, and only the capital requirement moves inside financial markets.

Takeaways:

With no change in capital requirements, the effect of this shock on consumption and output is rather small; however, the shock itself was not large. Note that the path followed by the credit-to-GDP ratio and the investment price, Q_t , in the inefficient solution are not good indicators for the direction of optimal policy.

6.6 Sensitivity Analysis

The size of the optimal adjustments in capital requirements is strongly influenced by two parameters: the variance of the idiosyncratic shocks, τ , and the average penalty for taking a flier on a risky loan, ξ . In Figure 6, we focus on the TFP shock. The circles in these diagrams represent the baseline calibrations. The maximum adjustment in the optimal capital requirements is especially sensitive to increases in τ . At the outer range of the values of τ that we consider, we can boost the change in capital requirements to a more substantive 0.75 percent in response to a TFP shock that, at its peak, still reduces output by 1.5 percent, just as in Figure 3.

7 Implementable Buffer Rules

The Ramsey policy derived in Section 6 was in response to three different shocks, each of which was considered in isolation. In practice policymakers face a much more difficult challenge: the economy is actually driven by a multiplicity of shocks, all occurring at the same time; policymakers have to respond to the full stochastic structure of the economy. In our model, we can derive the Ramsey policy when the economy is hit by a full constellation of shocks, but it is implausible to think that policymakers would be able to implement it. So, in this section, we consider simple policy rules in which the capital requirement responds to one or two observable endogenous variables, and we ask which, if any, of these rules can

closely mimic the actual Ramsey policy. Of particular interest will be Basel III’s capital buffer rule in which capital requirements respond positively to the credit-to-GDP ratio.

This exercise is neither easy nor straightforward. The first step is to decide which shocks drive the macroeconomy, and we will see that this decision is not innocent: a different choice of shocks can alter results dramatically. Here, we will consider two calibrations which fit the U.S. data rather well. In Calibration 1, we use the two macroeconomic shocks – TFP and ISP (investment specific) – that were considered in the last section; in Calibration 2, we expand the set of shocks to include the volatility shock. The moments we match are the variances, correlation, and auto-covariances of chained real GDP, chained real private investment, and the implicit price deflator for chained investment (divided by the price deflator for consumption).

The next step is to calibrate the shocks to make model moments match moments in the U.S. data. We allow each shock to follow an auto-regressive process of order 1, and we need to size the persistence parameters and the standard deviations of the innovations. We also want to size the investment adjustment cost parameter, ϕ , and the habits parameter, κ . To do this, we use a SMM (simulated method of moments) procedure. For these calibrations, we are focusing on variances, covariances, and auto-covariances of all the observed variables, with the estimation sample starting in 1980. We experiment with the SMM optimal weighting matrix, and we match observed moments from bandpass-filtered data (selecting standard business cycle frequencies) against analogous moments simulated from a sample of 2000 model observations (also bandpass filtered).

Finally, it should be noted that we are also calculating and imposing the Ramsey policy for capital requirements in our model simulations. So, the model output gives us data for the optimal dynamic capital requirements, and model data are generated under the assumption that the optimal capital requirements are in place. With that assumption, there is no discernible difference in the targeted moments when we add the volatility shock under our Calibration 2. The Ramsey policy varies capital requirements to avoid excessive risk-taking episodes, otherwise leaving little imprint on the macroeconomy. As we shall see, this additional shock will lead to a substantial deterioration of the performance of simple rules. For illustration, we choose the same parameterization as for the earlier example in Figure 5.

7.1 Matching Moments, Shock Processes and Variance Decompositions

Tables 4 and 7 show that both calibrations are very good; model moments are close to data moments. Moreover, the values of the distance functions reported at the bottom of the

tables show differences that are trivial, on the order of 2×10^{-7} .

Tables 2 and 3 show the calibrated shock processes and the variance decompositions associated with Calibration 1; Tables 5 and 6 report the analogous results for calibration 2. It may be interesting to note that the persistence parameter for the TFP shock in both calibrations is 0.79, which is somewhat lower than what is normally assumed in the RBC literature.¹⁹ Finally, the parameters for consumption habits and investment adjustment costs that minimize the distance function are 0.93 and 0.06 respectively.

In Calibration 1, both shocks are persistent. But in the variance decompositions, the TFP shock does all of the work for GDP and investment; the ISP shock only matters for the investment price. Note also that the ISP shock explains all the variation in the Ramsey policy setting, γ . In Calibration 2, all of the shocks are persistent. In the variance decompositions the TFP shock once again explains all of the variations in GDP and investment, while now the volatility shock explains the variation in the Ramsey policy settings.

7.2 Implementable Capital Buffer Rules

The Ramsey policy requires full knowledge of all the shocks, making its implementation virtually impossible in practice. Here, we focus on simple rules that may be able to mimic the optimal policy; these rules are based on one or two observable variables, and they are clearly implementable. The Basel III cyclical buffer, which runs off of the credit-to-GDP ratio, will be of particular interest. We will also compare these simple rules to more complex rules that are probably not implementable.

To derive the policy rules, we use data generated by our simulations. That is, we regress the Ramsey policy settings on one or more of the endogenous variables (and a constant). Then, we use a variety of measures to rank the alternative rules. The first, and perhaps the most obvious, measure is the R-square of the regression; the higher the R-square, the more closely the rule tracks the Ramsey settings. But there are other measures – performance measures – that focus on what the rule actually achieves. A good rule should minimize the frequency of excessive risk-taking episodes; the Ramsey policy eliminates them altogether. But recall that there is a tradeoff here. The frequency of episodes can also be minimized, or even eliminated, by simply setting the static capital requirement at a very high level. This cannot be the only performance measure that we consider since a very high capital requirement forces banks to limit the deposits they issue, and deposits are valued for their transactions services. So, the second performance measure is the average level of deposits that it achieves – the higher, the better.

¹⁹In most of the RBC literature, the persistence parameter is estimated by a simple auto-regression on TFP data.

Simple Rules Under Calibration 1

Table 8 reports our results for various policy rules under Calibration 1. The first column lists the variables in the rule; the second column gives the R-square for the rule's regression; the third and fourth columns show the regression coefficients; the fifth and sixth columns report the rule's performance measures: the average number of risk-taking quarters per 100 years and the average level of deposits when the static capital buffer is 10 basis points (that is, when the steady-state capital requirement is raised from 10 percent to 10.1 percent); and finally, the seventh and eighth columns report the performance measures when the static capital buffer is 30 basis points (or the steady-state capital requirement is raised to 10.3 percent).

The Ramsey policy allows no risk-taking episodes, and the average level of deposits is 16.25. These performance measures – 0 and 16.25 – are the gold standard, the standard to which the implementable rules can only hope to aspire.

The best implementable rule for Calibration 1 has capital requirements responding to the investment price. The R-square is 0.96, so it tracks the Ramsey policy quite well. And this simple rule comes close to meeting the Ramsey performance standards – no risk-taking episodes, and an average level of deposits of 16.23 (with a static buffer of just 10 basis points). It is easy to see why this rule does so well. Figures 3 and 4 show that for both of the shocks that drive the economy, the investment price falls while the Ramsey capital requirement rises. Moreover, in Table 3, the ISP shock explains all the variation in the Ramsey requirement, and 92 percent of the variation in the investment price. So the investment price is a very good signal for what should be done with the capital requirement.

By contrast, the Basel rule does very poorly. The Basel III guidance is to tighten capital requirements when the credit-to-GDP ratio is rising and relax them when the ratio is falling. In Table 8, the R-square for this rule is only 0.25. Moreover, the number of risk-taking quarters per 100 years is very high when the steady-state capital requirement is 10.1 percent, and the average level of deposits is very low. Note also that the sign of the regression coefficient is wrong, at least from the perspective of the Basel III recommendations. In the next row, we impose a positive coefficient, and the results are even worse, as might have been expected.

Raising the steady-state capital requirement to 10.3% brings a huge improvement in the Basel rule. But, the higher steady-state capital requirement is doing all of the work here: the number of risk-taking quarters falls dramatically, and the level of deposits rises dramatically. The latter result may seem counter intuitive, since higher capital requirements force banks to decrease the proportion of loans that are funded by bank deposits. The answer to this puzzle is that the level of output and loans is lower during risk-taking episodes. Limiting

the number of risk-taking episodes increases the average amount of credit that is extended, and this can raise the level of deposits even when deposits account for a lower fraction of the bank’s funding.

So why does the Basel rule itself do so badly? Figures 3 and 4 show that for both of the shocks that drive the economy, the credit-to-GDP path reverses direction midway through, while the paths of the Ramsey capital requirement are monotonic. And from the variance decompositions reported in Table 3, the ISP shock drives the Ramsey capital requirements, while it only explains 41 percent of the variation in the credit-to-GDP ratio.

Table 8 also reports the performance of a rule that focuses on GDP. That rule fares no better than the Basel rule. The R-square is virtually zero; so it is not tracking the Ramsey policy. And the performance measures are also bad.

The remaining rules are probably not implementable because of their informational requirements. The simplest is a rule that responds to the expected spread between the safe return and the deposit rate. This rule sounds sensible, given the discussion in Section 6.1, and indeed it has an R-square of 0.83; it tracks the Ramsey policy fairly well. However, its performance is so poor that risk-taking episodes can last beyond what our solution methods can accommodate, leading to convergence problems

The last two rules implausibly assume that the policymaker can observe the shocks and their innovations. Armed with all this information, the R-squares are 1.0. However, neither of these rules do any better than the simple investment price rule on the performance measures.

Simple Rules Under Calibration 2

Calibration 2 adds the volatility shock. Table 9 shows that the addition changes our results dramatically. Neither the investment price rule nor the Basel rule works well; they have low R-squares and poor performance measures unless the steady-state reserve requirement is raised from 10 percent to 11 percent. Here again, the work is being done by the static capital buffer, and not the rules themselves. The reason for the poor performance of these rules can be seen in the variance decompositions of Table 6. The volatility shock explains 97 percent of the variation in the capital requirement, but 0 percent of variation in the investment price and only 1 percent of the variation in the credit-to-GDP ratio.

The rule based upon the spread between the expected return on safe loans and the deposit rate does a better job of tracking the Ramsey policy, but once again the steady state is plagued by convergence problems. Only rules that assume an implausible amount of information, including the shocks processes and their innovations, come close to matching the performance of the Ramsey policy.

The Efficiency of Static Capital Buffers

The results reported in the previous sections seem to indicate that the steady-state capital requirement is an important instrument in the regulator’s tool kit. Table 10 bears that out. Here, there are no rules, just static capital buffers. The last row gives the performance measures achieved by the Ramsey planner. The first row with numbers reports the performance measures if the static capital requirement is raised from the 10 percent benchmark to 10.1 percent; they are not good. However, if the requirement is raised to 10.4 percent for Calibration 1, or 11.5 percent for Calibration 2, the results are almost as good as those achieved by the Ramsey planner. This suggests that the regulator need not bother with dynamic capital requirements. If the static capital requirement is raised to 11.5 percent, the performance measures for both calibrations are very close to the optimal ones. Note, however, that the optimal level of the buffers depends on the calibration we are using.

Takeaways: Calibrations 1 and 2 show that changing the shock structure that drives the economy can radically alter the ability of simple rules to perform well. Simple rules, like the Basel rule, do not perform well for either calibration. However, eschewing policy rules and increasing the static capital requirement by as little as 1 percent nearly achieves the performance standards set by the Ramsey policy.

8 Conclusion

In our model, bank risk taking is endogenous, and the temptation to take excessive (or socially inefficient) risk is enabled by limited liability and government deposit insurance, which protect banks and depositors from the more extreme losses. Both macroeconomic shocks and market volatility shocks can trigger bouts of excessive risk taking by lowering the expected return on safer investments. Capital requirements can eliminate that temptation by making banks keep more skin in the game, but this may come at the cost of limiting liquidity-producing deposits.

We provide examples in which a Ramsey planner would raise capital requirements in response to either cyclical booms or busts (depending upon the underlying shocks), and raise capital requirements in response to an increase in market volatility that has little consequence for the business cycle.

In practice, the policymaker’s problem is more difficult than responding to a single well-identified shock. The policymaker has to respond to the full constellation of shocks that drive the economy. Accordingly, the informational requirements for a regulator are daunting, even in our stylized model where we only have two projects that banks can finance. In practice

regulators would have to keep track of expected relative returns for a myriad possible projects.

We find it implausible to think that a policymaker could implement the optimal Ramsey policy in practice. In this environment, it is tempting to look for market indicators that might point the way to appropriate changes in the capital requirement. However, we showed that popular candidates – such as growth in the credit-to-GDP ratio – were unlikely to be a reliable indicators. To this end, we employed an SMM procedure to: (1) calibrate the shock processes that drive our model economy, (2) calculate the Ramsey policy in that environment, and (3) evaluate implementable policy rules against the Ramsey benchmark. Most policy rules fell into the risk-taking trap with an unfortunate frequency. Fortunately, we found that a small static buffer – slightly higher than the optimal steady-state capital requirement – avoided the Wile E. Coyote moments and achieved levels of deposits close to the Ramsey policy. Some finely tuned policy rules — such as a rule following the Basel III guidance on the setting of countercyclical capital buffers — may sound sensible but turn out to do more harm than good in our model. Fine tuning capital requirements seems exceedingly risky; the Hippocratic Oath – First, do no harm – may be an appropriate guide for well-intentioned regulators.

Table 1: Parameters

Value	Description	
<i>Conventional</i>		
β 0.99	Discount rate	
α 0.3	Capital share in production	
ρ_c 1.1	Elasticity of substitution for consumption	
δ 0.025	Depreciation rate	
ς_d 1.1	Interest rate elasticity of supply of deposits	
<i>Specific</i>		<i>Target/Explanation</i>
τ 0.05521	Standard deviation of idiosyncratic shock	$\frac{\text{Debt}}{\text{EBITDA}} = 6$
ξ 0.00076	Minus mean of idiosyncratic shock	Cap. requirement= 10%
ς_0 0.015	Relative weight on liquidity in the utility function	Quarterly rate on bank debt= 0.86%
f 0.0055	Linear Cost of Banking	$R^s - R^d = 2.26\%$
ϕ 0.06	Investment adjustment costs	estimated by SMM
κ 0.93	Habits	estimated by SMM
$\underline{\sigma}$ 0.01	Minimum risk that banks can take	needed for numerical solution method
$\bar{\sigma}$ 0.99	Maximum risk that banks can take	needed for numerical solution method

Table 2: Calibration 1, Shock Processes

	AR(1) param.	Innov. St. Dev.
TFP	0.79	0.0093
ISP	0.95	0.0052
Distance Function	0.0012289861	

Table 3: Calibration 1, Variance Decomposition

	var(GDP)	var(invest.)	var(invest. p.)	var(gamma)	var(credit/GDP)
TFP	100	99	8	0	59
ISP	0	1	92	100	41

Table 4: Calibration 1, Matching Moments

	Data	Model
Var(GDP)	0.92	0.97
Corr(GDP,Investment)	0.96	1.00
Corr(GDP,Investment Price)	0.08	0.08
Var(Investment)	27.68	27.68
Corr(Investment,Investment Price)	0.02	0.06
Var(Investment Price)	0.40	0.38
Autocorr(GDP)	0.93	0.88
Autocorr(Investment)	0.93	0.88
Autocorr(Investment Price)	0.87	0.88

Table 5: Calibration 2: Shock Processes

	AR(1) param.	Innov. St. Dev.
TFP	0.79	0.0093
ISP	0.95	0.0052
Volatility	0.80	0.0015
Distance Function	0.0012289856	

Table 6: Calibration 2, Variance Decomposition

	var(GDP)	var(invest.)	var(invest. p.)	var(gamma)	var(credit/GDP)
TFP	100	100	8	0	65
ISP	0	0	92	2	35
Volatility	0	0	0	98	0

Table 7: Calibration 2, Matching Moments

	Data	Model
Var(GDP)	0.92	0.97
Corr(GDP,Investment)	0.96	1.00
Corr(GDP,Investment Price)	0.08	0.08
Var(Investment)	27.68	27.68
Corr(Investment,Investment Price)	0.02	0.06
Var(Investment Price)	0.40	0.38
Autocorr(GDP)	0.93	0.88
Autocorr(Investment)	0.93	0.88
Autocorr(Investment Price)	0.87	0.88

Table 8: Simple Rules with Calibration 1

Simple rule	R square	Regression coefficients		Static buffer = 10 basis points		Static buffer = 30 basis points	
		First variable	Second variable	Quarters with excessive risk-taking (per 100 years)	Average deposit under simple rule	Quarters with excessive risk-taking (per 100 years).	Average deposit under simple rule.
Invest. p. (best state variable)	0.960	-0.087		0	16.23	0	16.20
Expected banking spread	0.881	0.842		115.6	11.50	0	16.20
GDP	0.002	-0.001		149.6	10.21	10.4	15.79
Credit/GDP	0.250	-0.005		149.2	10.18	4.4	16.02
Credit/GDP wih positive coef		0.005		158.8	9.87	38	14.68
Expected safe return and deposit rate	0.826	594.284	-594.312	convergence problems	convergence problems	convergence problems	convergence problems
All shock processes, innovations, expected safe return and deposit rate	1.000	Too many to show		0	16.23	0	16.20
All shock processes, innovations, and lagged capital requirement	1.000	Too many to show		0	16.23	0	16.20

Table 9: Simple Rules with Calibration 2

	Regression coefficients			Static buffer = 10 basis points	Static buffer = 50 basis points	Static buffer = 100 basis points			
Simple Rule	R Square	First variable	Second variable	Quarters with excessive risk-taking (per 100 years)	Average deposit under simple rule	Quarters with excessive risk-taking (per 100 years).	Average deposit under simple rule.	Number quarters with excessive risk-taking (per 100 years)..	Average deposit under simple rule..
1. Invest. p.	0.043	-0.066		195.6	8.273	69.6	13.297	6.0	15.830
2. Expected banking spread	0.613	0.773		211.2	7.647	77.6	12.991	6.8	15.802
3. GDP	0.000	-0.001		210.8	7.697	79.6	12.903	6.8	15.805
4. Credit/GDP	0.016	-0.005		208.4	7.777	76.8	13.027	7.2	15.788
5. Credit/GDP with positive coef		0.005		Convergence problems		83.2	12.780	6.8	15.805
6. Expected safe return and deposit rate	0.974	861.783		Convergence problems		Convergence problems		Convergence problems	
7. All shock processes, innovations, expected safe return and deposit rate	1.000	Too many to show	-861.892	0	16.223	0.0	16.151	0	16.061
8. All shock processes, innovations, and lagged capital requirement	1.000	Too many to show		0	16.223	0.0	16.151	0	16.061

Table 10: The Efficiency of Static Buffers

Static Buffer	Calibration 1 (excludes volatility shocks)		Calibration 2 (includes volatility shocks)	
	Number of quarters with excessive risk- taking (per 100 years)	Average deposit	Number of quarters with excessive risk- taking (per 100 years)	Average deposit
10 bp	149.2	10.261	210.8	7.678
20 bp	66.8	13.526	172.0	9.216
30 bp	10.8	15.785	140.8	10.479
40 bp	0	16.189	108.8	11.784
50 bp	0	16.171	79.2	12.920
100 bp	0	16.081	6.8	15.805
150 bp	0	15.991	0	15.991
Optimal Rule	0	16.251	0	16.241

Figure 1: Higher Capital Requirement Shock

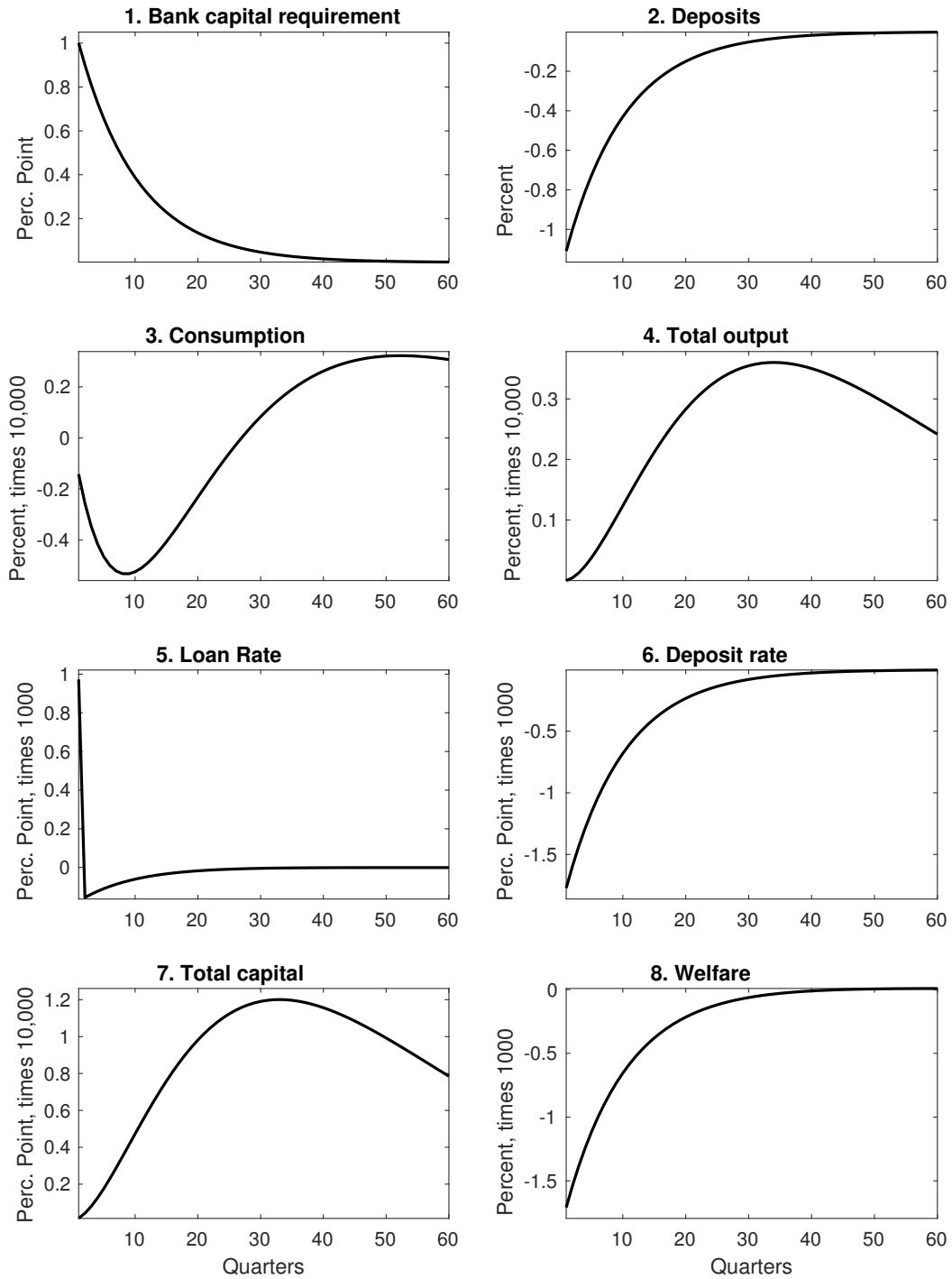


Figure 2: Capital Requirement Shocks

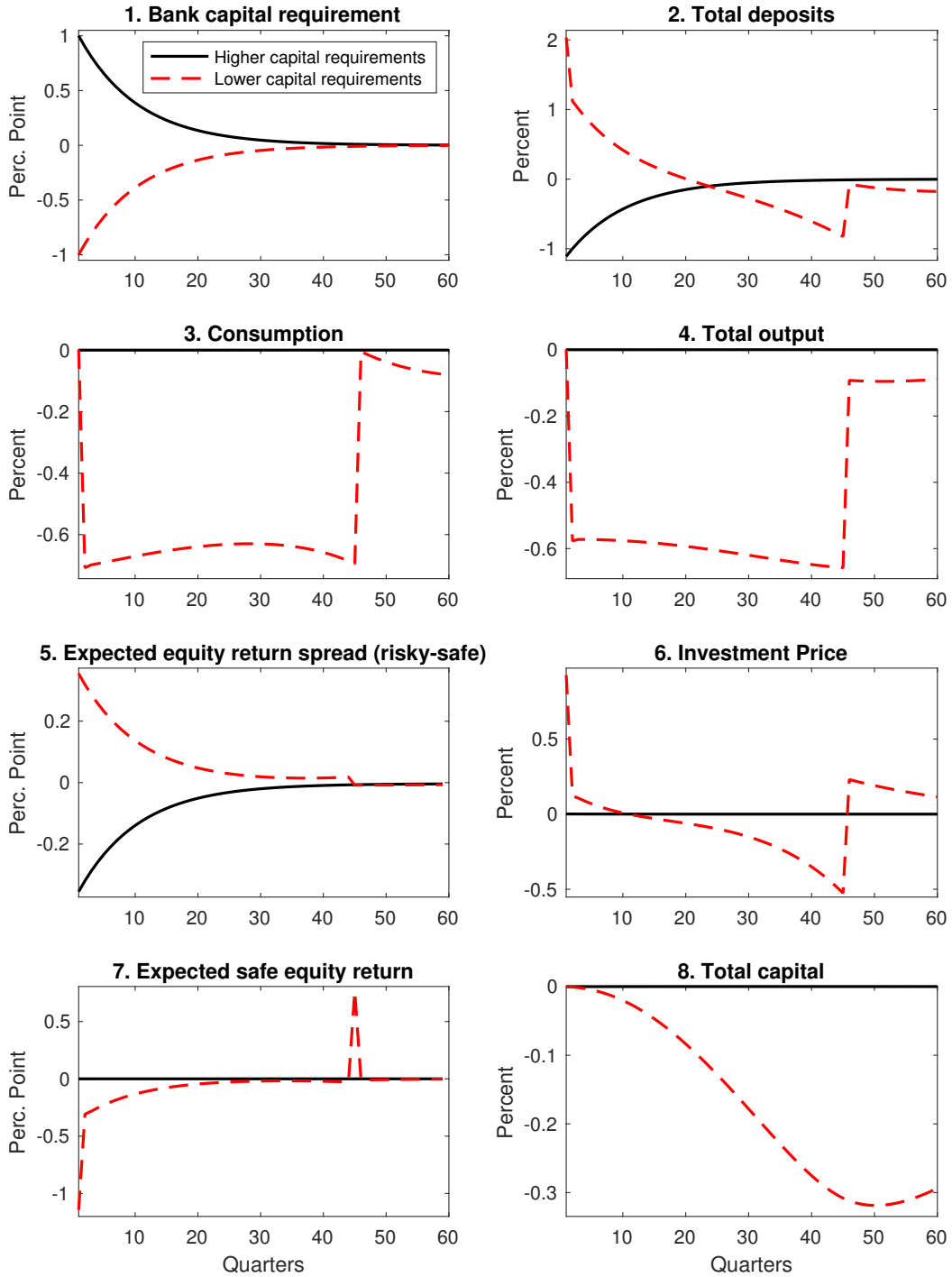


Figure 3: Negative TFP Shock

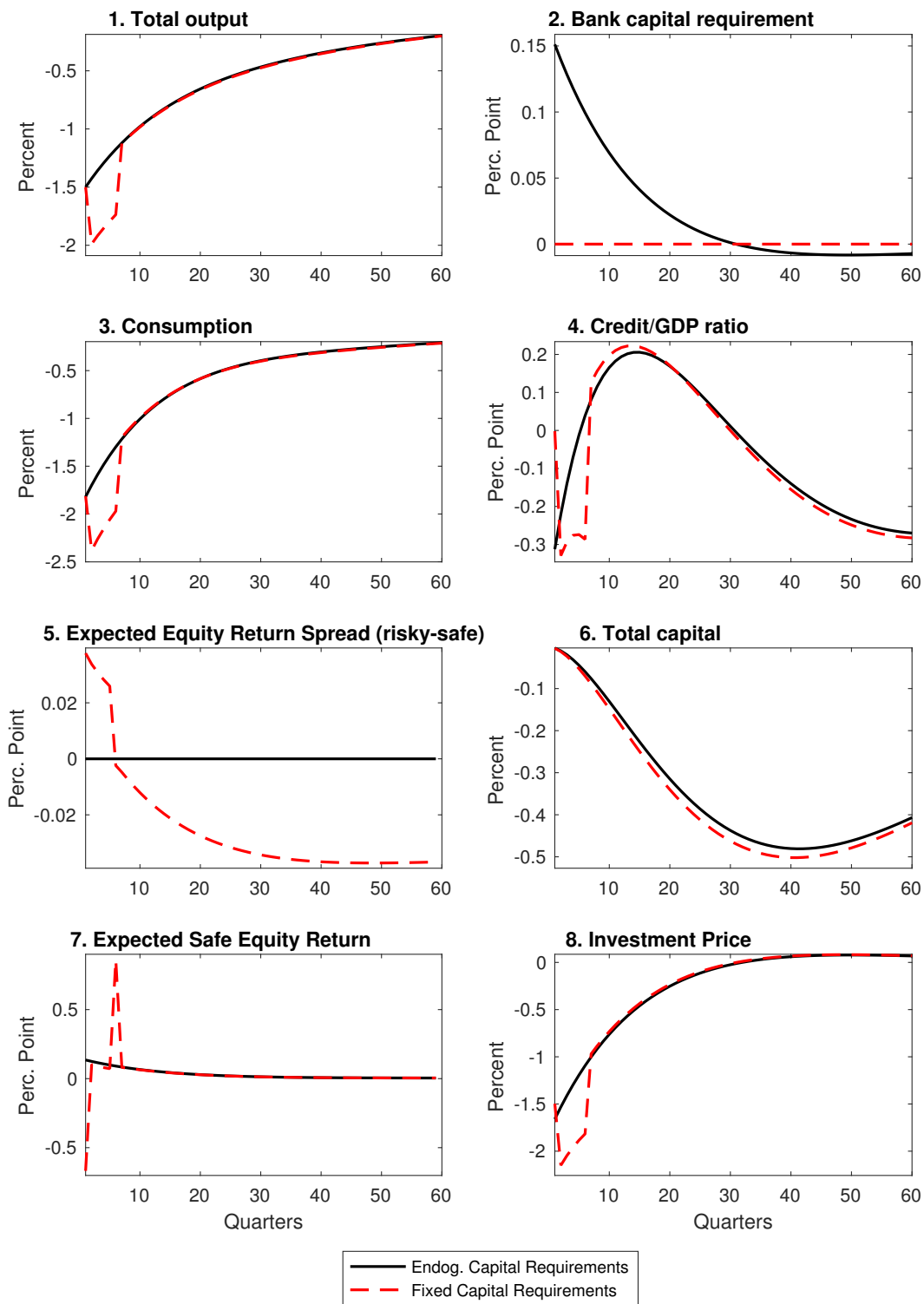


Figure 4: Positive Investment Shock

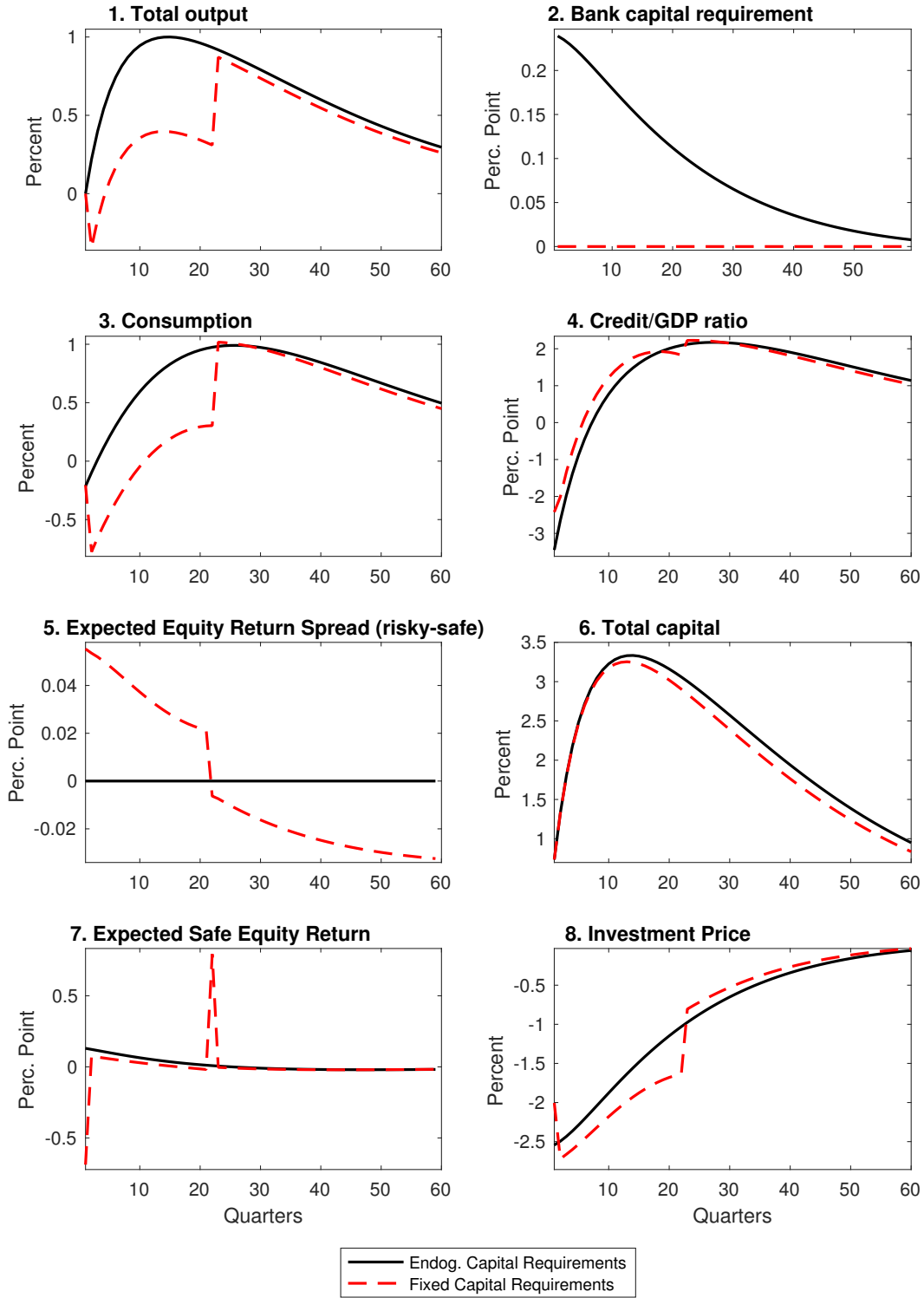


Figure 5: Volatility Shock

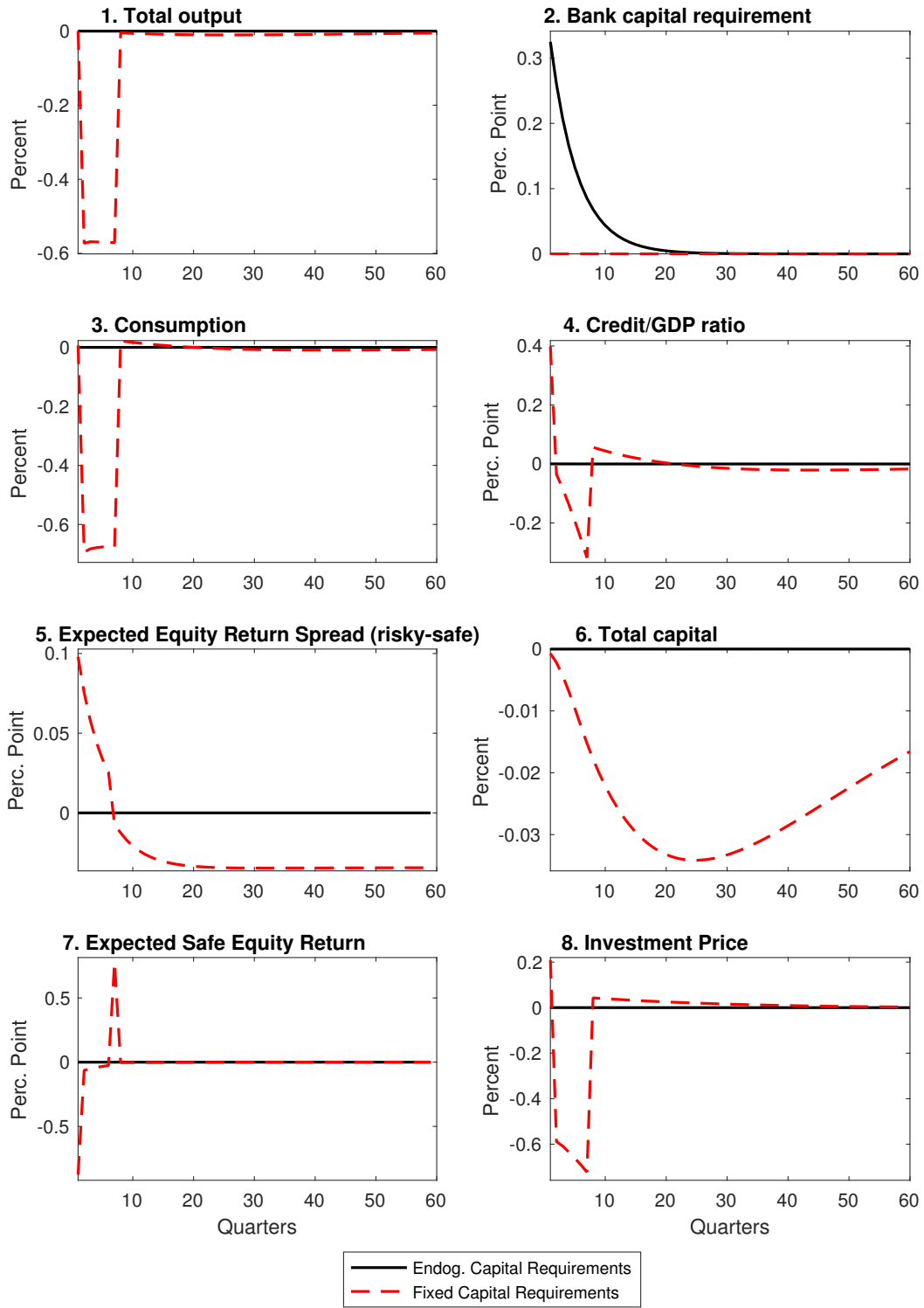
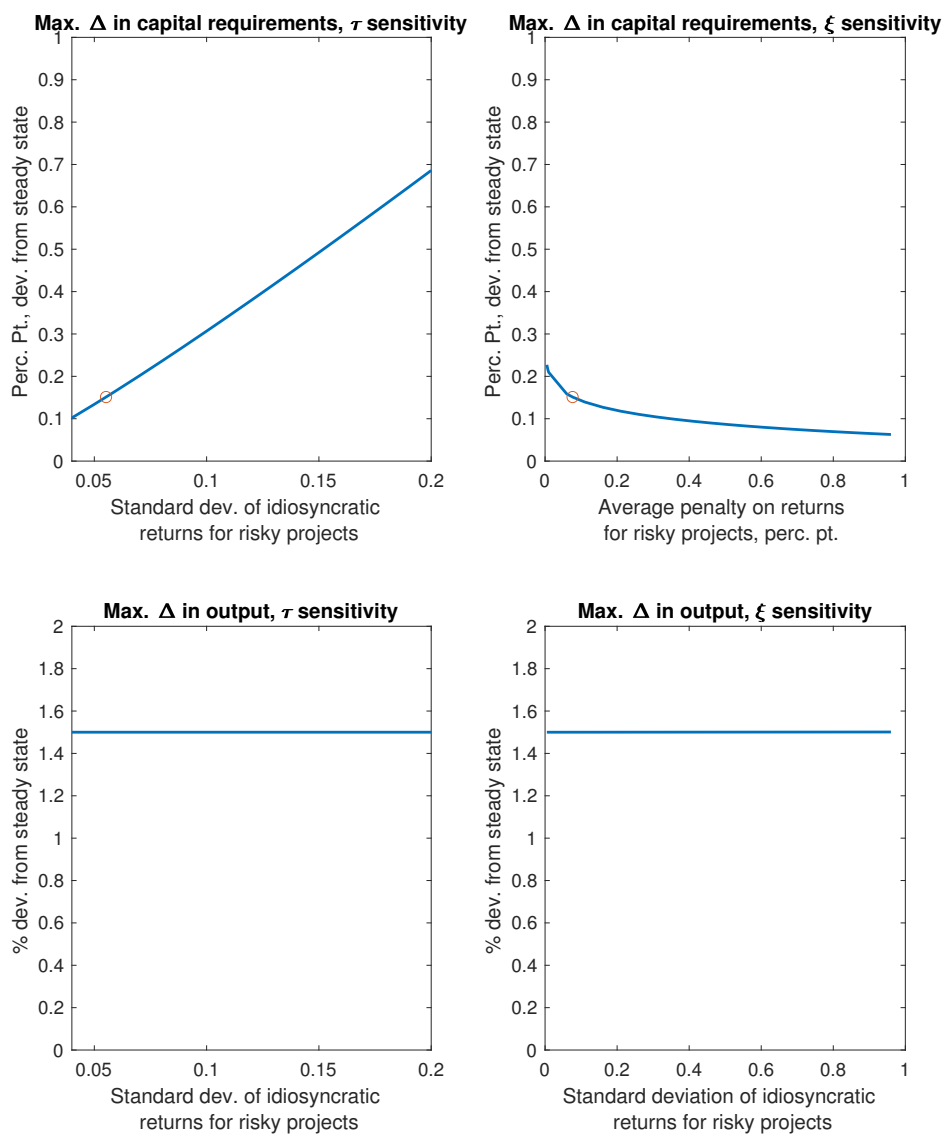


Figure 6: Sensitivity Analysis, TFP Shock



9 References:

- Altig, D., Christiano, L. J., Eichenbaum, M., & Linde, J. (2011). Firm-specific capital, nominal rigidities and the business cycle. *Review of Economic Dynamics*, 14 (2), 225–247.
- Angeloni, I., & Faia, E. (2013). Capital regulation and monetary policy with fragile banks. *Journal of Monetary Economics*, 60 (3), 311–324.
- Begenau, J. (2020). Capital requirements, risk choice, and liquidity provision in a business-cycle model. *Journal of Financial Economics*, 136 (2), 355–378.
- Christiano, L. J., Motto, R., & Rostagno, M. (2014). Risk shocks. *American Economic Review*, 104(1), 27–65.
- Collard, F., H. Dellas, B. Diba, & O. Loisel (2017). Optimal monetary and prudential policies. *American Economic Journal: Macroeconomics*, 9 (1), 40–87.
- Davydiuk, T. (2017). Dynamic bank capital requirements. Mimeo, SSRN.
- Elenev, V., Landvoigt, T., & Van Nieuwerburgh, S. (2021). A macroeconomic model with financially constrained producers and intermediaries. *Econometrica*, 89(3), 1361–1418.
- Faria-e-Castro, M. (2019). A quantitative analysis of countercyclical capital buffers. FRB St. Louis Working Paper, (2019-8).
- Gertler, M., & Kiyotaki, N. (2015). Banking, liquidity, and bank runs in an infinite horizon economy. *American Economic Review*, 105 (7), 2011–2043.
- Gertler, M., Kiyotaki, N., & Prestipino, A. (2020). A macroeconomic model with financial panics. *The Review of Economic Studies*, 87(1), 240–288.
- Gomes, J. F., Grotteria, M., & Wachter, J. (2018). Foreseen risks. NBER Working Paper No. 25277.
- Gorton, G., & Metrick, A. (2013). Securitization. In *Handbook of the Economics of Finance* (Vol. 2, pp. 1–70). Elsevier.
- Guerrieri, L., & Iacoviello, M. (2015). OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily. *Journal of Monetary Economics*, 70, 22–38.
- Jordà, Ò., Schularick, M., & Taylor, A. M. (2017). Macrofinancial history and the new business cycle facts. *NBER Macroeconomics Annual*, 31(1), 213–263.
- Malherbe, F. (2020). Optimal capital requirements over the business and financial cycles. *American Economic Journal: Macroeconomics*, 12 (3), 139–74.
- Martinez-Miera, D., & Suarez, J. (2014). A macroeconomic model of endogenous systemic risk taking. mimeo.
- Mendicino, C., Nikolov, K., Suarez, J., & Supera, D. (2018). Optimal dynamic capital requirements. *Journal of Money, Credit and Banking*, 50, 1271–1297.
- Mian, A., Sufi, A., & Verner, E. (2017). Household debt and business cycles worldwide.

Quarterly Journal of Economics, 132, 1755-1817.

Mian, A., Sufi, A., & Verner, E. (2020). How does credit supply expansion affect the real economy? the productive capacity and household demand channels. *Journal of Finance*, 75 (2), 949-994.

Schularick, M., & Taylor, A. M. (2012). Credit booms gone bust: Monetary policy, leverage cycles, and financial crises, 1870-2008. *American Economic Review*, 102, 1029-1061.

Van den Heuvel, S. J. (2008). The welfare cost of bank capital requirements. *Journal of Monetary Economics*, 55 (2), 298-320.