Bank Risk, Monetary Transmission, and Macroprudential Policy[*]

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Abstract

This paper investigates the influence of possible bank default and bank leverage constraints on monetary and macroprudential policy prescriptions. We build a New Keynesian model with banks that channel funds from households to firms. Banks face endogenous leverage constraints and are subject to costly default. We calibrate our model to the US economy and show that in the decentralized equilibrium, banks borrow more than the socially efficient level. A macroprudential policy that limits bank leverage reduces the risk of bank default and improves long-run welfare. In the short run, a "macroprudential-flavored" monetary policy can reduce financial propagation by affecting bank shadow values, while countercyclical capital regulation is effective for stabilizing asset prices. Our normative study shows that introducing countercyclicality to bank capital regulation achieves little welfare improvement if monetary policy is already used to mitigate financial acceleration. The jointly optimal policies suggest that policymakers should assign countercyclical macroprudential roles to monetary policy, and bank capital regulation should focus on the desired level of prudence.

1 Introduction

The 2007-2008 global financial crisis brought a public realization that the default of large banks is costly. This scenario led central banks and financial regulators worldwide to reconsider the desirable level and cyclicality of bank equity. The subsequent recession also drew public attention to the "bank risk-taking channel" of the monetary transmission mechanism, in which a lowered policy rate strengthens bank financing and promotes investment but also induces banks to take more risks (Adrian and Shin, 2010; Borio and Zhu, 2012; Yellen, 2014). The risk-taking channel of monetary policy implies that monetary policy can potentially play a macroprudential role. In this context, a few questions arise. What is the optimal level of leverage for banks in the long run? How should policymakers adjust banks' leverage over the

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business cycle? Do we need aggressive, countercyclical macroprudential policies if monetary policy can also play some role?

Our goal is to answer these questions in a dynamic stochastic general equilibrium (DSGE) model with banks that are subject to costly default. In our model, banks, which channel funds from households to firms, face the borrowing constraints of Gertler and Kiyotaki (2010), so the amount of funds they obtain is limited by their equity.[1] In such a model, an increase in bank equity would enhance bank lending and the production of physical capital relative to a frictionless economy, and lowering the policy rate would encourage banks to borrow. This framework provides the model for financial acceleration and the bank risk-taking channel of monetary transmission. The presence of such bank risk-taking channels of monetary policy, however, does not immediately imply that there is inefficiency in the level of bank leverage or that there is room for policies. To make banks' overborrowing feature explicit, we assume that banks are subject to costly default and that the deposit rate or funding cost of an individual bank is not affected by its leverage. This setting generates a trade-off: an increase in bank lending enhances investment while it also raises the probability of costly default.

We calibrate our model to match the US data of the bank balance sheet and bank default from the Federal Financial Institutions Examination Council (FFIEC) and Federal Deposit Insurance Corporation (FDIC). In the calibrated model, banks borrow more on average than the socially optimal level. First, we introduce a macroprudential policy in the form of a constant-rate tax on bank assets. Such a policy lowers the average return on bank assets, induces banks to limit their leverage, and reduces the probability of costly default by banks. The model suggests the optimal level for the prudential tax and the resulting equilibrium bank leverage. The optimal level of the prudential tax depends on the slackness of the financial constraint banks face. If the constraint is tight and bank leverage is already low without such a policy, inducing a higher capital ratio may be harmful to welfare.

Next, we study the role of monetary policy over the business cycle. We first examine the prescription of monetary policy when macroprudential policy is absent. Our results show that unlike in canonical New Keynesian models, perfectly price-stabilizing monetary policy is suboptimal. That is because the way the central bank sets the nominal rate affects bank profitability and leverage through the dynamics of real interest rates, so such policy can be used to mitigate financial propagation. As a result, if monetary policy is the only policy instrument, it should balance the inefficiency caused by both nominal rigidity and financial propagation. A Taylor-rule-type monetary policy that makes the nominal interest rate respond to output (or to other variables in the banking sector) can alleviate inefficiently large responses. This feature does not change even if (1) procyclical asset prices are absent; (2) a wage subsidy for workers is introduced to eliminate the steady-state distortion induced by monopolistic competition; or (3) the steady-state distortion of bank overborrowing is eliminated by a time-invariant macroprudential tax on bank assets.

Finally, we allow the macroprudential tax on bank assets to be countercyclical by making it respond to asset prices. When monetary policy aims solely at stabilizing inflation, the

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[1] The Kiyotaki and Moore (1997) collateral constraint directly determines the ratio of assets to equity. We adopt the borrowing constraint proposed by Gertler and Kiyotaki (2010) to allow this leverage ratio to dynamically respond to the economic condition.

macroprudential tax should respond aggressively to asset prices. In contrast, if monetary policy responds to asset prices, the macroprudential tax should be less countercyclical. The two policies are substitutes, though they mitigate financial acceleration differently. Monetary policy is effective in adjusting the real interest rate over business cycles. It affects the value of bank equity, which further alters bank leverage constraints through shadow prices. Countercyclical macroprudential taxes, on the other hand, reduce the overall return on bank assets and have a stabilizing effect on asset prices. We optimize the responsiveness parameters for both policy rules and find that policymakers should assign more stabilizing tasks to monetary policy than to macroprudential policy as the former is more effective in restraining bank leverage during booms, especially in an economy with high leverage. The incremental welfare improvement achieved by introducing countercyclicality in macroprudential policy is very moderate. However, because the use of monetary policy to influence the long-run equilibrium will incur additional price adjustment costs, macroprudential policy has the advantage of obtaining the long-run level of bank equity that is desirable. Our calibration result shows that the welfare gain from the level component of macroprudential policy (equivalent to a 0.157% permanent consumption increase) is larger than that from the countercyclical component (0.025%).

Our research adds to the literature that studies the role of monetary policy in quantitative macroeconomic models with banks. The models in the literature differ in how the financial sector is modeled, the types of frictions used, and the form of macroprudential policy studied. The work by Angelini et al. (2014) is one of the earliest attempts to consider monetary and macroprudential policies simultaneously. They find that potentially large gains can be achieved by introducing a macroprudential policy when the economy is subject to financial shocks.[2] Abbate and Thaler (2019) study a DSGE model with the bank 'risk-taking' channel of monetary policy.[3] While they do not study macroprudential policies, they conclude that monetary policy should control banks' risk-taking by stabilizing the real interest rate. Leduc and Natal (2018) study the interaction between monetary and macroprudential policies in a model without bank risk-taking. They argue that without macroprudential policies, monetary policy should actively respond to financial variables, but this response should be reduced when prudential policies are available. In work by De Paoli and Paustian (2017), macroprudential policy is used to subsidize bank borrowing in the study of a strategic interaction between monetary and macroprudential authorities.[4] Gelain and Ilbas (2017) study a lump-sum tax/subsidy to banks that directly changes the amount of bank equity and find that the welfare gain from coordination between monetary and macroprudential policy depends on policymakers' preference for stabilizing output. Angeloni and Faia (2013) study monetary and macroprudential policies in a New Keynesian model in which financial intermediaries are subject to bank runs. They show that monetary policy should respond to financial variables and that introducing countercyclical bank capital requirements can improve welfare.[5]

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[2] The macroprudential authority in their model is not subject to the friction faced by private banks.

[3] In their model, the scarcity of the equity buffer does not increase the probability of bank default, but banks with less equity choose projects with lower probabilities of success.

[4] Their environment abstracts from the accumulation of physical capital.

[5] To obtain banks' overborrowing, Angeloni and Faia (2013) make a rather complex assumption that bank managers essentially minimize their own share of bank profits, and hence, a probability of bankruptcy that is too low is not good. Quantitatively, the model requires that the bank manager takes a large share of

Silvo (2019) studies a policy that sets the bank's leverage, which in turn determines the intensity of the moral hazard in the financial sector. She finds that the optimal combination of monetary and macroprudential policies depends on the type of shock experienced. Both Angeloni and Faia (2013) and Silvo (2019) focus on the optimal responses to fluctuations, but the optimal level of prudence is not analyzed. Collard et al. (2017) study a model with bank risk-taking but without a channel in which monetary policy affects the intensity. In their framework, financial stability is left to macroprudential policy.[6] Mendicino et al. (2021) study the capital requirement that enforces bounds on bank leverage. They show that the transition cost of capital requirements from the low-bound regime to the high-bound regime depletes part of the long-run welfare gain attained by such bank capital requirements. The transitional cost also depends on monetary policy coordination and bank riskiness.[7]

The rest of the paper is organized as follows. Section 2 describes our model. Section 3 shows the calibration of the benchmark model and various numerical experiments regarding monetary and macroprudential policies. Section 4 concludes the paper.

2 Model

There are six sectors in the model: households, intermediate goods producers, capital producers, banks, the central bank and the government. Households work, consume and deposit in banks. Intermediate goods producers produce output and set prices subject to price adjustment costs. They need to borrow money to finance capital, but households cannot lend directly to the production sector. Banks work as financial intermediaries: they collect deposits from households and lend to intermediate goods producers. However, the funds that banks can borrow from households are limited due to a moral hazard-based financial constraint *à* la Gertler and Karadi (2011). Financial constraints serve as a financial accelerator that amplifies the effects of shocks on the economy.

Banks acquire physical capital and rent it to the production sector. Banks' funds are composed of internal net worth and external funds (deposits) from households. Further, we assume that banks' investment in capital is subject to both aggregate shocks and idiosyncratic shocks that are specific to each bank. Bank deposits are standard debt contracts, so the return on deposits is not contingent on the realization of the idiosyncratic shock. Therefore, it is possible for some banks to default on deposits. In this case, the bankruptcy procedure incurs repossession costs. We further assume that the government provides deposit insurance to households. The central bank in the model economy sets the nominal interest rate as a monetary policy, as in Woodford (1999).

2.1 Households

A representative household has a continuum of members with mass one, where a fraction ξ of them are workers, and the remaining $1-\xi$ are bankers. Within the household, workers

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the bank profits. Using Gertler and Kiyotaki's (2010) approach to modelling the banking sector greatly simplifies this point.

[6] In their extension, which they admit to be ad hoc, both policies become countercyclical at the optima.

[7] Their environment is abstracted from aggregate shocks.

supply labor to firms to earn wages, and each banker works at a financial intermediary and receives a lump-sum dividend payment when he/she exits the banking sector. The household maximizes the following discounted sum of utilities:

$$\mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} U(C_\tau, L_\tau) = \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left[\ln(C_\tau - hC_{\tau-1}) - \eta \frac{L_\tau^{1+\varphi}}{1+\varphi} \right], \tag{1}$$

where $\mathbb{E}_t(\cdot)$ denotes the conditional expectation given the information at time t, C_t is consumption, L_t is labor hours, β is the time discount factor, h is the habit parameter for consumption, φ is the inverse Frisch labor elasticity, and η is the weight parameter of labor disutility.

The aggregate price index is denoted as P_t. At the beginning of time t, the household holds deposits (in monetary terms) D_t^n in banks (so the deposits in real terms are $D_t = D_t^n/P_t$) and receives back $R_{t+1}D_t^n$ at the end of period t, where R_{t+1} is the contractual return of the deposits from time t to $t+1$. As we will explain later, some banks may default so households may not be fully repaid for their deposits. We assume that the government provides deposit insurance to households: they cover the loss of deposits to guarantee that households receive full repayment. Therefore, the household budget constraint in real terms is given by

$$C_t + T_t + D_t = w_t L_t + \frac{R_t D_{t-1}}{\pi_t} + \Pi_t, \tag{2}$$

where T_t is the lump-sum tax that the household pays to the government (real term), w_t is the real wage, $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the inflation rate, and Π_t is the payment received from other sectors (goods producers, capital producers and banks).

In every period, the household chooses consumption, labor and deposits (C_t, L_t, D_t) to maximize (1) subject to (2). The optimality condition yields the Euler equation and labor supply function:

$$\mathbb{E}_t \left(\beta \frac{R_{t+1}}{\pi_{t+1}} \frac{U_{c,t+1}}{U_{c,t}} \right) = 1, \tag{3}$$

$$w_t U_{c,t} = \eta L_t^{\varphi}, \tag{4}$$

where $U_{c,t} \equiv \frac{1}{C_t - hC_{t-1}} - \mathbb{E}_t \left(\frac{\beta h}{C_{t+1} - hC_t} \right)$ is the marginal utility of consumption at time t.

2.2 Goods Producers

The final good is produced from a variety of differentiated intermediate goods $Y_t(i)$, $i \in [0,1]$ according to a constant-returns-to-scale technology. Thus, the final good output Y_t is

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{5}$$

where $\epsilon > 1$ is the elasticity of substitution between different goods. Intermediate good producer i uses labor and capital inputs to produce differentiated intermediate goods through a Cobb-Douglas production function:

$$Y_t(i) = A_t K_t(i)^{\alpha} L_t(i)^{1-\alpha}, \tag{6}$$

where $Y_t(i)$ is the differentiated good produced by producer i, A_t is the total factor productivity, and $K_t(i)$ and $L_t(i)$ are the physical capital and labor inputs, respectively. Each goods producer has monopolistic power, and he/she can set the prices of his/her own products, $P_t(i)$. According to (5), producer i faces a downward-sloping demand curve:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t, \tag{7}$$

and the aggregate price level P_t is given by

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}}. \tag{8}$$

These producers face a convex cost for adjusting the prices of their goods, as in Rotemberg (1982). In every period, each producer chooses physical capital, labor inputs, and price $(K_t(i), L_t(i), P_t(i))$, respectively, to maximize the expected discounted sum of profits

$$\mathbb{E}_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left[\frac{P_\tau(i)}{P_\tau} Y_\tau(i) - w_\tau L_\tau(i) - z_\tau K_\tau(i) - \frac{\vartheta}{2}\left(\frac{P_\tau(i)}{P_{\tau-1}(i)} - 1\right)^2 Y_\tau\right] \tag{9}$$

subject to the production constraint

$$A_\tau K_\tau(i)^\alpha L_\tau(i)^{1-\alpha} = \left(\frac{P_\tau(i)}{P_\tau}\right)^{-\epsilon} Y_\tau. \tag{10}$$

In the objective function (9), z_t is the real rental rate of capital, and $\vartheta > 0$ is the degree of price rigidity. The stochastic discount factor $\Lambda_{t,\tau}$ takes the form

$$\Lambda_{t,\tau} = \beta^{\tau-t} \frac{U_{c,\tau}}{U_{c,t}}. \tag{11}$$

Let m_t^C denote the Lagrange multiplier of the production constraint at period t, which can be interpreted as the cost of one extra unit of production. In a symmetric equilibrium, we have that $P_t(i) = P_t$, and the optimality condition is given by (see Appendix)

$$w_t = (1-\alpha) m_t^C A_t \left(\frac{K_t}{L_t}\right)^\alpha, \tag{12}$$

$$z_t = \alpha m_t^C A_t \left(\frac{L_t}{K_t}\right)^{1-\alpha}, \tag{13}$$

$$(\pi_t - 1)\pi_t = \frac{\epsilon}{\vartheta}\left(m_t^C - \frac{\epsilon-1}{\epsilon}\right) + \mathbb{E}_t\left[\Lambda_{t,t+1}(\pi_{t+1} - 1)\pi_{t+1}\right]. \tag{14}$$

After the log-linearization of (14), we obtain the New Keynesian Phillips curve:

$$\hat{\pi}_t = \frac{(\epsilon - 1)}{\vartheta} \hat{m}_t^C + \beta \hat{\pi}_{t+1}. \tag{15}$$

The variable with the "hat" superscript is the log-deviation from its steady-state value.

In our model, producers lack funds and must borrow from banks to buy capital. For simplicity, we assume that intermediate good producers are funded without financial friction. Banks lend funds to them in the form of perfectly state-contingent claim so that they can commit to pay the entire cash flow to the banks. Therefore, physical capital is used by intermediate producers, but it essentially belongs to the banks.

The aggregate physical capital in the economy is accumulated by

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{16}$$

where I_t is the investment in period t and δ is the capital depreciation rate. The ex post real return of holding one unit of capital from period t to $t+1$ is

$$r_{k,t+1} = \frac{z_{t+1} + (1-\delta)q_{t+1}}{q_t}, \tag{17}$$

where q_t is the price of capital in real terms.

2.3 Capital Producers

Capital producers use final output to produce capital with flow-variable adjustment costs. They transfer their profits back to households in each period because the households have ownership. The capital producers choose the investment I_t to produce capital given capital price q_t in real terms subject to the adjustment costs:

$$\max \mathbb{E}_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left\{ q_\tau I_\tau - I_\tau \left[1 + \Psi\left(\frac{I_\tau}{I_{\tau-1}}\right)\right]\right\}.$$

where the investment adjustment cost function $\Psi(\cdot)$ satisfies $\Psi(1) = 0$, $\Psi'(1) = 0$ and $\Psi''(1) > 0$. The solution shows that the marginal cost of capital production equals the price of capital q_t:

$$q_t = 1 + \Psi\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}}\Psi'\left(\frac{I_t}{I_{t-1}}\right) - \mathbb{E}_t\left[\Lambda_{t,t+1}\left(\frac{I_{t+1}}{I_t}\right)^2 \Psi'\left(\frac{I_{t+1}}{I_t}\right)\right]. \tag{18}$$

2.4 Banks

The funds flow from banks to firms to finance physical capital for next-period production via "investment projects". Consider a bank that has net worth of n_t and wants to fund s_t units of investment projects in the economy. In equilibrium, S_t, the aggregate counterpart of s_t, corresponds to K_{t+1}. These investment projects pay off after one period. The bank's funds are limited, so it needs to borrow from households by issuing nominal deposits d_t^n. The bank's balance sheet in real terms is

$$q_t s_t = d_t + n_t \tag{19}$$

where $d_t = d_t^n / P_t$ is the amount of deposits in real terms. Specifically, the banker determines the capital structure by choosing the amount of deposits d_t given net worth n_t. Equivalently, the banker chooses the leverage ratio ϕ_t, which is defined as the ratio of the total value of bank assets to net worth:

$$\phi_t = \frac{q_t s_t}{n_t}. \tag{20}$$

The nominal return on the given project is subject to a bank-specific idiosyncratic shock equaling the average return $R_{k,t+1}(\equiv r_{k,t+1}\pi_{t+1})$ multiplied by a nonnegative random variable x that follows the probability density function $f(\cdot)$, $x \in [0, +\infty)$. If the banker borrows at a high level from households and the project results in a low realized return, it is possible that the bank will be unable to repay the contractual return on the deposits. When this happens, the bank becomes insolvent, but the banker is protected by limited liabilities, so he/she can claim bankruptcy, pay whatever remains back to the households and exit the banking sector.

To describe whether default occurs or not, it is useful to first analyze the case where the aggregate return on capital $R_{k,t+1}$ is known in advance. In this case, the only uncertainty about the project's return is idiosyncratic shock. We assume that when the bank cannot fully repay the depositors, the bankruptcy procedure causes a constant fraction $c \in (0, 1)$ of total bank assets to be lost.

Let $Q_t(\equiv P_t q_t)$ be the price of project/capital in monetary terms. There are two cases, depending on the bank balance sheet structure ϕ_t, the deposit rate R_{t+1}, and the realization of return on the project $xR_{k,t+1}$.

Case A: When $xR_{k,t+1}Q_t s_t < R_{t+1}d_t^n$, the bank cannot fully repay the depositors. In this case, the bank goes bankrupt, and the banker exits with nothing because he/she is a mere residual claimant. After the bankruptcy procedure, the depositors obtain the remaining assets $(1-c)xR_{k,t+1}Q_t s_t$ from the bank. Deposits are insured by a government deposit insurance scheme, so the depositors still receive full repayment.

Case B: The realized return on the project is high enough to fully repay the depositors, i.e., $xR_{k,t+1}Q_t s_t > R_{t+1}d_t^n$. In this case, the depositors obtain $R_{t+1}d_t^n$, and the banker obtains the remaining $xR_{k,t+1}Q_t s_t - R_{t+1}d_t^n$ and keeps it within the bank as net worth.

The threshold value of the idiosyncratic shock satisfies

$$\bar{x}R_{k,t+1}Q_t s_t = R_{t+1}d_t^n. \tag{21}$$

Using the real rates $r_{k,t+1} = R_{k,t+1}/\pi_{t+1}$ and $r_{t+1} = R_{t+1}/\pi_{t+1}$ and combining them with (19) and (20), we can express such a threshold as the function of bank leverage ϕ_t and both real interest rates:

$$\bar{x}(\phi_t; r_{t+1}, r_{k,t+1}) = \frac{R_{t+1}(q_t s_t - n_t)}{R_{k,t+1}q_t s_t} = \frac{r_{t+1}}{r_{k,t+1}}\left(1 - \frac{1}{\phi_t}\right). \tag{22}$$

From the above two possible cases, a law of motion for the net worth of a bank in real terms is given by

$$n_{t+1} = \begin{cases} \frac{1}{\pi_{t+1}}(xR_{k,t+1}q_t s_t - R_{t+1}d_t^n) = [(xr_{k,t+1} - r_{t+1})\phi_t + r_{t+1}]n_t, & \text{for } x > \bar{x}(\phi_t; r_{t+1}, r_{k,t+1}) \\ 0, & \text{otherwise.} \end{cases} \tag{23}$$

At the end of each period, if the bank stays solvent ($n_{t+1} > 0$), the banker faces an exogenous probability θ of staying in the banking sector. When bankers are forced to exit the banking sector with a probability of $1-\theta$, they bring all of their net worth back to their households for consumption.

Next, we describe how banks make leverage decisions when aggregate uncertainty is present, specifically, when the firm equity return from t to $t+1$ is unknown at time t as in (17). A bank chooses its leverage ratio given the distribution of the bank asset return $r_{k,t+1}$ and the deposit rate r_{t+1} before the idiosyncratic shock is realized.

At time t, the banker's objective is to choose ϕ_t to maximize the expected discounted value at the point of its exogenous exit ("terminal value"):

$$V_t = \max_{\phi_t} \mathbb{E}_t \sum_{\tau=t+1}^{\infty} \left[\Lambda_{t,\tau}\theta^{\tau-t-1}(1-\theta)n_\tau\right]. \tag{24}$$

Following Gertler and Karadi (2011), we assume a moral hazard problem in the banking sector. After a banker collects deposits from households and before he/she invests in projects, he/she has an outside option to divert a fraction Θ of the bank assets to his/her own family. Knowing the possibility of diversion by the banker, depositors limit the funds that they lend to the bank such that the banker's benefit from diverting funds does not exceed the benefit of not diverting them:

$$V_t \geq \Theta q_t s_t = \Theta \phi_t n_t. \tag{25}$$

We can solve the optimization problem of the banker by maximizing (24) subject to (23) and (25). By using the guess-and-verify method, the closed-form solution of the bank's optimization problem is given by:

$$V_t(\phi_t, n_t) = [(\mu_{1,t} - \mu_{2,t})\phi_t + \mu_{2,t}]n_t, \tag{26}$$

where the Lagrange multipliers $\mu_{1,t}$ and $\mu_{2,t}$ in (26) are recursively defined as

$$\mu_{1,t} = \mathbb{E}_t \Lambda_{t,t+1}\Omega_{t+1}\varsigma_{1,t+1} r_{k,t+1}, \tag{27}$$

$$\mu_{2,t} = \mathbb{E}_t \Lambda_{t,t+1}\Omega_{t+1}\varsigma_{2,t+1} r_{t+1}, \tag{28}$$

$$\Omega_{t+1} = (1-\theta) + \theta[(\mu_{1,t+1} - \mu_{2,t+1})\phi_{t+1} + \mu_{2,t+1}], \tag{29}$$

$$\mathbb{E}_t\varsigma_{1,t+1} = \int_{\bar{x}(\phi_t; r_{t+1}, \mathbb{E}_t r_{k,t+1})}^{\infty} x f(x) dx, \tag{30}$$

$$\mathbb{E}_t\varsigma_{2,t+1} = \int_{\bar{x}(\phi_t; r_{t+1}, \mathbb{E}_t r_{k,t+1})}^{\infty} f(x) dx. \tag{31}$$

As defined above, Ω_{t+1} is the shadow price of the net worth tomorrow, $\mu_{1,t}$ is the bank's private value of funds lent to firms, $\mu_{2,t}$ is the bank's private cost of issuing deposits (or the private value of a unit of the bank's net worth), $\mathbb{E}_t\varsigma_{1,t+1}$ is the expected value of the bank's return on assets (conditional upon the bank being solvent), and $\mathbb{E}_t\varsigma_{2,t+1}$ is the expectation of the probability of staying solvent.[8]

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[8] In Gertler and Kiyotaki (2010), if a negative aggregate shock is very large, it can deplete the net worth

As the borrowing constraint (25) is binding, by combining (25) and (26), the optimal bank leverage ratio is given by

$$\phi_t = \frac{\mu_{2,t}}{\Theta - (\mu_{1,t} - \mu_{2,t})}. \tag{32}$$

If we consider the evolution of the aggregate bank net worth N_t, the flows of new and old bankers need to be considered. At the end of period t, new bankers enter the banking sector with a small initial amount of bank capital.[9] The aggregate bank net worth evolves as

$$N_{t+1} = \theta \varrho_{t+1} N_t + N_{y,t}, \tag{33}$$

where ϱ_{t+1} is the ex post average growth rate of the bank's net worth:

$$\varrho_{t+1} = \int_{\bar{x}(\phi_t; r_{t+1}, r_{k,t+1})}^{\infty} \frac{[(x r_{k,t+1} q_t S_t - r_{t+1} D_t]}{N_t} f(x) dx. \tag{34}$$

and $N_{y,t}$ is the initial net worth that is brought by new bankers. For simplicity, it is assumed that $N_{y,t}$ is proportional to the total value of bank assets

$$N_{y,t} = \omega q_t S_t. \tag{35}$$

2.5 Resource Constraints, Government and the Central Bank

The loss caused by bank insolvency is paid in real units. Thus, the economy's aggregate resource constraint is given by:

$$\left[1 - \frac{\vartheta}{2} (\pi_t - 1)^2\right] Y_t - \Delta_t = C_t + I_t \left[1 + \Psi\left(\frac{I_t}{I_{t-1}}\right)\right] + G_t, \tag{36}$$

where Δ_t represents the aggregate loss due to bank default

$$\Delta_t = c \int_0^{\bar{x}(\phi_t, r_{t+1}, r_{k,t+1})} x r_{k,t+1} q_t S_t f(x) dx, \tag{37}$$

and G_t is government expenditure. The government keeps its budget balanced, so the lump-sum tax levied from households is used for funding government expenditures and for insuring bank deposits:

$$T_t = G_t + \zeta_t D_t, \tag{38}$$

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of a bank, and bankruptcy becomes a possible event. The closed-form solution for a banker implicitly excludes such nonlinearity by allowing the net worth to become negative in such extreme circumstances. This assumption lowers the banks' value and hence their leverage in the computed equilibrium, which may be a reason why the influence of bank leverage is relatively modest in our results. Investigating how much larger the acceleration effect would be if we did not utilize Gertler and Kiyotaki's simplification is left to future research.

[9] Some bankers become workers after bank failure. Additionally, another small fraction of bankers is forced to exit the banking sector at the end of each period. Some workers in turn become bankers with some start-up net worth to ensure that the proportions of workers and bankers remain constant over time.

where ζ_t is the household loss per unit of deposits.

To close the model, a monetary policy needs to be specified. In our baseline model, the central bank conducts a monetary policy with the following Taylor-type rule:

$$\ln\left(\frac{R_{t+1}}{\bar{R}}\right) = b_\pi \ln\left(\frac{\pi_t}{\bar{\pi}}\right) + b_Y \ln\left(\frac{Y_t}{\bar{Y}}\right), \tag{39}$$

where b_π and b_Y are responsiveness policy parameters, and the notations with bars are their steady-state values.

2.6 Macroprudential Policy

This section explains how we introduce a macroprudential policy (MPP) into the baseline model. We assume that the macroprudential authority regulates (or promotes) banks obtaining external finance from households. Specifically, it levies a tax $\tau_t > 0$ (or provides subsidies when $\tau_t < 0$) per unit of bank asset and transfers the tax revenue to the households in a lump-sum fashion.[10] Under this policy, the bank balance sheet becomes the following:

$$(1+\tau_t)q_t s_t = d_t + n_t. \tag{40}$$

The MPP rule establishes how the tax rate is determined. With the policy, the banker's value function and his/her optimal leverage decision are modified to

$$V_t(\phi_t, n_t) = [(\mu_{1,t} - (1+\tau_t)\mu_{2,t})\phi_t + \mu_{2,t}]n_t, \tag{41}$$

$$\phi_t = \frac{\mu_{2,t}}{\Theta - (\mu_{1,t} - (1+\tau_t)\mu_{2,t})}, \tag{42}$$

and the expressions of the Lagrange multipliers and the bank net worth accumulation function are also modified accordingly. A positive tax $\tau_t > 0$ lowers both the bank's profitability and the shadow value of bank assets in excess of the deposits, inducing bankers to decrease their leverage. Providing a subsidy has the opposite effect.

3 Results

This section shows the numerical results of our model. In Section 3.1, we explain how our baseline model is calibrated. In Section 3.2, we report the steady-state properties of the model. We show that the steady-state bank leverage in the decentralized equilibrium is higher than that in the second-best outcome and that introducing a macroprudential policy can increase steady-state welfare. In Section 3.3, we analyze monetary policy without a macroprudential policy. Our results show that when there is financial acceleration, solely stabilizing prices is no longer optimal. This is true even when (i) investment adjustment costs

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[10] Alternatively, we can assume that the tax revenue is transferred to banks at the end of each period. In this case, the lump-sum transfer enhances the bank's internal financial conditions, reducing the cost of external finance and therefore the risk premium. Other than that, the results are very similar. Equivalently, one can also assume a macroprudential authority who makes leverage decisions directly for banks subject to the same constraints as banks in the decentralized economy.

Table 1: Parameter values

Hosueholds:		
β	time discount factor	0.99
h	habit parameter	0.8
η	utility weight of labor	10.5
φ	inverse Frisch labor elasticity	1
Producers:		
α	capital share	1/3
δ	physical capital depreciation rate	0.025
Φ	investment adjustment cost parameter	1
Retailers:		
ϵ	elasticity of substitution	6
ϑ	price adjustment cost	30
Banks:		
c	cost of bankruptcy	0.2
θ	exogenous survival rate of banks	0.965
ω	the fraction of initial net worth of new bankers	0.0004
Θ	the fraction of diversion by bank manager	0.265
σ_x	dispersion of corporate return	0.0378
Central bank:		
$\bar{G}/\bar{Y}$	the ratio of government expenditure to GDP	0.2
b_π	inflation coefficient of the Taylor rule	1.5
b_Y	output gap coefficient of the Taylor rule	0.2

are absent; (ii) a wage subsidy to workers is used to eliminate the steady-state monopolistic competition distortion; and (iii) when the steady-state distortion of bank overborrowing is offset by a time-invariant macroprudential policy. A Taylor rule-type monetary policy that sets the nominal interest rate in response to both inflation and output, helps to reduce the inefficiencies caused by financial acceleration.

In Section 3.4, we introduce a time-varying macroprudential policy and analyze how it alters monetary policy prescription. We find that macroprudential policy and "macroprudential-flavored" monetary policy are close substitutes for mitigating financial acceleration. That is, when monetary policy focuses on stabilizing prices, a countercyclical macroprudential policy can significantly improve welfare. However, these two policies work through different channels. In the jointly optimized monetary and macroprudential policy rules, the central bank should assign more macroprudential tasks to monetary policy. The introduction of countercyclicality in a macroprudential rule achieves only moderate welfare improvement. It is better for macroprudential policy to focus on targeting the optimal *level* of the bank capital ratio.

3.1 Calibrations

The parameter values are summarized in Table 1. Most parameters are standard values from the literature. We assume an inflation rate of zero at the steady state: $\bar{\pi} = 1$. The time discount factor is set to $\beta = 0.99$, so the steady-state annual deposit rate is 4%. The habit parameter $h = 0.8$ and the inverse Frisch labor elasticity $\varphi = 1$ are standard.

Table 2: Steady-state values

Variables		Baseline model		Tighter leverage constraints	
		without MPP	MPP	without MPP	MPP
Return on capital (%)	$r_{k,t+1}$	1.24%	1.27%	1.25%	1.28%
Deposit return (%)	r_t	1.01%	1.01%	1.01%	1.01%
Bank leverage ratio	ϕ_t	10	8.932	9.524	8.899
Bank default probability (%)	$1 - \varsigma_{2,t}$	0.23%	0.07%	0.14%	0.07%
Capital	K_t	6.072	5.970	6.027	5.967
Net worth	N_t	0.607	0.668	0.633	0.670
Labor	L_t	0.3	0.2991	0.2995	0.2990
Output	Y_t	0.818	0.811	0.815	0.811
Consumption	C_t	0.4997	0.4990	0.4995	0.4990
Default loss	Δ_t	0.0025	0.0007	0.0015	0.0007
Bank asset tax	$\bar{\tau}$	0	0.00024	0	0.0011
Utility	U	-2.7758	-2.7742	-2.7747	-2.7742

The weight parameter of labor disutility is $\eta = 10.5$ so that the steady-state labor supply is 0.3. The elasticity of substitution between different intermediate goods is $\epsilon = 6$, and the price adjustment cost parameter is $\vartheta = 30$ so that it corresponds to the frequency of price adjustments in Calvo's (1983) setting. For the production sector, the capital share is $\alpha = 1/3$ and the physical capital depreciation rate is $\delta = 0.025$. The elasticity of the asset price to investment is $\Phi = 1$ so that the steady-state real asset price is normalized to unity. The parameters of the baseline monetary policy rule are set to $(b_\pi, b_Y) = (1.5, 0.2)$, which are common values from Taylor (1993) and Woodford (2003). The steady-state ratio of government expenditure to aggregate output is $\bar{G}/\bar{Y} = 0.2$.

For the parameters of the banking sector, we assume that the density function of bank idiosyncratic shock is log-normal with $\mu_x = 1$ and $\sigma_x = 0.0378$. The standard deviation σ_x is chosen to obtain a quarterly probability of bank default equal to 0.23% according to the data from the FFIEC and FDIC from 1984 to 2017. We choose the fraction of banker diversion $\Theta = 0.265$, the innitial net worth ratio of new bankers $\omega = 0.0004$, and the exogenous survival rate $\theta = 0.965$ to achieve the following three targets: (i) the steady-state leverage ratio is $\bar{\phi} = 10$ so that the average bank capital ratio is 10%; (ii) the annual credit spread is approximately 100 basis points; and (iii) banks survive for more than 7 years on average. The recovery rates of US banks are between 10% and 30% in James (1991), so we choose an intermediate value $c = 0.2$.

We consider one type of exogenous shock: a total factor productivity (TFP) shock. TFP shocks follow a first-order autoregressive process: $\ln \frac{A_t}{\bar{A}} = \rho_A \ln \frac{A_{t-1}}{\bar{A}} + \varepsilon_t^A$, where ε_t^A is i.i.d. with $\sigma_A = 0.0068$ and $\rho_A = 0.96$, as reported in Fernald (2014).

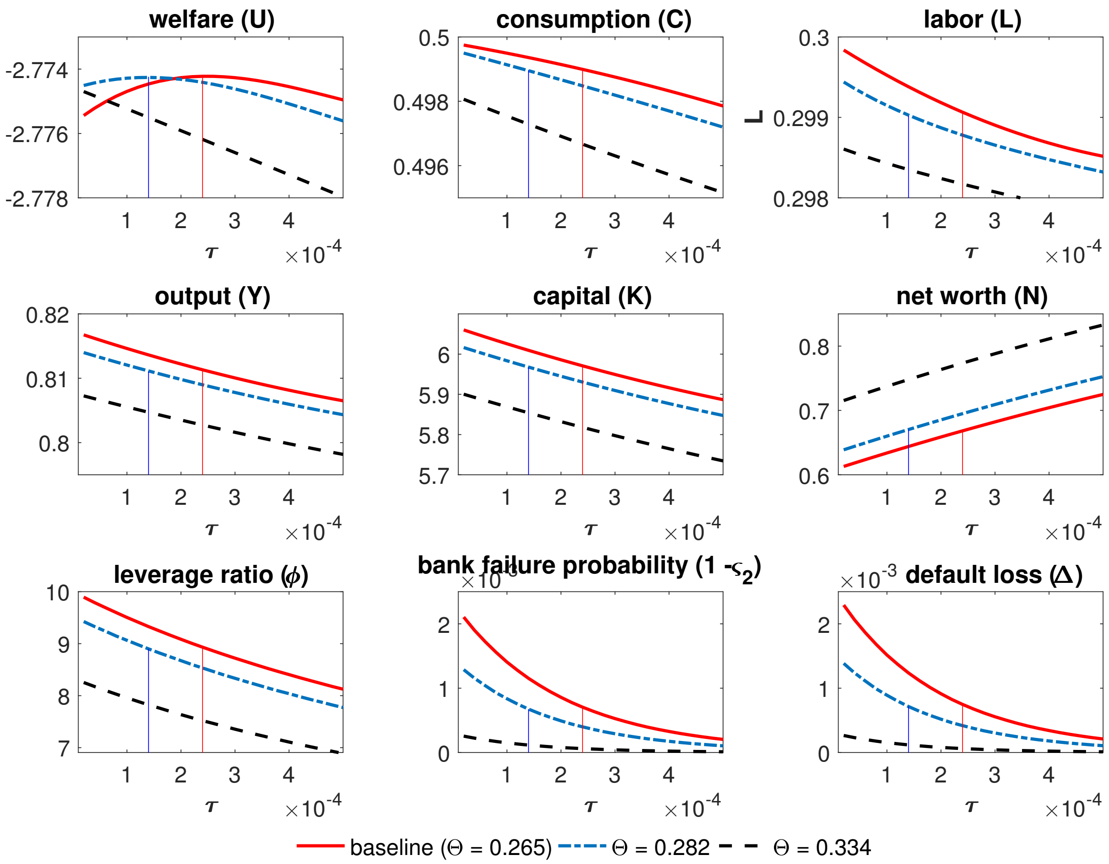

Figure 1: Long-run effect of macroprudential policy

This figure shows the steady-state household utility (U), consumption (C), labor (L), and other key variables at different levels of the bank asset tax rate $\bar{\tau}$.

3.2 Steady-State Welfare

We first examine the steady-state properties under the benchmark calibration. In the literature on financial accelerators, the existence of financial friction restricts the ability of borrowers to obtain funds. Consequently, the decentralized economy exhibits "underborrowing" in steady states compared with a frictionless economy. Nonetheless, the decentralized equilibrium achieves the second-best outcome in steady states. In contrast, introducing the possibility of bank default and the resulting costs generates negative externalities on the aggregate resources, which are exacerbated (i) when banks rely heavily on external finance and (ii) when banks have limited liability. Bank net worth plays a key role here because limited net worth implies potentially higher leverage.

Is the steady-state bank leverage optimal in the decentralized equilibrium of such a model? To answer this question, we solve for the steady states of the model with different levels of macroprudential tax $\bar{\tau}$. Figure 1 shows the steady-state levels of household lifetime utility, consumption, hours worked, and some other key variables under different levels of

Table 3: Welfare gain from a steady-state tax on bank assets

	Baseline ($\Theta = 0.265$)	$\Theta = 0.282$	$\Theta = 0.334$
Optimal steady-state tax rate ($\bar{\tau}$)	0.00024	0.00014	−0.00014
Optimal bank capital ratio ($\bar{\Gamma}$) (%)	11.2	11.2	11.2
Consumption equivalent ($\bar{\gamma}$) (%)	0.157	0.045	0.067

$\bar{\tau}$. By (42), a higher level of $\bar{\tau}$ lowers banks' profitability when investing in firm equity and tightens their financial constraints, which decreases the bank leverage ratio. This reduces the funds that banks lend to firms, so the steady-state capital and other real variables (e.g., the output, investment, consumption, and labor supply) are lower. Second, the ratio of bank net worth to the total value of bank assets (or "capital ratio", defined as $\Gamma_t = 1/\phi_t$) increases. The probability of bank failure $(1 - \bar{\varsigma}_1)$ and the corresponding default loss ($\bar{\Delta}$) are lower. The lower level of $\bar{\Delta}$ alleviates the decreases in consumption and investment.

The top-left panel of Figure 1 shows the steady-state household utility versus $\bar{\tau}$ (red line under the baseline calibration). The curve is hump-shaped, and the maximal steady-state household utility is achieved when the tax rate is set to $\bar{\tau} = 0.00024$. In that case, the bank capital ratio is raised from 10% to 11.2%. In terms of the consumption equivalent $\bar{\gamma}$, raising the bank capital ratio to 11.2% achieves a welfare gain of 0.157% (see the first column of Table 3). When $\bar{\tau}$ is raised from a low level, the positive effect of a lower $\bar{L}$ on the steady-state household utility surpasses the negative effect of a lower $\bar{C}$. By contrast, when $\bar{\tau}$ is already large, the benefit of the macroprudential policy in reducing bank default loss is smaller than the negative impact of restraining investment and production.

Bank financial constraints play a crucial role. From (42), a larger Θ tightens the incentive compatibility constraint for bankers, and households lend less funds to banks. As a result, the leverage is lower than that in the baseline model. To illustrate the role of financial frictions, we consider two other scenarios in which banks face tighter financial constraints: $\Theta = 0.282$ and $\Theta = 0.334$. The steady-state leverage is reduced to 9.524 and 8.333, respectively.

Three aspects are worth noting. First, when the financial constraint is tighter, the optimal macroprudential tax is smaller than that in the baseline model ($\bar{\tau} = 0.00014$), and the welfare improvement is smaller ($\bar{\gamma} = 0.045\%$). Second, when Θ is above a certain level, introducing macroprudential policy to decrease bank leverage lowers steady-state welfare because bank leverage is already low. In fact, in this case, subsidizing bank assets ($\bar{\tau} < 0$) improves welfare. Third, we find that in any case, the optimal bank capital ratio is close to that under the baseline calibration (11.2%). At this point, the benefit of reducing bank default and the cost of limiting firm investment coincide.

3.3 Monetary Policy

For the remainder of this section, we analyze the dynamic properties of our model. This subsection investigates the welfare implications of monetary policy when macroprudential policy is absent. Figure 2 shows the impulse responses of key variables to a one-standard-

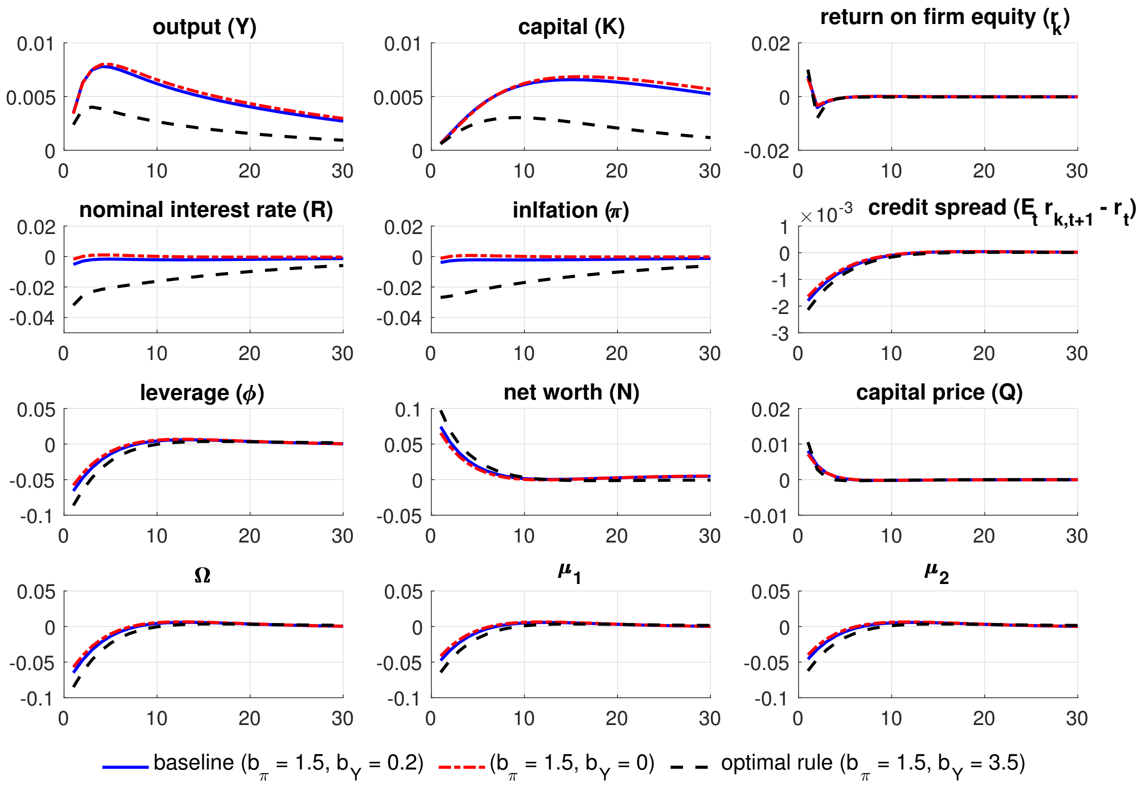

Figure 2: Impulse responses without macroprudential policy

This figure shows the impulse responses to a one-standard-deviation TFP increase. This figure compares the baseline model with two other monetary policy stances: when responding only to inflation ($b_\pi = 1.5, b_Y = 0$) and when choosing the optimized rule ($b_\pi = 1.5, b_Y = 3.5$).

deviation increase in productivity (i) under the baseline model ($b_\pi = 1.5, b_Y = 0.2$); (ii) when the nominal rate responds only to inflation ($b_\pi = 1.5, b_Y = 0$); and (iii) when the responsiveness parameters are chosen to maximize the representative household's utility ($b_\pi = 1.5, b_Y = 3.5$).[11]

By comparing the three different monetary stances, one can see that the nominal rate responding actively to output reduces the variance in the output but increases the variance in inflation. Such a result also holds in canonical New Keynesian models (see Galí, 2015). The welfare implications in our model are, however, different from those in the canonical models. In the canonical New Keynesian models, nominal rigidity is the only distortion if the inefficiency caused by monopolistic competition is eliminated by a wage subsidy to workers. In this case, the optimal monetary policy would naturally be "perfect price stabilization", and stabilizing output would be undesirable. Our model, however, has two kinds of distortions,

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[11] We use a second-order approximation of the model to evaluate the performances of different monetary policy (and potentially, macroprudential policy) stances, as in Schmitt-Grohé and Uribe (2007). For policy implementation, our study focuses on simple rules that are functions of observables only. The results of the Ramsey-optimal commitment monetary policy and the jointly optimal monetary and macroprudential policies are available upon request.

nominal rigidity and financial frictions, and the latter amplifies the effect of TFP shocks compared to that in the economy without financial frictions. In this case, a trade-off emerges between stabilizing inflation and output. The variance in the output can be reduced by making the nominal rate (the bank's borrowing rate) respond to additional variables such as the output itself, but such a policy improves welfare at the cost of increasing the variance in inflation. This is true especially when the calibrated economy has high leverage and large financial acceleration.

The above recommendation that monetary policy be used to curb inefficient responses is similar to the findings of Leduc and Natal (2018). They consider a Bernanke-Gertler-Gilchrist type model and demonstrate that monetary policy prescription in their framework depends crucially on two settings: investment adjustment costs and steady-state distortion due to monopolistic competition. In other words, if they either (i) remove investment adjustment costs or (ii) eliminate steady-state distortion by using a wage subsidy, the optimal monetary policy becomes close to perfect price stabilization. Different from their results, the monetary policy prescription in our model is not affected by these changes, as we will see below.

First, we set the adjustment cost function to $\Psi(\cdot) = 0$ and mute the procyclicality of asset prices. We find that the welfare gain from monetary policy reacting to output ($b_\pi = 2, b_Y = 8$) is still substantial. This is because in our model, there are two channels of financial propagation. The first channel is through procyclical asset prices: an increase in asset prices raises the return on bank assets and increases net worth, allowing banks to obtain more funds to finance physical capital purchases. This channel is also present in Leduc and Natal (2018). The second channel is through bank shadow values and leverage, which is a feature of Gertler-Kiyotaki (2010) type bank financial constraints. By setting the nominal rate in response to the output, the policy further reduces the credit spread $\mathbb{E}_t r_{k,t+1} - r_{t+1}$ when the economy is in a boom. The reduction in future bank profitability lowers the shadow values of the net worth and bank assets Ω_t, $\mu_{1,t}$, and $\mu_{2,t}$. By (42), the banks' ability to obtain funds per unit of net worth is limited. Through this channel, responding further to output can reduce leverage and dampen the positive responses of investment. This shadow value channel is absent in Leduc and Natal (2018), as bank leverage in their model is mainly determined by bank reserve requirements.

Next, we conduct two exercises to examine the effect of steady-state distortions. We follow Leduc and Natal (2018) and introduce a positive wage subsidy to eliminate the steady-state distortion of monopolistic competition. The results show that the optimized responsiveness parameter based on output is slightly smaller than that under the baseline model ($b_\pi = 1.5, b_Y = 2.8$) but still positive. This implies that perfect price stabilization remains suboptimal when such steady-state distortion is eliminated. Second, we use the optimal time-invariant macroprudential tax found in Section 3.2 ($\bar{\tau} = 0.00024$) to eliminate the steady-state distortion induced by bank overborrowing. In this case, the optimized monetary policy responsiveness parameters ($b_\pi = 1.5, b_Y = 3.25$) are close to those under the baseline model. These results imply that the difference between the natural and optimal responses of the output to shocks is time-varying even if the steady-state distortion is eliminated. Such a result is different from those in Faia and Monacelli (2007) and Leduc and Natal (2018), who find that a perfect price-stabilizing policy is close to optimal if steady-state monopolistic competition distortion is eliminated. This is because the financial acceleration in our model is partially driven by the bank shadow value channel. Even if the steady-state distortion

Table 4: Monetary policy (without time-varying macroprudential policy)

	Baseline model			No capital adj. costs	Optimal ss. MPP
	Benchmark	PPS	Optimized rule	Optimized rule	Optimized rule
(b_π, b_Y)	$(1.5, 0.2)$	N.A.	$(1.5, 3.5)^*$	$(2, 8)^*$	$(1.5, 3.25)^*$
Std. of inflation	0.0121	0	0.0868	0.0828	0.0809
Std. of output	0.0300	0.0359	0.0132	0.0108	0.0133
CE ($\bar{\gamma}$) (%)	0	-0.0240	0.0204	0.0261	0.181

Note: The first three columns show the results obtained under the baseline model. The second column represents the scenario where prices are perfectly stabilized, and the third column gives the results when the Taylor rule parameters are chosen optimally. The fourth column contains the results for the optimized interest rate rule without capital adjustment costs. The last column shows the optimized rule when the steady-state distortion is eliminated by a macroprudential tax. Policy coefficients with asterisks are optimized values.

is removed, there is still room for the application of monetary policy. The deviation from perfect price stabilization in our model provides a theoretical case for Taylor's (1993) rule.[12]

3.4 Time-Varying Macroprudential Policy

This section investigates how time-varying macroprudential policy (MPP) affects the fluctuation component of welfare and how it relates to monetary policy. We first analyze the welfare performance of our MPP rule under the baseline monetary policy and under a monetary policy that is chosen optimally in the presence of a time-invariant MPP. Next, we find the jointly optimized monetary and macroprudential policy parameters.

The MPP rule we consider takes the following form:

$$\ln \tau_t - \ln \bar{\tau} = \tau_0(\ln Q_t - \ln \bar{Q}), \tag{43}$$

where $\bar{\tau}$ is the average tax rate, and $\tau_0 > 0$ is the responsiveness to the percentage change in the capital price. Under this policy, when a favorable shock hits the economy and the asset price Q_t increases, the macroprudential tax induces banks to cut leverage and curb their expansion of lending, so the policy has a flavor of countercyclical capital requirements. We use the optimal steady-state tax rate $\bar{\tau} = 0.00024$ from Section 3.2 and investigate how the time-varying component of (43) affects welfare.

We first investigate the effect of the above MPP rule under the baseline monetary policy. Figure 3 shows the impulse responses to a positive TFP shock under a constant MPP ($\tau_0 = 0$) and a countercyclical policy in which τ_0 is chosen optimally ($\tau_0^* = 5.8$). The asset price Q_t is more stabilized under the countercyclical policy. By (17), the return on capital $r_{k,t}$ is stabilized. Through the stabilization of the bank shadow values Ω_t, $\mu_{1,t}$, and $\mu_{2,t}$ (Eqs. (27)-(29)), both bank leverage and net worth are stabilized. This process reduces inefficient

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[12] Bernanke and Gertler (1999, 2001) argue that monetary policy should focus on stabilizing inflation. De Fiore et al. (2011) claim that the optimal reaction to technological shocks is complete inflation stabilization. Fiore and Tristani (2013) and Andrés et al. (2013), by contrast, support the deviation of monetary policy from perfect price stabilization. Our paper complements the latter group.

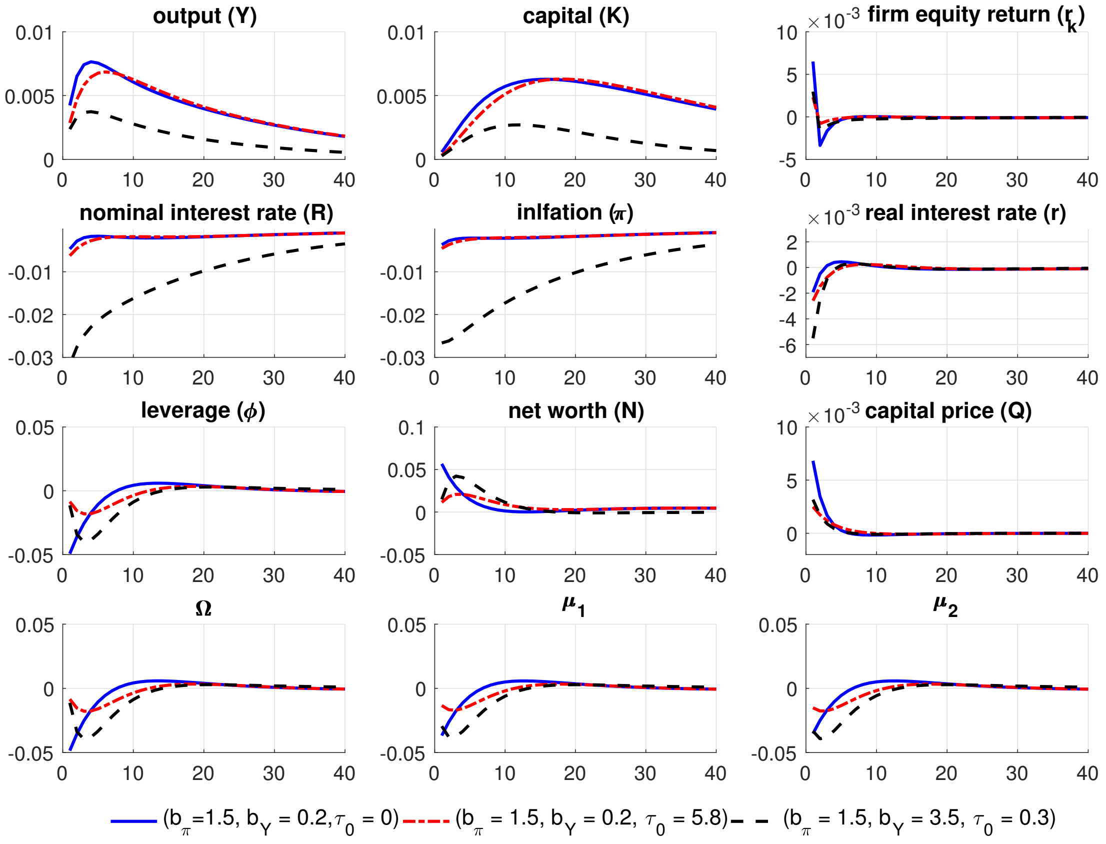

Figure 3: Impulse responses with macroprudential policy

This figure shows the impulse responses to a one-standard-deviation TFP increase: constant MPP with the baseline monetary policy ($b_\pi = 1.5, b_Y = 0.2, \tau_0 = 0$), countercyclical MPP with the baseline monetary policy ($b_\pi = 1.5, b_Y = 0.2, \tau_0 = 5.8$), and countercyclical MPP with the optimized monetary rule ($b_\pi = 1.5, b_Y = 3.5, \tau_0 = 0.3$). $\bar{\tau}$ is set to 0.00024.

fluctuations in the output and physical capital. Table 5 shows the welfare improvement in terms of the consumption equivalent when the countercyclical MPP rule is introduced ($\bar{\gamma} = 0.162\%$). The welfare improvement is slightly larger than that obtained with the constant tax ($\bar{\gamma} = 0.157\%$).

Next, we evaluate the performance of the MPP when the monetary policy rule is set to deal with financial acceleration ($b_\pi = 1.5, b_Y = 3.5$) (we call the monetary policy that reacts to output "macroprudential" monetary policy). In this case, the optimal MPP rule is less countercyclical ($\tau_0 = 0.3$). Although introducing a countercyclical MPP improves welfare, the improvement is now much smaller than that under the baseline monetary policy. This implies that monetary and macroprudential policies are substitutes when aiming to stabilize the inefficient responses that originate from financial frictions. However, the channels through which the two policies work are slightly different. To visualize this, we also plot the responses in the case where macroprudential monetary policy is combined with an MPP that is less countercyclical ($b_\pi = 1.5, b_Y = 3.5$, and $\tau_0 = 0.3$) in Figure 3. One can see that this

Table 5: Welfare under different monetary and macroprudential policy rules

	Baseline monetary rule		Optimized monetary rule		Joint optimal
MPP tax	Constant	Optimized	Constant	Optimized	
(b_π, b_Y)	$(1.5, 0.2)$	$(1.5, 0.2)$	$(1.5, 3.5)$	$(1.5, 3.5)$	$(1.5, 2.75)^*$
τ_0	0	5.8*	0	0.3*	0.4*
CE (γ) (%)	0.157	0.162	0.1816	0.1817	0.1819

Note: the policy parameters with asterisks are optimized values.

combination has a better stabilizing effect on the real variables. Monetary policy is effective in reducing leverage because the way the central bank sets the nominal rate directly affects the real rate. By responding to output, monetary policy further reduces the real rate and the shadow values of the bank deposits and net worth ($\mu_{2,t}$). In contrast, countercyclical MPP is more effective in stabilizing asset prices Q_t and the return on assets $r_{k,t}$. Its overall effect on bank leverage is smaller than that of macroprudential monetary policy.

Finally, we find the jointly optimized parameters for both policies: $b_\pi = 1.5$, $b_Y = 2.75$, and $\tau_0 = 0.4$ (the last column of Table 5). The achieved welfare gain is 0.1819% in terms of the consumption equivalent. Again, the incremental improvement compared with that from the combination of a constant MPP and an optimized monetary policy is small.

In our framework, monetary policy, which affects the cost of finance directly, is more effective in treating inefficiently large fluctuations. In addition, because the economy has high leverage at the steady state, so for macroprudential policy, it is more important to correctly set the level of bank equity to reduce the inefficiency caused by bank default.

4 Concluding Remarks

This paper studies the long-run effect of macroprudential policy, as well as its short-run interaction with monetary policy, in a DSGE model with risky banks. In the long run, a macroprudential policy that regulates bank leverage should balance the benefit of reducing the bank default risk and the cost induced by a reduction in investment. Our calibrated model implies that such a policy improves welfare when the economy has high bank leverage.

Our results also highlight the influence of the borrowing constraints faced by financial intermediaries (Gertler and Kiyotaki, 2010) on monetary and macroprudential policy prescriptions. Financial acceleration induced by the endogenous leverage constraints of banks amplifies the deviations of real variables from their efficient paths. Such amplification is large when the economy has high leverage, and it leaves room for "macroprudential" monetary policy and countercyclical macroprudential policy. These two policies affect bank lending through different channels. By setting the nominal interest rate in response to output, monetary policy can reduce bank leverage by lowering the shadow values of bank net worth and limiting banks' abilities to borrow. Countercyclical macroprudential taxes on bank assets, on the other hand, reduce bank asset returns and therefore stabilize the procyclicality of asset prices. As a result, both policies are effective in mitigating financial propagation. The joint optimization of policy rules suggests that cyclical macroprudential tasks should be assigned more to monetary policy. Macroprudential policy, on the other hand, should focus on the level of prudence and target the optimal long-run bank equity ratio.

Our normative implications crucially hinge on the way financial intermediaries and financial constraints are modeled. We employ the financial constraints of Gertler and Kiyotaki (2010), so the financial intermediaries amplify the effects of aggregate shocks through their net worth. Although the total bank assets are amplified overall compared to those in the frictionless economy, the model lacks a clear mechanism by which the level of bank risk taking increases in boom periods (e.g., with positive TFP shocks). One way to obtain such a mechanism would be to introduce some agency problems into the banking sector. We intend to explore this topic in future research.[13]

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[13] Liu (2021) introduces a manager-shareholder agency problem to a banking model, where banks make endogenous dividend policy decisions to capture the cyclical properties of bank equity and leverage in US data.

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A Appendix

A.1 The system of equations

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}, \tag{44}$$

$$\left[1 - \frac{\vartheta}{2}\left(\pi_t - 1\right)^2\right] Y_t - \Delta_t = C_t + I_t \left[1 + \Psi\left(\frac{I_t}{I_{t-1}}\right)\right] + G_t, \tag{45}$$

$$\Delta_t = c \int_0^{\bar{x}(\phi_t, r_{t+1}, r_{k,t+1})} x r_{k,t+1} q_t K_t f(x) dx, \tag{46}$$

$$K_{t+1} = (1-\delta) K_t + I_t, \tag{47}$$

$$\mathbb{E}_t\left(\beta \frac{R_{t+1}}{\pi_{t+1}} \frac{U_{c,t+1}}{U_{c,t}}\right) = 1, \tag{48}$$

$$w_t U_{c,t} = \eta L_t^{\varphi}, \tag{49}$$

$$U_{c,t} = \frac{1}{C_t - hC_{t-1}} - \mathbb{E}_t\left(\frac{\beta h}{C_{t+1} - hC_t}\right), \tag{50}$$

$$\Lambda_{t,t+1} = \beta \frac{U_{c,t+1}}{U_{c,t}}. \tag{51}$$

$$r_{k,t+1} = \frac{z_{t+1} + (1-\delta) q_{t+1}}{q_t}, \tag{52}$$

$$w_t = (1-\alpha) m_t^C A_t \left(\frac{K_t}{L_t}\right)^{\alpha}, \tag{53}$$

$$z_t = \alpha m_t^C A_t \left(\frac{L_t}{K_t}\right)^{1-\alpha}, \tag{54}$$

$$(\pi_t - 1)\pi_t = \frac{\epsilon}{\vartheta}\left(m_t^C - \frac{\epsilon - 1}{\epsilon}\right) + \mathbb{E}_t\left[\Lambda_{t,t+1}(\pi_{t+1} - 1)\pi_{t+1}\right], \tag{55}$$

$$(1+\tau_t) q_t K_t = D_t + N_t, \tag{56}$$

$$\bar{x}(\phi_t; r_{t+1}, r_{k,t+1}) = \frac{r_{t+1}}{r_{k,t+1}}\left(1 - \frac{1}{\phi_t}\right), \tag{57}$$

$$\phi_t N_t = Q_t K_t, \tag{58}$$

$$\phi_t = \frac{\mu_{2,t}}{\Theta - (\mu_{1,t} - (1+\tau_t)\mu_{2,t})}, \tag{59}$$

$$\mu_{1,t} = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \varsigma_{1,t+1} r_{k,t+1}, \tag{60}$$

$$\mu_{2,t} = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \varsigma_{2,t+1} r_{t+1}, \tag{61}$$

$$\Omega_{t+1} = (1-\theta) + \theta[(\mu_{1,t+1} - (1+\tau_{t+1})\mu_{2,t+1})\phi_{t+1} + \mu_{2,t+1}], \tag{62}$$

$$\mathbb{E}_t \varsigma_{1,t+1} = \int_{\bar{x}(\phi_t; r_{t+1}, \mathbb{E}_t r_{k,t+1})}^{\infty} x f(x) dx, \tag{63}$$

$$\mathbb{E}_t \varsigma_{2,t+1} = \int_{\bar{x}(\phi_t; r_{t+1}, \mathbb{E}_t r_{k,t+1})}^{\infty} f(x) dx, \tag{64}$$

$$N_t = \theta \varrho_t N_{t-1} + N_{y,t}, \tag{65}$$

$$\varrho_t = \int_{\bar{x}(\phi_{t-1}; r_t, r_{k,t})}^{\infty} \frac{[(x r_{k,t} q_{t-1} K_{t-1} - r_t D_{t-1}]}{N_{t-1}} f(x) dx, \tag{66}$$

$$N_{y,t} = \omega q_t K_t. \tag{67}$$

$$\ln\left(\frac{R_{t+1}}{\bar{R}}\right) = b_\pi \ln\left(\frac{\pi_t}{\bar{\pi}}\right) + b_Y \ln\left(\frac{Y_t}{\bar{Y}}\right), \tag{68}$$

$$r_{t+1} = \frac{R_{t+1}}{\mathbb{E}_t \pi_{t+1}}, \tag{69}$$

$$\pi_t = \frac{P_t}{P_{t-1}}, \tag{70}$$

$$q_t = \frac{Q_t}{P_t}, \tag{71}$$

$$\ln \tau_t - \ln \bar{\tau} = \tau_0 (\ln Q_t - \ln \bar{Q}). \tag{72}$$

A.2 The optimization problem of bankers: guess-and-verify method

At time t, given bank net worth n_t, the banker's problem is to choose bank leverage ratio ϕ_t to maximize the following objective:

$$V_t = \max_{\phi_t} \mathbb{E}_t \sum_{\tau=t+1}^{\infty} \left[\Lambda_{t,\tau} \theta^{\tau-t-1} (1-\theta) n_\tau \right], \tag{73}$$

The Bellman equation of the banker's problem is given by

$$V_t = \mathbb{E}_t \Lambda_{t,t+1} \left[(1-\theta) n_{t+1} + \theta V_{t+1} \right], \tag{74}$$

and a low of motion of bank net worth is

$$n_{t+1} = \begin{cases} \frac{1}{\pi_{t+1}} (x R_{k,t+1} q_t s_t - R_{t+1} d_t^n) = [(x r_{k,t+1} - r_{t+1}) \phi_t + r_{t+1}] n_t, & \text{for } x > \bar{x}(\phi_t; r_{t+1}, r_{k,t+1}) \\ 0, & \text{otherwise.} \end{cases} \tag{75}$$

Substituting (75) into (73) to replace n_τ with $n_{\tau-1}$, we have

$$V_t = \max_{\phi_t} \mathbb{E}_t \sum_{\tau=t+1}^{\infty} \left[\Lambda_{t,\tau} \theta^{\tau-t-1} (1-\theta) \left(\int_{\bar{x}(\phi_{\tau-1}; r_\tau, r_{k,\tau})}^{\infty} [(x r_{k,\tau} - r_\tau) \phi_{\tau-1} + r_\tau] f(x) dx \right) n_{\tau-1} \right]. \tag{76}$$

If we use the notations of $\varsigma_{1,t}$ and $\varsigma_{2,t}$ in (30)-(31), The objective function becomes

$$V_t = \max_{\phi_t} \mathbb{E}_t \sum_{\tau=t+1}^{\infty} \left\{ \Lambda_{t,\tau} \theta^{\tau-t-1} (1-\theta) \left[(\varsigma_{1,\tau} r_{k,\tau} - \varsigma_{2,\tau} r_\tau) \phi_{\tau-1} + \varsigma_{2,\tau} r_\tau \right] n_{\tau-1} \right\}. \tag{77}$$

The guess solution takes the following form

$$V_t(\phi_t, n_t) = [(\mu_{1,t} - \mu_{2,t})\phi_t + \mu_{2,t}]n_t, \tag{78}$$

where the Lagrange multipliers in the above expression (78) is consistent with (27)-(29). Now we need to verify that the solution satisfy the Bellman equation (74) for all t. Substituting (78) into (74), the right-hand side of the Bellman equation is

$$RHS = \mathbb{E}_t\Lambda_{t,t+1}\left\{(1-\theta)n_{t+1} + \theta[(\mu_{1,t+1} - \mu_{2,t+1})\phi_{t+1} + \mu_{2,t+1}]n_{t+1}\right\} = \mathbb{E}_t(\Lambda_{t,t+1}\Omega_{t+1}n_{t+1}). \tag{79}$$

The second equality holds because of the definition of Ω_{t+1} in (29). Substituting the expression of the Lagrange Multipliers (27)-(29) into the guess solution (78), we have

$$\begin{aligned} V_t &= \mathbb{E}_t[(\varsigma_{1,t+1}\Lambda_{t,t+1}\Omega_{t+1}r_{k,t+1} - \varsigma_{2,t+1}\Lambda_{t,t+1}\Omega_{t+1}r_{t+1})\phi_t + \varsigma_{2,t+1}\Lambda_{t,t+1}\Omega_{t+1}r_{t+1}]n_t \quad (80) \\ &= \mathbb{E}_t\{\Lambda_{t,t+1}\Omega_{t+1}[(\varsigma_{1,t+1}r_{k,t+1} - \varsigma_{2,t+1}r_{t+1})\phi_t + \varsigma_{2,t+1}r_{t+1}]n_t\} \quad (81) \end{aligned}$$

According to the bank net worth accumulation function (75), the expected bank net worth n_{t+1} at time t is

$$\mathbb{E}_t n_{t+1} = [(\varsigma_{1,t+1}r_{k,t+1} - \varsigma_{2,t+1}r_{t+1})\phi_t + \varsigma_{2,t+1}r_{t+1}]n_t. \tag{82}$$

By substituting (82) into (81), the value function V_t, which is also the left hand side of the Bellman equation, is

$$V_t = LHS = \mathbb{E}_t(\Lambda_{t,t+1}\Omega_{t+1}n_{t+1}) \tag{83}$$

From above, $LHS = RHS$, so the Bellman equation is satisfied for any t with the value function (78).

A.3 Welfare Results

A.3.1 Welfare surface of monetary policy coefficients

Figure 4 plots the welfare surface against two monetary policy parameters (b_π, b_Y) without cyclical macroprudential policy ($\tau_0 = 0$). We choose the coefficient on inflation $b_\pi > 1$ to guarantee the Blanchard-Kahn condition.[14] Given a positive value of b_Y, the welfare displays a non-monotonic change when b_π increases. The welfare change is also non-monotonic in term of b_Y when the value of b_π is small. The above welfare surface implies that pursuing perfect price stabilization is suboptimal. Instead, the optimized parameter values that maximizes the household's utility are $(b_\pi, b_Y) = (1.5, 3.5)$ according to our numerical result.

A.3.2 Alternative monetary policy rule: reacting to financial variables

We consider an alterntive monetary policy rule when the nominal interest rate is set to react to financial variables (such as the asset price Q_t):

$$\ln\left(\frac{R_t}{\bar{R}}\right) = b_\pi \ln\left(\frac{\pi_t}{\bar{\pi}}\right) + b_Q \ln\left(\frac{Q_t}{\bar{Q}}\right), \tag{84}$$

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[14] When $b_\pi \leq 1$, the system is indeterminate unless the coefficient on output b_Y is very large.

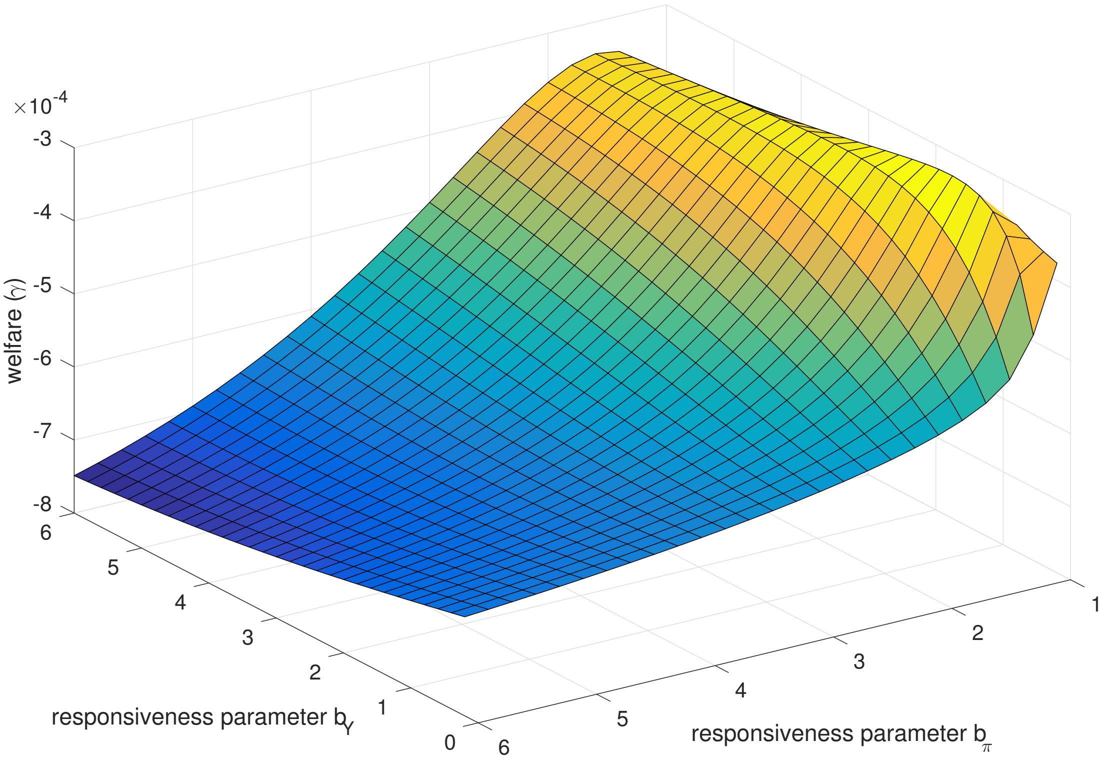

Figure 4: Welfare surface against two monetary policy parameters (b_Y, b_π) without countercyclical macroprudential policy.

We conduct the similar numerical exercise as in Section 3.3, and results are reported in Table 6. We find that setting the nominal rate to react to Q_t improves welfare because it stabilizes the responses of real variables and mitigates financial acceleration. Such result is similar to the baseline interest rate rule when the interest rate is adjusted in response to the change in output.The result still holds when the steady-state distortion is eliminated by a constant macroprudential tax. The difference is that the responsiveness parameter to Q_t is larger. It is because the response of the asset price to a TFP shock is smaller than that of output under the policy rule of (84).

The result is different when we consider the monetary policy prescription without procyclical asset prices. In this case, the asset price remains constant. Since our alternative monetary policy sets the nominal interest rate in response to changes in asset prices, the endogenous component of the alternative rule loses one dimension, so the welfare is lower than that under the baseline monetary rule.

A.3.3 Jointly optimized monetary and macroprudential rules

To find the monetary and macroprudential policy parameters that are optimal jointly, we search the grid of three policy parameters (b_π, b_Y, τ_0), where b_π ranges from 1.1 to 8, b_Y from

Table 6: Monetary Policy (without Time-varying Macroprudential Policy)

	Baseline	PPS	Optimized rule	No capital adj. costs	Optimal ss. MPP
(b_π, b_Q)	$(1.5, b_Y = 0.2)$		$(1.75, 25.5)^*$	$(1.5, /)^*$	$(1.5, 22)^*$
Std. of inflation	0.0121	0	0.0605	0.0022	0.0618
Std. of output	0.0300	0.0359	0.0107	0.0324	0.0101
CE $(\bar{\gamma})$ (%)	0	-0.0240	0.0235	-0.002	0.0178

Note: The first columns show the results under the baseline model. The second column represents the scenario when prices is perfectly stabilized. The third column is when the Taylor rule parameters are chosen optimally. The fourth column is for the optimized interest rate rule without capital adjustment costs. The last column shows the optimized rule when the steady-state distortion is eliminated by a macroprudential tax.

0 to 8, and τ_0 from -8 to 8. To build an image of how the welfare is affected by τ_0, we plot the welfare curve versus τ_0 under two monetary policy stances: (i) the baseline Taylor rule ($b_\pi = 1.5, b_Y = 0.2$) and (ii) the optimized interest rate rule of (39) without countercyclical MPP ($b_\pi^* = 1.5, b_Y^* = 3.5$). In Figure 5, one can see that the "macroprudential" monetary policy ($b_\pi^* = 1.5, b_Y^* = 3.5$) achieves higher welfare, and the optimal coefficient of MPP tax on asset prices (τ_0) is smaller compared with the baseline model.

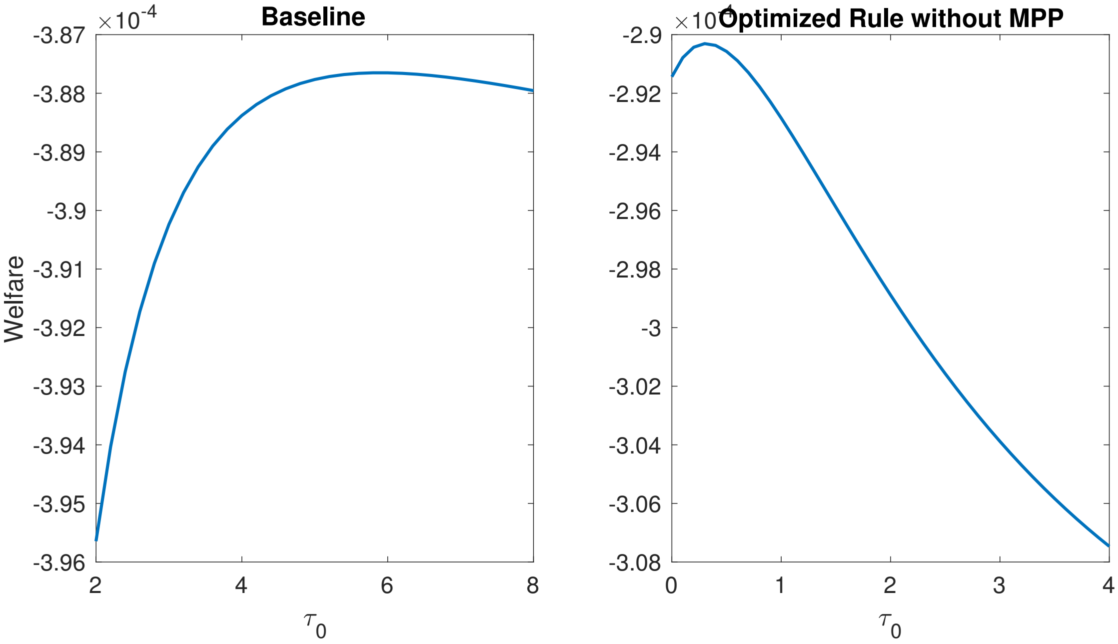

Figure 5: Welfare curve against countercyclical macroprudential parameter τ_0

The left panel shows the welfare (consumption equivalent) under the baseline monetary policy rule ($b_\pi = 1.5, b_Y = 0.2$), and the right panel shows the welfare result under the optimized "macroprudential" monetary policy rule ($b^*_\pi = 1.5, b^*_Y = 3.5$).