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*Research Article*

# Coordination Effects and Optimal Policy Choices of Macroprudential Policy and Monetary Policy

**Haifeng Pan**[1] **and Dingsheng Zhang**[2]

[1]*School of Mathematics and Finance, Anhui Polytechnic University, Wuhu 241000, China*
[2]*China Economics and Management Academy, Central University of Finance and Economics, Beijing 100081, China*

Correspondence should be addressed to Haifeng Pan; panhaifeng708@126.com

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Considering three monetary policy rules, together with two endogenous macroprudential policies that are credit constraints (loan to value, LTV) for households and counter-cyclical capital (capital requirement ratio, CRR) for bankers, this paper establishes a dynamic stochastic general equilibrium (DSGE) model. Based on the welfare analysis of different combinations of macroprudential rules and monetary policy rules, this paper identifies the optimal policy combinations and analyzes the coordination effects between macroprudential policies and monetary policies. The results show that no matter what kind of monetary policy rules is implemented, the introduction of macroprudential rules has improved the level of total social welfare. In the optimal "two pillars" framework of monetary policies and macroprudential rules, the main objective of monetary policy is to stabilize price inflation, and the macroprudential policy to be implemented is the CRR macroprudential policy. This combination can effectively promote the stability of the real estate market, financial market, and macroeconomy, while maximizing the improvement of total social welfare.

## 1. Introduction

The real estate industry has strong financial attributes; both the supply and demand of real estate are constrained by the credit environment. The large fluctuation of housing prices easily leads to the systematic risk of financial market and the instability of macroeconomy. The U.S. subprime mortgage crisis has shown that housing prices and mortgage debt have played important roles in the financial crisis and economic recession. Meanwhile, the fragility and instability of the financial system have led to large fluctuations in the real estate industry. The relationship among real estate market, financial market, and real economy is becoming more and more complex. The establishment of a sound financial system, operation mechanism, and supervision system can promote the formation of a good financial ecology and the healthy development of macroeconomy. Under the background of frequent economic crisis, weak recovery, and constant trade friction, macroprudence bhg has gradually become an important way for countries to intervene in the market.

The main goal of macroprudential policy is to limit the accumulation of financial risks in order to reduce the possibility and negative impact of systemic financial risks. When the economy is overheating and the credit is booming, the credit scale should be appropriately reduced. On the contrary, when the economy is in a downturn, the credit scale should be moderately expanded. For the implementation of macroprudential policy, one way is to implement a prudent monetary policy, that is, the central bank's monetary policy focuses on price stability and economic growth, while taking into account other objectives such as asset price fluctuations, financial stability, and other factors. Another way is to implement an independent macroprudential policy. As one of the three pillars of Basel III, the capital ratio requirement (CRR) is widely accepted in the world. In 2015, the Basel III stipulated 8% for the minimum capital requirement ratio, together with no less

than 2.5% for counter-cyclical capital requirement ratio, with 10.5% in the total ratio. In the period of economic prosperity, financial markets are often accompanied by the agglomeration of financial risks. In order to meet the requirements of CRR, banks need to hold more capital to cope with the economic downturn in the boom period and to protect the banking industry from the expansion of credit growth. In addition, the loan to value (LTV) can be used as an effective tool to strengthen macroprudence [1]. Cerutti et al. analyzed the macroprudential tools used in 119 countries from 2000 to 2013. The results showed that LTV was one of the most popular macroprudential tools, and LTV constraints effectively reduced the credit growth in the household sector [2]. In recent years, CRR and LTV have been widely used as effective macroprudential tools.

The introduction of each kind of macroprudential tools will have an impact on the transmission mechanism of the economic system and create a new regulatory environment. In the economic system, considering both LTV and CRR macroprudential policies and clarifying their coordination mechanism with monetary policies have become urgent problems to be solved.

The structure of this paper is as follows: Section 1 is the introduction; Section 2 reviews the relevant literature; Section 3 establishes a multisector DSGE model; Section 4 introduces the welfare analysis methods and calibrates the parameters; Section 5 is the model simulation; Section 6 is a conclusion.

## 2. Literature Review

At present, there are many theoretical and empirical researches on the impact of monetary policy on housing prices and economic growth. Most studies on the impact of macroprudential policies on housing prices are based on DSGE framework. For the introduction of macroprudential policies, it mainly includes prudent monetary policies and independent macroprudential policies.

Regarding the macroprudential monetary policy targeting housing prices, most literature believe that it is beneficial to restrain the fluctuation of housing prices and reduce the welfare loss caused by economic fluctuation through an accelerator mechanism [3]. Chen pointed out that the housing price could be used as one of the influencing factors affecting interest rates; in addition, the credit constraint policy had obvious effects, which should be put into the economic system as a macroprudential tool [4]. Faia and Monacelli introduced asset prices into Taylor's monetary policy rules, and the results showed that the welfare was increased and the stability of the financial market was improved [5]. However, some documents show that the central bank's direct intervention in housing prices through monetary policy has little effect [6]. Kannan et al. showed that the macroprudence of monetary policy on credit growth and asset prices was conducive to curbing the credit market cycle; besides, constant and rigid policies would increase the risk of policy errors, which could reduce the stability of macroeconomy [7]. In addition, it is possible that the implementation of monetary policy in consideration of housing prices has restrained the rise of housing prices, but at the same time, it may have other negative effects such as the continuous rise of inflation rate and the increase of output fluctuation. Therefore, it is often necessary to coordinate macroprudential policy with monetary policy.

Regarding the LTV macroprudential tool, it directly affects the scale of borrowing, which in turn affects the housing demand of households. On the other hand, the change of credit constraint will cause the change of family's housing wealth. Since housing is the main asset of the family and has a stronger wealth effect than other assets, it indirectly affects economic growth through consumption channels [8, 9]. The implementation of the LTV macroprudential policy will help to reduces the procyclical nature of the financial sector and economic growth, as well as reduce systemic risks. Wang established a DSGE model including the commercial banking sector. The research showed that the macroprudential tools of credit constraints stabilized housing prices, which was conducive to the prevention of financial system risks [10]. Meng et al. pointed out that the macroprudential policy considering credit factors was conducive to stabilizing housing prices and alleviating the imbalance between real estate and the development of real economy [11]. However, some literature show that credit restraint macroprudence may cause other problems while improving financial stability. Gelain et al. constructed a DSGE model of housing market, and the research showed that credit constraints could reduce the volatility of household debt scale but would increase the volatility of inflation, consumption, and output [12].

Regarding the CRR macroprudential tool, Akram showed that counter-cyclical capital requirements had a significant impact on housing prices and credit growth [13]. Bekiros et al. showed that the counter-cyclical capital rules relying on credit gap could help banks cope with the expected and unexpected impact of capital, as well as improve the stability of the financial market and the welfare level of family [14]. Rubio and Carrasco-Gallego studied the macroprudential effect of counter-cyclical capital under Basels I, II, and III. The research showed that the welfare effect of each department was different under various capital ratio requirements and corresponding monetary policy rules were needed to achieve the optimal control effect [15].

To sum up, most of the literature believes that the interaction between macroprudential policies and monetary policies can play a role of internal stabilizer and help monetary policies achieve the goal of price stability and economic growth. A few literature studies believe that the coordination should be determined on a case-by-case basis [16].

At present, there are few studies on the role of macroprudential policies considering both credit constraint and counter-cyclical capital in the economic system. Angelini et al. used a DSGE model to analyze the interaction between macroprudential policies and monetary policies [17]. The results showed that the effect of macroprudential tools on macroeconomy was limited in normal period, but it was more obvious after the financial crisis. In their study, they discussed the coordination effects between different policies

but did not analyze the welfare change and the optimal policy. Yu showed that capital adequacy requirements could reduce the volatility of output and inflation, while LTV tools were ineffective in most cases [18]. Ma and Chen showed that the coordination of monetary policy, credit policy, and financial regulatory policy needed to be paid attention to; besides, policy conflicts might lead to the increase of policy implementation cost, thus weakening the effect of the policy. However, their study did not consider the impact of housing prices [19]. Fan and Gao studied the optimal coordination of capital supervision, credit scale, and monetary policy. The results showed that monetary policy should pay attention to the fluctuation of financial asset price, and it was better to consider credit price than credit scale in monetary policy. At the same time, it was necessary to strengthen the regulation of counter-cyclical capital [20].

In summary, most of the literature studies believe that the coordination of monetary policies and macroprudential policies can stabilize prices and prevent financial risks. However, the main goal of monetary policy is to stabilize price inflation or to consider the factors of output and housing prices further; besides, the effect and evaluation of the two policy combinations need further study. In addition, few literature studies integrate LTV, CRR, and monetary policies into the same economic system and systematically analyze the coordination effects of monetary policy with LTV and CRR, as well as the optimal selection of macroprudential tools.

Referring to Iacoviello [21], this paper constructs a DSGE model to analyze coordination effects of macroprudential policies and monetary policies. The theoretical contribution of this paper mainly includes the following aspects: firstly, innovating LTV rules by considering the influence of LTV on economic growth and housing prices, the prudential mechanism of macroeconomy is introduced into LTV. When housing prices rise or output increases, LTV will decline automatically, which in turn increases the degree of credit constraints. Furthermore, the main consideration in CRR is the stability of the financial market. Secondly, three monetary policy rules are considered in the model. Thirdly, through the welfare analysis of different combinations and the mechanism and coordination effect of interaction are systematically discussed, and the optimal policy combination is determined.

The practical value of this paper mainly includes the following aspects: firstly, macroprudential policies may be related to other policies, especially monetary policies. Macroprudential policies will have a direct or indirect impact on the variables of monetary policies and then affect the transmission mechanism of monetary policies. The differences in the interaction between macroprudential policies and monetary policies that focus on different factors, together with the impact of different macroprudential policies on the welfare of various sectors, need to be thoroughly clarified. Secondly, we clarify the transmission mechanism of macroprudential tools in the field of real estate and discuss whether relevant policies have played a role in stabilizing housing prices and improving the stability of macroeconomy and financial system. Thirdly, we give some suggestions for the choice of macroprudential policy tools. LTV is a common macroprudential tool. In addition, the Basel III imposes requirements on CRR. Therefore, it is very important to evaluate the impact of LTV and CRR on macroeconomy and financial market and determine the appropriate macroprudential tools. Fourthly, the institutional reform often exceeds the basis of theoretical research and market development; besides, the macroprudential framework and policy implementation often face with many challenges, and it is necessary to analyze relevant policies in a structured approach from a theoretical perspective. This study can provide some reference for macroprudential authorities.

## 3. Model Design

*3.1. Patient Households.* Patient households maximize the lifetime utility function given by

$$E_0 \sum_{t=0}^{\infty} \beta_s^t \left( \ln C_{s,t} + j_t \ln H_{s,t} - \nu \frac{\left(N_{s,t}\right)^{1+\eta}}{1+\eta} \right), \tag{1}$$

where $E_0$ is the expectation operator, $\beta_s \in (0,1)$ is the discount factor for patient households, $C_{s,t}$, $H_{s,t}$, and $N_{s,t}$ represent consumption, housing holdings, and work hours in period $t$, respectively, and $j_t$ denotes the housing preference shock, which is subject to the random process:

$$\ln j_t = \left(1-\rho_j\right)\ln \overline{j} + \rho_j \ln j_{t-1} + e_{j,t}, \tag{2}$$

where $\overline{j}$ represents the steady-st$\rho_j \in (-1,1)$ate value, denotes the persistence of preference shock, and $e_{j,t}$ stands for a white noise, subject to the normal distribution with mean 0 and variance $\sigma_j^2$.

The budget constraint of patient households is

$$C_{s,t} + b_{s,t} + q_t\left(H_{s,t} - H_{s,t-1}\right) = \frac{R_{s,t-1} b_{s,t-1}}{\pi_t} + w_{s,t} N_{s,t} + F_{s,t}, \tag{3}$$

where $q_t$ is the housing price in period $t$, $R_{s,t-1}$ is the nominal interest rate of deposits from $t-1$ to $t$, $b_{s,t}$ denotes the deposits in period $t$, $P_t$ denotes the price level in period $t$, $F_{s,t}$ denotes the transfer payments from intermediate entrepreneurs, $\pi_t = (P_t/P_{t-1})$ denotes the inflation rate in period $t$, and $w_{s,t}$ denotes the real wage level in period $t$.

The first-order conditions of the optimization problem for patient households are as follows:

$$\frac{1}{C_{s,t}} = \beta_s E_t \left( \frac{R_{s,t}}{C_{s,t+1}\pi_{t+1}} \right), \tag{4}$$

$$\frac{j_t}{H_{s,t}} = \frac{q_t}{C_{s,t}} - \beta_s E_t \left( \frac{q_{t+1}}{C_{s,t+1}} \right), \tag{5}$$

$$\nu\left(N_{s,t}\right)^{\eta} = \frac{w_{s,t}}{C_{s,t}}. \tag{6}$$

Equation (4) is the Eulerian equation to express the intertemporal condition of consumption. Equation (5)

represents the intertemporal condition of housing. Equation (6) is the labor-supply condition.

*3.2. Impatient Households.* Impatient households maximizing the lifetime utility function given by

$$E_0 \sum_{t=0}^{\infty} \beta_b^t \left( \ln C_{b,t} + j_t \ln H_{b,t} - \nu \frac{\left(N_{b,t}\right)^{1+\eta}}{1+\eta} \right), \tag{7}$$

where $\beta_b \in (0,1)$ is the discount factor for impatient households. The budget constraint and the borrowing constraint are

$$C_{b,t} + q_t\left(H_{b,t} - H_{b,t-1}\right) + \frac{R_{b,t-1} b_{b,t-1}}{\pi_t} = b_{b,t} + w_{b,t} N_{b,t},$$
$$b_{b,t} \le \kappa_t E_t \left( \frac{q_{t+1} H_{b,t} \pi_{t+1}}{R_{b,t}} \right), \tag{8}$$

where $b_{b,t}$ denotes loans in period $t$, $R_{b,t}$ denotes the nominal borrowing rate, and $\kappa_t$ denotes the ratio of loan to housing value, which is an endogenous variable as a measure of the tightening of the credit market.

The first-order conditions of the optimization problem for impatient households are as follows:

$$\frac{1}{C_{b,t}} = \beta_b E_t \left( \frac{R_{b,t}}{C_{b,t+1}\pi_{t+1}} \right) + \lambda_t R_{b,t},$$
$$\frac{j_t}{H_{b,t}} = \frac{q_t}{C_{b,t}} - \beta_b E_t \left( \frac{q_{t+1}}{C_{b,t+1}} \right) - \lambda_t \kappa_t E_t \left( q_{t+1}\pi_{t+1} \right), \tag{9}$$
$$\nu\left(N_{b,t}\right)^{\eta} = \frac{w_{b,t}}{C_{b,t}},$$

where $\lambda_t$ denotes the Lagrangian multiplier on the borrowing constraint of impatient households. These first-order conditions can be interpreted analogously to those of patient households.

*3.3. Bankers.* Bankers maximize the utility function given by

$$E_0 \sum_{t=0}^{\infty} \beta_f^t \ln\left(C_{f,t}\right), \tag{10}$$

where $\beta_f \in (0,1)$ is the discount factor for the bankers. $\mathrm{div}_{f,t}$ are dividends, which are fully consumed by bankers every period, that is, $C_{f,t} = \mathrm{div}_{f,t}$.

The budget constraint of bankers is

$$\mathrm{div}_{f,t} + b_{b,t} + \frac{R_{s,t-1} b_{s,t-1}}{\pi_t} = b_{s,t} + \frac{R_{b,t-1} b_{b,t-1}}{\pi_t}. \tag{11}$$

As in [21], this paper assumes that the balance of bank assets and liabilities is subject to regulatory restrictions and needs to meet the capital ratio requirements, specifically,

$$\frac{b_{b,t} - b_{s,t}}{b_{b,t}} \ge \mathrm{CRR}_t. \tag{12}$$

The first-order conditions of the optimization problem are as follows:

$$\frac{1}{\mathrm{div}_{f,t}} = \beta_f E_t \left( \frac{R_{s,t}}{\mathrm{div}_{f,t+1}\pi_{t+1}} \right) + \gamma_t,$$
$$\frac{1}{\mathrm{div}_{f,t}} = \beta_f E_t \left( \frac{R_{b,t+1}}{\mathrm{div}_{f,t+1}\pi_{t+1}} \right) + \left(1 - \mathrm{CRR}_t\right)\gamma_t, \tag{13}$$

where $\gamma_t$ denotes the Lagrangian multiplier on the capital constraint of bankers.

*3.4. Final Entrepreneurs.* There are a large number of final product entrepreneurs, which are continuously distributed on the interval $[0,1]$. The final entrepreneurs will produce intermediate products as final products, specifically,

$$Y_t = \left( \int_0^1 Y_t(z)^{((\varepsilon-1)/\varepsilon)} \mathrm{d}z \right)^{(\varepsilon/(\varepsilon-1))}, \tag{14}$$

where $\varepsilon > 1$ is the elasticity of substitution between intermediate products.

The demand curve for the intermediate product can be obtained:

$$Y_t(z) = \left( \frac{P_t(z)}{P_t} \right)^{-\varepsilon} Y_t. \tag{15}$$

The price index is given by

$$P_t = \left( \int_0^1 P_t(z)^{1-\varepsilon} \mathrm{d}z \right)^{(1/(1-\varepsilon))}. \tag{16}$$

*3.5. Intermediate Entrepreneurs.* In order to introduce sticky prices, similar to Iacoviello [22], entrepreneurs are divided into intermediate entrepreneurs and final entrepreneurs. The intermediate product market is a monopolistic competitive market, and the production function of intermediate entrepreneurs is

$$Y_t(z) = A_t N_{s,t}(z)^{\alpha} N_{b,t}(z)^{1-\alpha}, \tag{17}$$

where $\alpha \in [0,1]$ is the share of patient household labor.

The marginal cost can be determined by solving the cost minimization problem of intermediate entrepreneurs. There is

$$\frac{w_{s,t} N_{s,t}(z)}{w_{b,t} N_{b,t}(z)} = \frac{\alpha}{1-\alpha}. \tag{18}$$

The marginal cost of intermediate entrepreneurs is

$$\mathrm{MC}_t = \frac{1}{A_t} w_{b,t}^{1-\alpha} w_{s,t}^{\alpha} \left( \alpha^{-\alpha} (1-\alpha)^{-(1-\alpha)} \right). \tag{19}$$

As in Calvo [23], there is a pricing mechanism with stickiness in the intermediate product market. In each period, $1-\theta$ proportion of intermediate entrepreneurs will change prices, while $\theta$ proportion of intermediate entrepreneurs can only adjust prices based on steady-state inflation levels. Therefore, the price level can be expressed as

$$P_t = \left(\theta P_{t-1}^{1-\varepsilon} + (1-\theta) P_t^{*\,(1-\varepsilon)}\right)^{(1/(1-\varepsilon))}, \tag{20}$$

where $P_t^*(z)$ is the optimal price set by the intermediate entrepreneurs who change the price.

Referring to Schmitt and Uribe [24], the optimization conditions of the intermediate entrepreneurs can be transformed into the following forms:

$$\begin{aligned} x_t^1 &= \frac{1}{X_t}\left(\frac{P_t^*}{P_t}\right)^{-1-\varepsilon} Y_t + \theta\beta_s \frac{C_{s,t}}{C_{s,t+1}} \frac{P_t}{P_{t+1}}\left(\frac{P_t^*}{P_{t+1}^*}\right)^{-1-\varepsilon} x_{t+1}^1, \\ x_t^2 &= \left(\frac{P_t^*}{P_t}\right)^{-\varepsilon} Y_t + \theta\beta_s \frac{C_{s,t}}{C_{s,t+1}} \frac{P_t}{P_{t+1}}\left(\frac{P_t^*}{P_{t+1}^*}\right)^{-\varepsilon} x_{t+1}^2, \\ x_t^2 &= x_t^1 \frac{\varepsilon}{\varepsilon - 1}. \end{aligned} \tag{21}$$

*3.6. Central Bank.* According to the different dependent factors, this paper considers three types of monetary policy rules, as follows:

Taylor Rule 1: interest rate changes depend on the effects of inflation, defined as

$$R_t = (R_{t-1})^{r_R}\left(\pi_t^{1+r_\pi} R^*\right)^{1-r_R} \exp\left(\varepsilon_{R,t}\right). \tag{22}$$

Taylor Rule 2: interest rate changes depend on the effects of inflation and output, defined as

$$R_t = (R_{t-1})^{r_R}\left(\pi_t^{1+r_\pi}\left(\frac{Y_t}{Y^*}\right)^{r_Y} R^*\right)^{1-r_R} \exp\left(\varepsilon_{R,t}\right). \tag{23}$$

Taylor Rule 3: interest rate changes not only depends on the effects of inflation and output but also depends on the effects of housing prices, which is called the general prudent monetary policy, defined as

$$R_t = (R_{t-1})^{r_R}\left(\pi_t^{1+r_\pi}\left(\frac{Y_t}{Y^*}\right)^{r_Y}\left(\frac{q_t}{q^*}\right)^{r_q} R^*\right)^{1-r_R} \exp\left(\varepsilon_{R,t}\right), \tag{24}$$

where $R^*$, $Y^*$, and $q^*$ represent steady-state values of interest rate, output, and housing price, respectively; $r_R \in [0,1]$ is the interest rate inertia parameter; $r_\pi \geq 0$, $r_Y \geq 0$, and $r_q \geq 0$ represent the response coefficients of interest rate to inflation gap, output gap, and housing price gap, respectively; and $\varepsilon_{R,t}$ stands for a white noise with mean 0 and variance $\sigma_\varepsilon^2$.

### 3.7. Macroprudential Authority

*3.7.1. LTV Macroprudential Rule.* In general models, LTV parameters that reflect credit constraints are often fixed and do not change with changes of the economic environment. Credit constraints reflect the willingness of lenders to expand loans and reflect the degree of tightening and easing of the credit market. Therefore, credit constraints are important factors affecting housing prices, and different LTV will lead to different effects of housing prices on the response to exogenous shocks. When the LTV is high, the credit constraints become loose, borrowers will be able to borrow more funds, and the credit tends to boom; while when the LTV is low, the borrowing scale will be limited. The LTV macroprudential rule is

$$\kappa_t = \kappa\left(\frac{Y_t}{Y^*}\right)^{-m_y}\left(\frac{q_t}{q^*}\right)^{-m_q}, \tag{25}$$

where $\kappa$ denotes the steady-state value of LTV and $m_y \geq 0$ and $m_q \geq 0$ represent the response coefficients of LTV to the output gap and housing price gap, respectively. When output increases and housing prices rise, the LTV will automatically decrease to a certain extent, which will limit the credit boom.

*3.7.2. CRR Macroprudential Rule.* In order to consider the stability of the financial system and reduce the systemic risk, this paper considers the impact of loans deviating from the steady state by internalizing CRR. The role of this rule is that the capital requirement ratio of the banking sector fluctuates near the steady-state value, corresponding to 10.5% of Basel III. When the credit growth is too high above its steady-state value, the CRR will increase, which will automatically increase the capital ratio requirements, thus avoiding the credit surplus [14]. The CRR macroprudential rule is

$$\mathrm{CRR}_t = \mathrm{CRR}\left(\frac{b_t}{b^*}\right)^{\phi_b}, \tag{26}$$

where CRR denotes the steady-state value of $\mathrm{CRR}_t$ and $\phi_b$ represents the response coefficient of $\mathrm{CRR}_t$ to loan gap.

*3.8. Market Clearing.* The market clearing conditions of the product market are as follows:

$$C_{s,t} + C_{b,t} + C_{f,t} = Y_t. \tag{27}$$

The total supply of housing is fixed, and it is normalized to unity:

$$H_{s,t} + H_{b,t} = 1. \tag{28}$$

## 4. Welfare Analysis Methods and Parameter Calibration

*4.1. Welfare Analysis Methods.* According to the above model, the utility functions of patient households, impatient households, and bankers are as follows:

$$\begin{aligned} W_{s,t} &= E_t \sum_{k=0}^{\infty} \beta_s^k \left(\ln C_{s,t+k} + j_{t+k} \ln H_{s,t+k} - \nu \frac{\left(N_{s,t+k}\right)^{1+\eta}}{1+\eta}\right), \\ W_{b,t} &= E_t \sum_{k=0}^{\infty} \beta_s^k \left(\ln C_{b,t+k} + j_{t+k} \ln H_{b,t+k} - \nu \frac{\left(N_{b,t+k}\right)^{1+\eta}}{1+\eta}\right), \\ W_{f,t} &= E_t \sum_{k=0}^{\infty} \beta_s^k \left(\ln C_{f,t+k}\right). \end{aligned} \tag{29}$$

Social welfare is the weighted sum of the individual welfare for patient households, impatient households, and bankers, as follows:

$$W_t = \omega_s W_{s,t} + \omega_b W_{b,t} + \omega_f W_{f,t}, \tag{30}$$

where $\omega_s = 1 - \beta_s$, $\omega_b = 1 - \beta_b$, and $\omega_f = 1 - \beta_f$.

In order to analyze the welfare changes intuitively, the welfare of different policy combinations is compared with the benchmark model ($W^{\text{Bench}}$), and the welfare changes caused by the policy implementation are obtained. Consumption compensation changes are used to measure welfare changes, specifically,

$$\begin{aligned} \text{WL}_s &= 1 - \exp\left[(1-\beta_s)\left(W_s - W_s^{\text{Bench}}\right)\right], \\ \text{WL}_b &= 1 - \exp\left[(1-\beta_b)\left(W_b - W_b^{\text{Bench}}\right)\right], \\ \text{WL}_f &= 1 - \exp\left[\left(1-\beta_f\right)\left(W_f - W_f^{\text{Bench}}\right)\right], \end{aligned} \tag{31}$$

where WL denotes the changes of social welfare measured by consumption compensation.

*4.2. Parameter Calibration.* According to Iacaviello, together with Zheng and Di, the discount factors of patient households, impatient households and bankers, i.e., $\beta_s$, $\beta_b$, and $\beta_f$, are calibrated as 0.99, 0.95, and 0.935, respectively [22, 25]. Referring to Calvo, Liu, and Guo et al., the proportion parameter $\theta$ that does not change in the sticky price is set as 0.75 [23, 26, 27]. For a long time, the proportion of real estate loans for the first set of housing in China is 30%, that is, the total loan accounted for 70% of the total asset value; therefore, the steady-state value $\kappa$ is calibrated as 0.7. According to Liu, the steady-state value of the housing marginal effect parameter $j$ in the utility function is calibrated as 0.1 [26]. According to He et al., together with Gao and Gong, the reciprocal of labor-supply elasticity $\eta$ is calibrated as 1 [28, 29]. Referring to Zhao and Zhang, the price markup $X$ is set at 1.2 [30]. According to Liang et al., together with Luo and Cheng et al., the labor output elasticity $\alpha$ is calibrated as 0.64 [31, 32]. Referring to Li, the parameters $\gamma_R$, $\gamma_\pi$, and $\gamma_Y$ in Taylor's monetary policy rules are calibrated as 0.8, 0.7, and 0.3, respectively [33]. Referring to Zhao and Zhang, the coefficient of influence $\gamma_q$ of housing prices in the prudent monetary policy rule is calibrated as 0.1 [30]. According to Rubio and Carrasco, the parameters are set to $[0, 1]$ in order to analyze the sensitivity of the output and housing price coefficients in the LTV rule [34]. The parameter intervals in the CRR rule are set to $[0, 5]$. Then, the optimal parameters are solved in the interval. Referring to Zheng and Di, the persistence parameters of housing preference shock and technology shock, i.e., $\rho_j$ and $\rho_A$, are calibrated as 0.95 and 0.90, respectively [25].

## 5. Model Simulation

### 5.1. Analysis of the Combination of LTV Macroprudential Rules and Monetary Policy Rules

*5.1.1. Welfare Analysis of the Combination of LTV Macroprudential Policies and Monetary Policies.* The coordination of LTV macroprudential policies and monetary policies is analyzed without considering CRR rules, i.e., $\phi_b = 0$. Considering the combination of three monetary policies and LTV rules, the paper compares and analyzes the optimal policy effect in different situations. LTV rules are divided into three cases: firstly, the LTV macroprudential rule only considers the factor of output, that is, $m_q = 0$; secondly, the LTV macroprudential rule only considers the factor of housing prices, that is, $m_y = 0$; thirdly, the LTV macroprudential rule considers the factors of both output and housing prices. The welfare analysis and impulse response analysis were carried out in Matlab environment using the Dynare toolbox. Table 1 shows the welfare changes of the combination of LTV macroprudential rules and three monetary policy rules.

According to Table 1, we can draw the following conclusions: firstly, no matter what kind of monetary policy rules, when the LTV rule only depends on output, the welfare improvement is the smallest. Secondly, when the LTV rule depends on both output and housing prices, $m_y = 0$ in the optimal parameters, which is consistent with the optimal parameters when the LTV only considers housing prices. Therefore, the optimal LTV macroprudential rules only need to rely on the factor of housing prices; at the same time, the welfare of impatient households and bankers increase, and the welfare of patient households declines. Thirdly, no matter what kind of monetary policy rules, the introduction of LTV macroprudential policies has increased the stability of the financial market and improved the total social welfare.

In summary, no matter what monetary policy rules the central bank implements, the introduction of LTV macroprudential rules can improve the total social welfare. If the main goal of monetary policies implemented by the central bank is to expand from stabilizing price inflation to promoting economic growth and stabilizing the real estate and financial system, it can partially fulfill the function of implementing macroprudential policy independently. However, the problem that may appear in reality is that there may be some conflicts among multiple objectives, so it is necessary to balance the various objectives.

*5.1.2. Optimal Combination of LTV Macroprudential Policies and Monetary Policies.* We use the model that only considers Taylor rule 1 as the benchmark model, compare the optimal combination of three monetary policies and LTV macroprudential policies with the benchmark, and get the welfare changes of the optimal policy combination in the three situations, as shown in Table 2.

According to Table 2, when the Taylor monetary policy rule depends on the factors of output, inflation, and housing prices, the LTV macroprudential rule considers the factor of housing prices and the total social welfare improves the most.

### 5.2. Analysis of the Combination of CRR Macroprudential Rules and Monetary Policy Rules

*5.2.1. Welfare Analysis of the Combination of CRR Macroprudential Policies and Monetary Policies.* The coordination

Table 1: Welfare improvement of the optimal combination of monetary policy rules and LTV macroprudential rules.

| | Optimal parameters in LTV | Patient households | Impatient households | Bankers | Total social welfare |
|---|---|---|---|---|---|
| Taylor 1 + LTV macroprudential rules | | | | | |
| LTV only depends on output | $m_y = 0.16$ | −0.2241 | 0.6480 | −0.0910 | 0.0242 |
| LTV only depends on housing prices | $m_q = 0.60$ | −0.6274 | 0.8442 | 3.9934 | 0.2955 |
| LTV only depends on output and housing prices | $m_q = 0.60$; $m_y = 0$ | −0.6274 | 0.8442 | 3.9934 | 0.2955 |
| Taylor 2 + LTV macroprudential rules | | | | | |
| LTV only depends on output | $m_y = 0$ | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| LTV only depends on housing prices | $m_q = 0.60$ | −0.4089 | 0.6953 | 2.8011 | 0.2128 |
| LTV only depends on output and housing prices | $m_q = 0.60$; $m_y = 0$ | −0.4089 | 0.6953 | 2.8011 | 0.2128 |
| Taylor 3 + LTV macroprudential rules | | | | | |
| LTV only depends on output | $m_y = 0$ | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| LTV only depends on housing prices | $m_q = 0.53$ | −0.2231 | 0.6441 | 1.9097 | 0.1541 |
| LTV only depends on output and housing prices | $m_q = 0.53$; $m_y = 0$ | −0.2231 | 0.6441 | 1.9097 | 0.1541 |

*Note*. When the LTV only depends on the factor of output, the solution is carried out in the [0, 1] interval with step 0.01 for parameter $m_y$. When the LTV depends on the factor of housing prices, the solution is carried out in the [0, 1] interval with step 0.01 for parameter $m_q$. When the LTV depends on the factors of both output and housing prices, $m_y$ takes 0.01 as the step in the [0, 1] interval, $m_q$ takes 0.01 as the step in the [0, 1] interval, and all the combinations of the two parameters are used to solve the problem. Combined with the improvement of the total social welfare, the optimal welfare is determined. In order to make the meaning of the sign intuitive, the welfare changes were multiplied by minus $10^4$. When the welfare change value is positive after conversion, it means welfare improvement; in addition, when it is negative, it means welfare loss, the same below.

Table 2: Welfare changes of the optimal combination of LTV macroprudential rules and monetary policy rules.

| | Parameters and variables | Case one | Case two | Case three |
|---|---|---|---|---|
| Taylor rules | $r_R$ | 0.8 | 0.8 | 0.8 |
| | $r_\pi$ | 0.7 | 0.7 | 0.7 |
| | $r_Y$ | 0 | 0.3 | 0.3 |
| | $r_q$ | 0 | 0 | 0.1 |
| LTV rules | $m_q$ | 0.6 | 0.6 | 0.53 |
| | $m_y$ | 0 | 0 | 0 |
| Patient households | $WL_s$ | −0.6274 | −0.2203 | −1.3826 |
| Impatient households | $WL_b$ | 0.8442 | 9.9658 | 6.7444 |
| Bankers | $WL_f$ | 3.9934 | 12.0796 | 16.7064 |
| Total social welfare | WL | 0.2955 | 1.2813 | 1.4093 |

of CRR macroprudential policies and monetary policies are analyzed without considering LTV rules, i.e., $m_y = 0$ and $m_q = 0$. In order to solve the optimal combination under different parameters, we cycle the parameters of CRR macroprudential rules in the range of [0, 5] with the step of 0.01 for three monetary policy rules and further determine the optimal parameters according to the maximization of total welfare and finally determine the optimal combination strategy of Taylor rules and CRR rules. The results show that the optimal parameters of welfare maximization in the three combination cases are $\phi_b = 3.94$, $\phi_b = 4.03$, and $\phi_b = 4.80$. Table 3 shows the welfare changes of the combination of CRR macroprudential rules and three monetary policy rules.

According to Table 3, no matter what monetary policy rules the central bank implements, the introduction of CRR macroprudential rules can improve the total social welfare. In addition, with the increase of the types of factors considered in monetary policy, the improvement of total social welfare caused by the introduction of CRR macroprudential policy decreases, in which the welfare of patient households and bankers increases, while that of impatient households decrease.

*5.2.2. Optimal Combination of CRR Macroprudential Policies and Monetary Policies.* We use the model that only considers Taylor rule 1 as the benchmark model, compare the optimal combination of three monetary policies and CRR macroprudential policies with the benchmark, and get the welfare changes of the optimal policy combination in the three situations, as shown in Table 4.

According to Table 4, the welfare improvement of case one is the largest in the combination of three monetary policy rules and CRR macroprudential rules. Although the welfare improvement of Case 1 is not much larger than that of Case 2 and Case 3, it can be noted that one of the major advantages of Case 1 is that only inflation factors need to be considered in the monetary policies. Case 1 makes the

Table 3: Welfare improvement of the optimal combination of monetary policy rules and CRR macroprudential rules.

| | Optimal CRR parameter | Patient households | Impatient households | Bankers | Total social welfare |
|---|---|---|---|---|---|
| Taylor 1 + CRR macroprudential rules | 3.94 | 0.0036 | −5.6603 | 67.6732 | 4.1158 |
| Taylor 2 + CRR macroprudential rules | 4.03 | 0.0966 | −2.8716 | 43.5952 | 2.6911 |
| Taylor 3 + CRR macroprudential rules | 4.80 | −0.0094 | −1.6149 | 41.7888 | 2.6354 |

Table 4: Welfare changes of the optimal combination of CRR macroprudential rules and monetary policy rules.

| | Parameters and variables | Case 1 | Case 2 | Case 3 |
|---|---|---|---|---|
| Taylor rules | $r_R$ | 0.8 | 0.8 | 0.8 |
| | $r_\pi$ | 0.7 | 0.7 | 0.7 |
| | $r_Y$ | 0 | 0.3 | 0.3 |
| | $r_q$ | 0 | 0 | 0.1 |
| CRR rules | $\phi_b$ | 3.94 | 4.03 | 4.80 |
| Patient households | $\mathrm{WL}_s$ | 0.0036 | 0.2852 | −1.1689 |
| Impatient households | $\mathrm{WL}_b$ | −5.6603 | 6.3955 | 4.4840 |
| Bankers | $\mathrm{WL}_f$ | 67.6732 | 52.9116 | 56.6445 |
| Total social welfare | WL | 4.1158 | 3.7619 | 3.8944 |

objectives of the central bank simpler, which helps to improve the efficiency of policy implementation and avoids conflicts among multiple policy objectives.

*5.3. Analysis of the Optimal Policy Combination of Macroprudential Policies and Monetary Policies.* According to Tables 2 and 4, we can see that in the optimal "two pillar" framework of monetary policies and macroprudential policies, the main goal of monetary policies is to stabilize price inflation, and the macroprudential mechanism is to implement the macroprudential policy of counter-cyclical capital for bankers. The optimal policy combination can effectively promote the stability of the real estate market, financial market, and macroeconomy and maximize the improvement of the total social welfare simultaneously. A properly separated and coordinated regulatory framework between monetary policies and macroprudential policies is conducive to achieving price stability and economic growth, taking into account the stability of the real estate market and financial market and effectively preventing systemic risks.

*5.4. Impulse Response Analysis of a Housing Preference Shock.* Figure 1 shows the impulse response of a housing preference shock. Due to the rigidity of real estate supply in a certain period, the increase of real estate demand will inevitably lead to a large increase in housing prices. The wealth effect of the rising housing prices and the mortgage effect of the rising value of housing mortgage assets promote the increase of credit scale and housing demand of households as well as the increase of housing holdings. The rapid growth of housing prices, credit, and output make the financial market and real estate market fluctuate greatly.

After the implementation of the LTV macroprudential policy, when housing prices rise, the LTV will automatically decline, making the credit scale and housing holdings of impatient households decline; in addition, employment declines, output falls, and wages fall, resulting in the decline of the real disposable income and consumption of impatient households. Under the macroprudential mechanism of LTV, the inflation level drops and the real debt interest expenditure of impatient households increases, which also has a crowding out effect on consumption and a certain degree of restraint on output.

When housing demand increases, housing prices rise and the scale of impatient household credit increases. However, based on the CRR macroprudential policy, the proportion of counter-cyclical capital requirements is increased automatically, which restrains the increase of credit scale and housing holdings of impatient households. The credit scale and housing holdings of impatient households under the CRR mechanism are between that of benchmark model and that of LTV rules; besides, the real estate market and financial market are more stable. In addition, the housing prices are also between the benchmark model and LTV rules, which has a certain inhibition on the rise of housing prices. Wages, employment, consumption, and output have increased.

To sum up, compared with the LTV macroprudential mechanism, the CRR macroprudential mechanism makes the impact of housing preference shock on the financial market and real estate market less and achieves the goals of restraining housing prices, promoting financial market stability and macroeconomic growth, with better implementation effect.

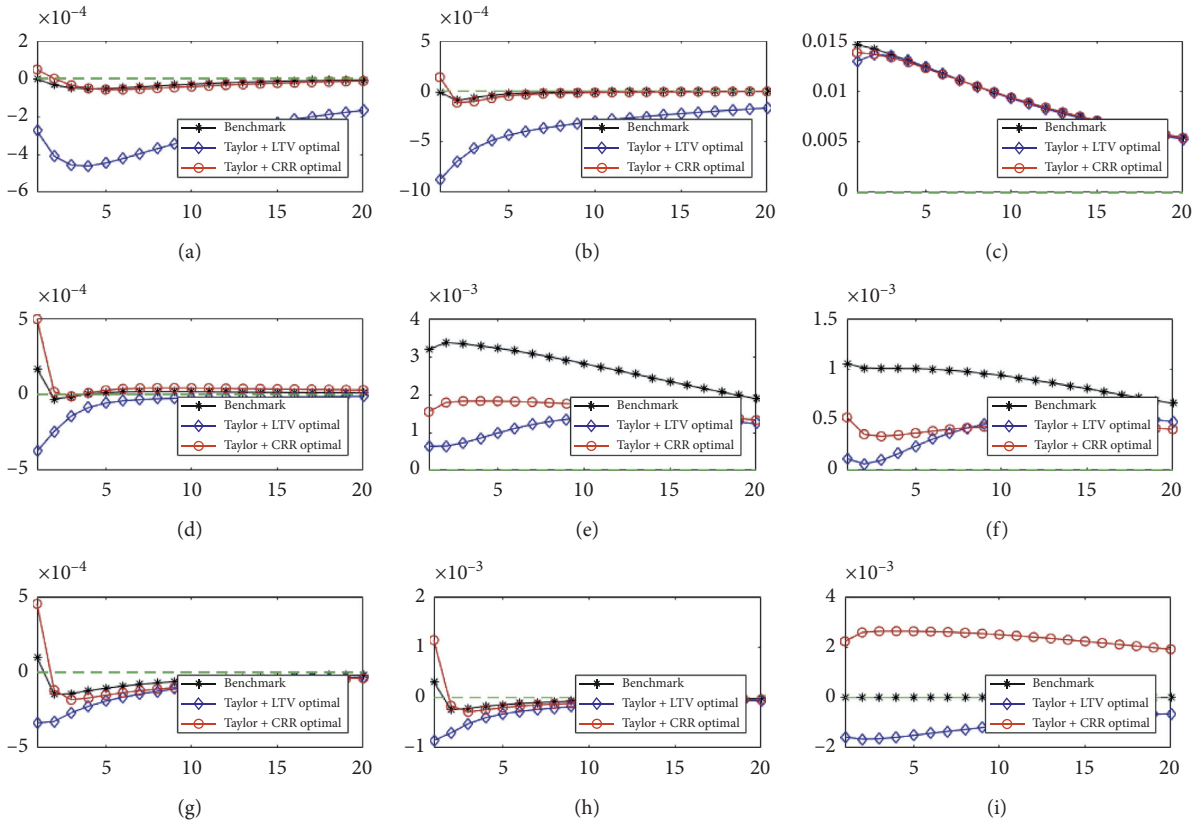


Figure 1: Impulse response analysis of a housing preference shock. (a) Rs, (b) Pai, (c) q, (d) y, (e) bb, (f) Hb, (g) Cb, (h) Wb, and (i) kappa CRR.

## 6. Conclusions

Based on the analysis framework of the DSGE model considering the housing market, this paper identifies the optimal policy combinations, discusses the fluctuation characteristics of the main macroeconomic variables, and analyzes the coordination effects between macroprudential policies and monetary policies. The results show the following.

Firstly, irrespective of the kind of monetary policy rules, the total social welfare has been improved after the introduction of endogenous LTV or CRR macroprudential rules. Secondly, when implementing the prudent monetary policy rule, that is, the target of interest rate includes inflation, output, and housing price factors, the welfare improvement of introducing LTV or CRR macroprudential rules is smaller than that of the other two monetary policies. Compared with the standard monetary policy rule, the interest rate that reacts to the output will limit the financial accelerator effect of credit constraints and reduce the improvement of total social welfare. In addition, the interest rate that reacts to the output and housing prices has a stronger macroprudential effect. The central bank can partially complete the functions of prudential regulators through the appropriate combination of parameters in the monetary policy rules; however, it will also make the central bank consider too many factors in the formulation of monetary policies, thus bearing too many functions and affecting the effect of policy implementation. Thirdly, the monetary policy rules that constitute the optimal policy combination with LTV rules are prudent monetary policy rules, which need to consider inflation, output, and housing prices; the monetary policy rules that constitute the optimal policy combination with CRR rules are standard Taylor monetary policy rules, which only need to consider the single factor of inflation. Fourthly, by comparing the welfare analysis of various combinations of monetary policy rules and macroprudential rules, we obtain the optimal policy combination. In the optimal "two pillar" framework, the main goal of monetary policy is to stabilize price inflation; macroprudential policy is to implement the CRR macroprudential policy for bankers. The optimal combination can effectively promote the stability of the real estate market, financial market, and macroeconomy and make the improvement of the total social welfare the largest.

In conclusion, the optimal control of monetary policy is mainly to stabilize price inflation; besides, the macroprudential policy of CRR is mainly to control the scale of credit. By acting on the financial market, CRR rules can restrain the excessive expansion of credit leverage, reduce the risk of financial institutions, enhance the counter periodicity, and improve the stability of the financial market. The establishment of a "two pillar" financial regulatory framework of monetary policies and macroprudential policies, through their coordination and complementation, can

effectively prevent systemic financial risk and improve total social welfare on the basis of maintaining price stability and economic growth.

## Data Availability

The results of this work are obtained by model simulation. The program and data are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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