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以 DSGE 模型探討臺灣總體審慎與貨幣政策對房屋市場的監理

Regulating Housing Market in Taiwan: An Analysis of Monetary/Macroprudential Policies Using a DSGE Model

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摘要

我國中央銀行負有穩定經濟、金融市場之責任，不僅需維持通貨膨脹、總體產出、外匯等於一定水準，對臺灣人民相當重要的房屋不動產市場亦是受監理之標的。與此同時，有鑑於 2008 年金融風暴，各國紛紛採用總體審慎政策維持金融穩定。本文主要探討總體審慎與貨幣政策在臺灣的最佳組合，尤其是房屋價格該由何種手段監理，以最小化經濟波動並最大化社會福利增加，並探討經濟體中不同角色之福利權衡。

本文以 Tsai et al. [2022] 及 Rubio and Carrasco-Gallego [2014] 為基礎，建立小型開放動態隨機一般均衡模型，並在模型中加入總體審慎部門以及福利分析，用以探討經濟穩定與福利的問題。本文的發現顯示，若以社會福利極大化為目標，監理房屋市場波動的責任應由貨幣政策承擔。然而，以總體審慎監理房價及限制信用擴張將是次佳政策。

關鍵詞: 小型開放隨機一般均衡模型、福利分析、房屋市場、借貸限制式、貨幣政策、總體審慎政策、貸款乘數

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Abstract

The primary responsibility of the central bank in Taiwan is to stabilize the economy and financial markets. This entails maintaining inflation, overall output, and foreign exchange at a certain level. Additionally, the central bank also supervises the housing and real estate market, which holds significant importance for the people of Taiwan. In light of the global financial crisis in 2008, countries have implemented comprehensive prudential policies to ensure financial stability. This paper focuses on the optimal combination of macroprudential and monetary policies in Taiwan, particularly in terms of supervising house prices. The objective is to minimize economic fluctuations and maximize increases in social welfare. The welfare trade-offs of different roles within the economy are also explored.

To address these issues, this paper establishes a small open dynamic stochastic general equilibrium model based on the research conducted by Tsai et al. [2022] and Rubio and Carrasco-Gallego [2014]. The model incorporates macroprudential and welfare analysis to examine economic stability and welfare.

The findings of the study indicate that if the aim is to maximize social welfare, the responsibility for monitoring housing market volatility should lie with monetary policy. However, macroprudential monitoring of housing prices and the limitation of credit expansion represent a viable second-best policy option.

Keywords: Small Open DSGE, Welfare, Housing Market, Collateral Constraints, Monetary Policy, Macroprudential Policy, LTV Ratio

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1 Introduction

Housing assets have held paramount importance for Taiwanese, and the notion that individuals should possess their land or residences is deeply ingrained, as exemplified by the adage, “Along with real estate comes about wealth.” According to the 2020 National Wealth Report of Taiwan, the portfolio of assets includes a significant portion of land, accounting for 42.26%, and the second largest portion is allocated to housing, accounting for 22.51%. Furthermore, when considering general households, housing assets calculated by market price, constitute approximately 31.54% of the total household assets. Consequently, acquiring a comprehensive understanding of the housing market in Taiwan emerges as a crucial matter.

The focal point of this thesis revolves around macroprudential policies. In the aftermath of the global financial crisis of 2007-2009, various macroprudential policies have been devised by central banks to alleviate systemic risks. These include the loan-to-value (LTV) ratio, credit-to-GDP ratio, debt-to-income ratio, and leverage ratio. The European Systemic Risk Board recognizes LTV as one of the primary macroprudential instruments to “mitigate and prevent excessive credit growth and leverage.” Consequently, it has gained widespread popularity as a means to curtail credit expansion worldwide, often serving as a cap on collateral. In this thesis, the focus lies specifically on the LTV ratio, where regulatory authorities have imposed an upper limit on credit, thereby restricting an individual’s borrowing capacity. This measure ensures that credit expansion does not perpetuate indefinitely, thereby promoting stability within the housing market. In Taiwan, the central bank plays a pivotal role in the enforcement of LTV regulations within the housing market, where it establishes limitations on borrowing practices, consequently rendering the process of acquiring mortgage loans more demanding.

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In addition to macroprudential policies, central banks could still use monetary policy to change the interest rate and influence the housing market. According to Iacoviello and Neri [2010], housing prices demonstrate a greater responsiveness to monetary policy shocks compared to consumer prices. This leads us to consider the optimal coordination between monetary and macroprudential policies, aiming to achieve the most effective approach in stabilizing the economy, without subjecting individuals to undue distortions resulting from the policy framework.

To undertake a comprehensive examination of the coordination between these two policies in Taiwan, it is necessary to incorporate macroeconomics activities. Therefore, I have employed the Dynamic Stochastic General Equilibrium (DSGE) framework to analyze the aforementioned issues. In this study, the Taiwan economy has been modeled and adjusted from Tsai et al. [2022], and the parameters have been calibrated in accordance with their estimations. In the model, I have incorporated macroprudential policy, specifically the LTV ratio using the Taylor rule. It is worth noting that, in the original work by Tsai et al. [2022], first-order approximations were used. However, exact solutions were derived in this case to fulfill the requirements of welfare analysis. Additionally, impulse response analyses were conducted, yielding results consistent with their findings in model construction. Furthermore, an analysis of the welfare trade-offs experienced by three kind of individuals: savers, borrowers and entrepreneurs has been conducted. The welfare analysis in this paper follows the methodology presented in Rubio and Carrasco-Gallego [2014], which minimizes a loss function representing the volatility of the economy. To determine optimal parameters for different policy regimes, an adjusted loss function has been proposed. To gain further insights into the underlying mechanisms, I further present the mean and standard deviations of various endogenous variables using second-order

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perturbation.

The findings of this thesis are as follows: First, regulating housing prices through monetary policy rather than macroprudential policy can lead to greater stability and maximum social welfare. Second, when monetary policy takes housing price fluctuations into account, savers in this economy are negatively impacted the most, while entrepreneurs benefit the most, resulting in an overall improvement in social welfare. Third, differences between borrowers and entrepreneurs become more apparent when domestic borrowing conditions are poor, as entrepreneurs can access foreign financial markets.

The following sections of the paper continues as follows: Section 2 reviews DSGE models in discussing Taiwan housing markets. Section 3 describes the model of this thesis. Section 4 presents the impulse response analyses. Section 5 defines the welfare measure and explores the welfare trade-offs by increasing the parameters controlled by macroprudential and monetary policies. Section 6 defines the loss function, identifies the optimal parameters under six different policy regimes, and examines the welfare trade-off further. Section 7 concludes the paper and discusses its implications for policymakers and future research.

2 Literature Review

The quantity of literature discussing the Taiwan economy utilizing a small open DSGE model is relatively limited. In Teo [2009b], a small open new Keynesian DSGE model was constructed, based on Adolfson et al. [2007]. The model incorporates multiple sources of real and nominal rigidities, personal liquidity preference, and assumes the existence of only one type of household. The author closed the economy by introducing a friction on the foreign finance market, and employed Bayesian method to estimate the parameters

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using Taiwanese data. The model features a money supply growth rate rule rather than a Taylor-style model, with the primary objective of studying monetary policy and the business cycle dynamics specific to Taiwan.

Li [2014] constructed a small open economy model by adopting the framework of the Iacoviello and Neri [2010] model and utilizing the method of Kollmann [2002] to incorporate the foreign financial market. The model considers the presence of savers and borrowers within the economy, and the research questions are similar to those in this paper, focusing on determining the optimal policy coordination for the overall economy. The author finds that using interest rate to regulate the housing market is more effective than employing macroprudential LTV measures from a social welfare standpoint.

Our finding is similar to that of Li [2014], but the approach is different. Firstly, the optimal parameters in Li [2014] are obtained by directly maximizing the welfare function, whereas in my analysis, I have utilized a loss function minimization approach. In defense, I argue that welfare is not directly observable, whereas the loss function, representing market variabilities, is observable to regulatory institutes and can can serve as a justification for their decision-making processes. Second, the parameter search of Li [2014] is conducted separately for interest rate rule and the macroprudential rule, with one set of parameters being held fixed at a time. In contrast, my method undertakes a joint parameter search, recognizing the potential interactions between the two rules. This approach enhances the possibility of attaining optimized parameters by considering the interactions between these rules.

Chu [2018] also built the model utilizing the Iacoviello and Neri [2010] model framework, incorporating both savers and borrowers, and imposing a monopolistic competitive structure on both domestic and foreign banking sectors. The objective of the thesis is

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to examine the impact of taxes on the housing market, specifically investigating the differential effects of property tax and transfer tax. The housing market is further divided into resident and investment segments, and the author discovered a strong interconnection between the prices of these two markets.

Tsai et al. [2022] developed a medium-sized DSGE model based on the frameworks presented in Iacoviello [2005] and Wang [2021]. Additionally, they incorporated the foreign financial market component from the model proposed by Kollmann [2002]. This DSGE model considers various economic agents such as savers, borrowers, and entrepreneurs. To estimate the parameters of the DSGE model, Tsai et al. [2022] employed a Bayesian method. The estimated parameters from their work were directly utilized in this paper to calibrate the model being discussed. Furthermore, Tsai et al. [2022] conducted a comparison between the DSGE model and VAR (Vector Autoregression) models with different settings. They found that the combined DSGE-VAR model, which involves projecting the DSGE model onto a BVAR (Bayesian Vector Autoregression) model, demonstrated favorable performance in predicting macroeconomic activities.

3 Model

In this study, a small open DSGE model was developed to emulate the economy of Taiwan. The model was adapted from the framework of Tsai et al. [2022] and was fine-tuned by incorporating several modifications and simplifications. For the notations, the subscript t of a variable represents the value of the variable in period t, while variables without subscripts represent steady-state values.

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3.1 Final Producers

Firstly, the final producers in the economy operate under perfect competition, transforming both domestic goods $y_{d,t}$ and imported goods $y_{m,t}$ into a homogenous final good y_t, using the production function:

$$y_t = \left[(1-\omega_m)^{\frac{1}{\kappa_z}} y_{d,t}^{\frac{\kappa_z - 1}{\kappa_z}} + \omega_m^{\frac{1}{\kappa_z}} y_{m,t}^{\frac{\kappa_z - 1}{\kappa_z}} \right]^{\frac{\kappa_z}{\kappa_z - 1}}. \tag{1}$$

Here, κ_z is the substitution coefficient between domestic and foreign goods in the production function, and ω_m is the proportion of import to final goods in the steady-state, representing the openness of the economy.

Given the final good price P_t, the domestic goods price $P_{d,t}$, and the import goods price $P_{m,t}$, solving the profit maximization problem indicates the demand function for both components:

$$y_{d,t} = (1-\omega_m) \left(\frac{P_{d,t}}{P_t} \right)^{-\kappa_z} y_t = (1-\omega_m) p_t^{\kappa_z} y_t, \tag{2}$$

$$y_{m,t} = \omega_m \left(\frac{P_{m,t}}{P_t} \right)^{-\kappa_z} y_t = \omega_m \left(\frac{p_t}{X_{m,t} e_t} \right)^{\kappa_z} y_t. \tag{3}$$

Here, $p_t = \frac{P_t}{P_{d,t}}$ represents the real final good price of the final good, $X_{m,t} = \frac{P_{m,t}}{S_t P_t^*}$ is the import price markup, where S_t is the nominal exchange rate, and P_t^* is the foreign good price in terms of foreign currency, and $e_t = \frac{S_t P_t^*}{P_{d,t}}$ represents the real exchange rate. The real final good price therefore satisfies

$$p_t^{1-\kappa_z} = (1-\omega_m) + \omega_m (X_{m,t} e_t)^{1-\kappa_z}. \tag{4}$$

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Inflation rates are related as:

$$\frac{\Pi_t}{\Pi_{d,t}} = \frac{P_t/P_{t-1}}{P_{d,t}/P_{d,t-1}} = \frac{p_t}{p_{t-1}}, \tag{5}$$

$$\frac{\Pi_{m,t}}{\Pi_{d,t}} = \frac{P_m/P_{m-1}}{P_{d,t}/P_{d,t-1}} = \frac{X_{m,t}e_t}{X_{m,t-1}e_{t-1}}. \tag{6}$$

The variable Π_t represents the inflation rate of final goods prices, while $\Pi_{d,t}$ and $\Pi_{m,t}$ represent the inflation rates of domestic and import goods prices, respectively.

In the steady-state, $P_t = P_{d,t} = P_{m,t}$ due to the purchasing power parity assumption, which implies $p = X_m \cdot e = 1$ in the steady-state.

3.2 Domestic Retailers

Domestic retailers operate competitively. They buy heterogeneous products from infinitesimal wholesale firms, indexed by $s \in [0,1]$, under the Dixit-Stiglitz monopolistic competition setting. Retailers combine those wholesale goods using the following technology:

$$y_{d,t} = \left[\int_0^1 y_{d,t}(s)^{\frac{\xi-1}{\xi}} ds\right]^{\frac{\xi}{\xi-1}}, \tag{7}$$

where ξ is the elasticity of substitution between heterogeneous goods.

Given domestic goods price $P_{d,t}$ and the domestic goods wholesale price $P_{d,t}(s)$, the maximization problem for domestic retailors is:

$$\max_{y_{d,t}(s)} P_{d,t}y_{d,t} - \int_0^1 P_{d,t}(s)y_{d,t}(s)ds \tag{8}$$

Solving the problem yields the demand function of the domestic retailers for each small

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wholesale firm:

$$y_{d,t}(s) = \left[\frac{P_{d,t}(s)}{P_{d,t}}\right]^{-\xi} y_{d,t}. \tag{9}$$

Also, under the Dixit-Stiglitz setting, the domestic goods price will be set at

$$P_{d,t} = \left[\int_0^1 P_{d,t}(s)^{1-\xi} ds\right]^{\frac{1}{1-\xi}}. \tag{10}$$

3.3 Export Firms

Competitive export firms purchase heterogeneous products from domestic wholesale firms and pack them similarly under the Dixit-Stiglitz setting:

$$y_{x,t} = \left[\int_0^1 y_{x,t}(s)^{\frac{\xi-1}{\xi}} ds\right]^{\frac{\xi}{\xi-1}}. \tag{11}$$

The demand function for each small wholesale firm then is

$$y_{x,t}(s) = \left[\frac{P_{d,t}(s)}{P_{d,t}}\right]^{-\xi} y_{x,t}. \tag{12}$$

For simplicity, we assume that the combining substitution of elasticity technology ξ in (7) and (11) take the same value.

The foreign economy's demand for the small open economy, following McCallum and Nelson [1999], Teo [2009a] and Dib [2011], is set as

$$y_{x,t} = \omega_x y_a (e_t/e)^{\kappa_x} ex_t, \tag{13}$$

where ω_x is the proportion of y_x to y_a in steady-state, κ_x is the foreign elasticity of sub-

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stitution between domestic and import goods, y_a is the output from entrepreneurs or the GDP of the economy, and ex_t is the foreign demand shock.

3.4 Wholesale Firms

Wholesale firms, which are owned by savers of the economy, buy homogeneous inputs $y_{a,t}$ from entrepreneurs with wholesale price P_t^w and are owned by savers of the economy. For each small wholesale firm s, it differentiates $y_{a,t}(s)$ into

$$y_{a,t}(s) = y_{d,t}(s) + y_{x,t}(s) \tag{14}$$

and sells them to the domestic retailers $(y_{d,t}(s))$ and export firms $(y_{x,t}(s))$ respectively with no further cost. The wholesale firms sell those intermediates under Calvo sticky price setting. In each term, a proportion of θ_d firms cannot choose their price freely. The optimal price setting $\bar{P}_{d,t}(s)$ for firm s is to satisfy:

$$\sum_{k=0}^{\infty} \theta_d^k \mathbb{E}_t \left\{ \Lambda_{t,t+k} \left[\frac{\bar{P}_{d,t}(s)}{P_{d,t+k}} - \frac{X_d}{X_{d,t+k}} \right] y_{a,t+k}(s) \right\} = 0, \tag{15}$$

where $\Lambda_{t,k} = (\beta^s)^k (uc_{t+k}^s)/(uc_t^s)$ is the stochastic discount factor of savers, uc^s is savers' the marginal utility of consumption, $X_{d,t} = P_{d,t}/P_t^w$ is the wholesale firm's price markup, and $X_d = \frac{\xi}{\xi-1}$ is the steady state markup.

To make this infinite horizon scheme computable without resorting to linear approximation, we follow Fernández-Villaverde and Rubio-Ramírez [2006], and turn the setting

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into a set of recursive equations:

$$
\begin{aligned}
\xi\Theta_{1,d,t} =&(\xi-1)\Theta_{2,d,t}, &(16)\\
\Theta_{1,d,t} =&uc_t^s y_{a,t}/X_{d,t} + \beta^s\theta_d\mathbb{E}_t\{\Pi_{d,t+1}^{\xi}\}\Theta_{1,d,t+1}, &(17)\\
\Theta_{2,d,t} =&uc_t^s\Pi_{d,new,t}y_{a,t} + \beta^s\theta_d,\mathbb{E}_t\left\{\frac{\Pi_{d,t+1}^{\xi-1}\Pi_{d,new,t}}{\Pi_{d,new,t+1}}\right\}\Theta_{2,d,t+1}, &(18)\\
1 =&\theta_d\Pi_{d,t}^{\xi-1} + (1-\theta_d)\Pi_{d,new,t}^{1-\xi}, &(19)
\end{aligned}
$$

where $\Theta_{1,d,t}$ and $\Theta_{2,d,t}$ are auxiliary variables, and $\Pi_{d,new}$ is the inflation rate of the optimal price setting.

Instead of following Tsai et al. [2022], the decision to not employ log-linearization for (15) is based on the argument put forth by Benigno and Woodford [2012]. According to their findings, a second-order perturbation is necessary for accurately assessing welfare through numerical evaluation. Therefore, it is necessary to specify the exact model instead of using a linear approximated one.

3.5 Import Retailers

The settings for import retailers are similar to those for domestic retailers, as both operate in competitive markets and combine heterogeneous products from wholesale firms. The import retailers buy heterogeneous goods from import wholesale firms, and combine the goods using the Dixit-Stiglitz technology:

$$y_{m,t} = \left[\int_0^1 y_{m,t}(s)^{\frac{\xi-1}{\xi}}ds\right]^{\frac{\xi}{\xi-1}}. \tag{20}$$

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After solving the maximization problem, the demand function for each import wholesale firm is given by

$$y_{m,t}(s) = \left[\frac{P_{m,t}(s)}{P_{m,t}}\right]^{-\xi} y_{m,t}, \tag{21}$$

where $P_{m,t}$ is the import good retail price, and $P_{m,t}(s)$ is the import good wholesale price. The import good price is set at

$$P_{m,t} = \left[\int_0^1 P_{m,t}(s)^{1-\xi} ds\right]^{\frac{1}{1-\xi}}. \tag{22}$$

3.6 Import Wholesale Firms

The import wholesale firms are owned by savers. They buy homogeneous goods from foreign countries at cost $S_t P_t^*$. They turn those homogeneous goods into heterogeneous intermediates and sell them to import retailers. Assume at each term, a proportion of θ_m import wholesale firms could not set their price freely, then the optimal price $\bar{P}_{m,t}(s)$ satisfies

$$\sum_{k=0}^{\infty} \theta_m^k \mathbb{E}_t \left\{\Lambda_{t,t+k} \left[\frac{\bar{P}_{m,t}(s)}{P_{m,t+k}} - \frac{X_m}{X_{m,t}}\right] y_{m,t+k}(s)\right\} = 0, \tag{23}$$

where $X_{m,t} = \frac{P_{m,t}}{S_t P_t^*}$ is the import price markup, and $X_m = \frac{\xi}{\xi-1}$.

This infinite optimal price scheme can also be computed by writing into a set of recur-

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sive equations

$$\xi\Theta_{1,m,t} = (\xi-1)\Theta_{2,m,t}, \tag{24}$$

$$\Theta_{1,m,t} = \lambda_t^s y_{m,t}/X_{m,t} + \beta\theta_m \mathbb{E}_t\{\Pi_{m,t+1}^{\xi}\}\Theta_{1,m,t+1}, \tag{25}$$

$$\Theta_{2,m,t} = \lambda_t^s \Pi_{m,new,t} y_{m,t} + \beta\theta_m \mathbb{E}_t\{\Pi_{m,t+1}^{\xi-1}\Pi_{m,new,t}/\Pi_{m,new,t+1}\}\Theta_{2,m,t+1}, \tag{26}$$

$$1 = \theta_m \Pi_{m,t}^{\xi-1} + (1-\theta_m)\Pi_{m,new,t}^{1-\xi}, \tag{27}$$

where $\Theta_{1,m,t}$ and $\Theta_{2,m,t}$ are auxiliary variables, and $\Pi_{m,new}$ is the inflation rate of the optimal import wholesale price.

3.7 Entrepreneurs

Entrepreneurs produce homogeneous goods using the Cobb-Douglas technology:

$$y_{a,t} = A_t(k_{t-1})^{\mu}(h_{t-1}^e)^{\nu}\left[(n_t^s)^{\alpha}(n_t^b)^{1-\alpha}\right]^{1-\mu-\nu}, \tag{28}$$

where h^e represents the proportion of houses owned by entrepreneurs, n_t^s and n_t^b represent the labor hours contributed by savers and borrowers, respectively, k denotes the level of capital accumulation, and A represents the technology shock. Returns on k, h^e, n^s, n^b are $\mu, \nu, (1-\mu-\nu)\alpha$, and $(1-\mu-\nu)(1-\alpha)$, respectively.

Entrepreneurs maximize their utility function through adjusting consumption, capital accumulation, labor usage, housing and borrowing:

$$\max \mathbb{E}\sum_{t=0}^{\infty}(\beta^e)^t d_t \log(c_t^e - \varepsilon_c c_{t-1}^e), \tag{29}$$

where β^e is the entrepreneurs' time discount factor, d is the inter-temporal shock, and ε_c

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is the consumption habit formation parameter.

Entrepreneurs are subject to the budget constraint

$$
\begin{aligned}
&p_t(c_t^e + i_t) + q_t(h_t^e - h_{t-1}^e) + w_t^s n_t^s + w_t^b n_t^b \\
&\quad = \frac{y_{a,t}}{X_{d,t}} + (b_t^e - \frac{R_{t-1}}{\Pi_{d,t}} b_{t-1}^e) + e_t \left[b_t^{e^*} - \frac{R_{t-1}^*}{\Pi_t^*} b_{t-1}^{e^*} - \frac{\Phi^*}{2}(b_t^{e^*} - b^{e^*})^2 \right], \qquad (30)
\end{aligned}
$$

where i represents the investment, w^s and w^b represent the real wage rate for two kinds of households, q represent the real price of houses, b^e and b^{e^*} represent the borrowing amount from domestic and foreign respectively, R and R^* represent the interest rate of domestic and foreign respectively, and Π^* represents the foreign inflation rate. The term $\frac{\Phi^*}{2}(b_t^{e^*} - b^{e^*})^2$ characterizes the friction of borrowing from a foreign economy that deviates from the steady-state level.

The law of capital accumulation is

$$
k_t = a_t^i i_t + (1-\delta)k_{t-1} - \frac{\Phi}{2}\left(\frac{k_t}{k_{t-1}} - 1\right)^2 k_{t-1}, \qquad (31)
$$

where a_i is the capital accumulation technology, and δ is the depreciation rate. The term $\frac{\Phi}{2}\left(\frac{k_t}{k_{t-1}} - 1\right)^2 k_{t-1}$ is the friction loss due to the fluctuation of capital accumulation.

Entrepreneurs are required to provide collateral for both domestic and foreign borrowing, with a proportion of α^e of their housing serving as collateral for domestic borrowing, and $(1-\alpha^e)$ of their housing serving as collateral for foreign borrowing. The domestic collateral constraint is defined by the inequality:

$$
R_t b_t^e \leq \mathbb{E}_t \left[m_t \alpha_t^e \Pi_{d,t+1} q_{t+1} h_t^e \right], \qquad (32)
$$

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while the foreign collateral constraint is defined as follows, based on Iacoviello and Minetti [2006]:

$$e_t R_t^* b_t^{e^*} \leq \mathbb{E}_t \left\{ \Pi_{d,t+1}(1-\alpha_t^e) q_{t+1} h_t^e \left[1 - \frac{(1-m^{e^*})}{qh^e}(1-\alpha_t^e) q_{t+1} h_t^e \right] \right\}, \tag{33}$$

where m and m^{e^*} represent the domestic and foreign loan-to-value ratios, respectively.

The marginal utility of entrepreneurs is

$$uc_t^e = \mathbb{E}_t \left[\frac{d_t}{c_t^e - \varepsilon_c c_{t-1}^e} - \frac{\beta^e d_{t+1} \varepsilon_c}{c_{t+1}^e - \varepsilon_c c_t^e} \right], \tag{34}$$

and the first order conditions are listed as follows:

$$\lambda_t^e p_t = uc_t^e, \tag{35}$$

$$\begin{aligned} \lambda_t^e q_t = \mathbb{E}_t \Bigg[& \beta^e \lambda_{t+1}^e \left(\frac{\nu y_{a,t+1}}{X_{d,t+1} h_t^e} + q_{t+1} \right) + m_t \mu_t^e \alpha_t^e q_{t+1} \Pi_{d,t+1} \\ & + \mu_t^{e^*} (1-\alpha_t^e) \Pi_{d,t+1} q_{t+1} \left(1 - \frac{2(1-m^{e^*})(1-\alpha_t^e)}{qh^e} q_{t+1} h_t^e \right) \Bigg], \end{aligned} \tag{36}$$

$$\lambda_t^e = \mathbb{E}_t \left[\beta^e \lambda_{t+1}^e \frac{R_t}{\Pi_{d,t+1}} + \mu_t^e R_t \right], \tag{37}$$

$$[1 - \Phi^*(b_t^{e^*} - b^{e^*})] \lambda_t^e e_t = \mathbb{E} \left[\beta^e \lambda_{t+1}^e e_{t+1} \frac{R_t^*}{\Pi_{t+1}^*} + \mu_t^{e^*} e_t R_t^* \right], \tag{38}$$

$$w_t^s = \frac{\alpha(1-\mu-\nu) y_{a,t}}{n_t^s X_{d,t}}, \tag{39}$$

$$w_t^b = \frac{(1-\alpha)(1-\mu-\nu) y_{a,t}}{n_t^b X_{d,t}}, \tag{40}$$

$$\frac{p_t}{a_t^i} \lambda_t^e [1 + \Phi(k_t - k_{t-1})] = \mathbb{E} \left\{ \beta^e \lambda_{t+1}^e \left[\frac{\mu y_{a,t+1}}{X_{d,t+1} k_t} + \frac{p_{t+1}}{a_{t+1}^i} \left((1-\delta) - \frac{\Phi}{2} \left(1 - \frac{k_{t+1}^2}{k_t^2} \right) \right) \right] \right\}, \tag{41}$$

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$$\mathbb{E}_t[\mu_t^e m_t \Pi_{d,t+1} q_{t+1}] = \mathbb{E}_t \left\{ \mu_t^{e^*} \Pi_{d,t+1} q_{t+1} \left[1 - \frac{2(1-m^{e^*})(1-\alpha_t^e)}{qh^e} q_{t+1} h_t^e \right] \right\}, \quad (42)$$

where λ_t^e, μ_t^e, and $\mu_t^{e^*}$ are the Lagrange multipliers of the constraints.

3.8 Savers

Savers choose consumption, housing, and working hours to maximize their utility function:

$$\max_{c_t^s, h_t^s, n_t^s} \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta^s)^t d_t \left[\log(c_t^s - \varepsilon_c c_{t-1}^s) + j_t \log(h_t^s - \varepsilon_h h_{t-1}^s) - \frac{\tau_t}{1+\eta} (n_t^s)^{1+\eta} \right], \quad (43)$$

where β^s is the savers' discount factor, η is the substitution parameter of labor providing, and c^s, h^s and n^s represent consumption, housing, and labor hour choice. j and τ represent the shocks in housing and working preferences respectively.

Savers are subject to the following budget constraint:

$$\begin{aligned} & p_t c_t^s + q_t(h_t^s - h_{t-1}^s) + b_t^s + e_t\left(b_t^{s^*} - \frac{R_{t-1}^*}{\Pi_t^*} b_{t-1}^{s^*} - \frac{\Phi^*}{2}(b_t^{s^*} - b^{s^*})^2\right) + tax_t \\ & = w_t^s n_t^s + \frac{R_{t-1}}{\Pi_{d,t}} b_{t-1}^s + div_t^s, \end{aligned} \quad (44)$$

where div_t^s is the dividend from owning wholesale firms, and tax_t is the tax collected by the government. Since the discount factor is the highest among the three agents in the economy, savers are only able to lend money and do not borrow. In this model, savers can lend money to entrepreneurs and borrowers domestically, as well as to foreign economies, subject to an adjustment cost $\frac{\Phi^*}{2}(b_t^{s^*} - b^{s^*})^2$ similar to entrepreneurs.

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The first order conditions are listed below:

$$uc_t^s = \mathbb{E}_t \left(\frac{d_t}{c_t^s - \varepsilon_c c_{t-1}^s} - \frac{\beta^s d_{t+1} \varepsilon_c}{c_{t+1}^s - \varepsilon_c c_t^s} \right), \tag{45}$$

$$uh_t^s = \mathbb{E}_t \left(\frac{j_t d_t}{h_t^s - \varepsilon_h h_{t-1}^s} - \frac{\beta^s j_{t+1} d_{t+1} \varepsilon_h}{h_{t+1}^s - \varepsilon_h h_t^s} \right), \tag{46}$$

$$\lambda_t^s p_t = uc_t^s, \tag{47}$$

$$\lambda_t^s q_t = \mathbb{E}_t(\beta^s \lambda_{t+1}^s q_{t+1}) + uh_t^s, \tag{48}$$

$$d_t \tau_t (n_t^s)^\eta = \lambda_t^s w_t^s, \tag{49}$$

$$\lambda_t^s = \beta^s \mathbb{E} \left(\lambda_{t+1}^s \frac{R_t}{\Pi_{d,t+1}} \right), \tag{50}$$

$$(1 + \Phi^*(b_t^{s^*} - b^{s^*}))\lambda_t^s e_t = \beta^s \mathbb{E}_t \left(\lambda_{t+1}^s e_{t+1} \frac{R_t^*}{\Pi_{t+1}^*} \right). \tag{51}$$

It is worth noting that combining (50) and (51) and applying log-linearization can yield the uncovered interest rate parity condition:

$$\mathbb{E}_t \left[\log \left(\frac{S_t}{S_{t-1}} \right) \right] = \log \left(\frac{R_t}{R} \right) - \log \left(\frac{R_t^*}{R^*} \right) + \Phi^* b^{s^*} \log \left(\frac{b_t^{s^*}}{b^{s^*}} \right). \tag{52}$$

3.9 Borrowers

The setting of borrowers is similar to savers. They choose consumption, housing, and labor to maximize the utility:

$$\max_{c_t^b, h_t^b, n_t^b} \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta^b)^t d_t \left[\log(c_t^b - \varepsilon_c c_{t-1}^b) + j_t \log(h_t^b - \varepsilon_h h_{t-1}^b) - \frac{\tau_t}{1+\eta} (n_t^b)^{1+\eta} \right]. \tag{53}$$

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Borrowers are subject to the budget constraint:

$$p_t c_t^b + q_t(h_t^b - h_{t-1}^b) = w_t^b n_t^b + \left(b_t^b - \frac{R_{t-1}}{\Pi_{d,t}} b_{t-1}^b\right). \tag{54}$$

In this economy, borrowers do not save but instead borrow funds from savers. It is important to note that borrowers in this economy do not have access to the foreign borrowing market. The lack of access to foreign borrowing yields interesting behavior reflecting the asymmetry between entrepreneurs and borrowers, particularly when the domestic borrowing condition is poor.

The domestic borrowing collateral constraint is

$$R_t b_t^b \leq \mathbb{E}_t \left(m_t q_{t+1} \Pi_{d,t+1} h_t^b\right). \tag{55}$$

First order conditions are listed below:

$$uc_t^b = \mathbb{E}_t \left(\frac{d_t}{c_t^b - \varepsilon_c c_{t-1}^s} - \frac{\beta^b d_{t+1} \varepsilon_c}{c_{t+1}^b - \varepsilon_c c_t^b}\right), \tag{56}$$

$$uh_t^b = \mathbb{E}_t \left(\frac{j_t d_t}{h_t^b - \varepsilon_h h_{t-1}^b} - \frac{\beta^b j_{t+1} d_{t+1} \varepsilon_h}{h_{t+1}^b - \varepsilon_h h_t^b}\right), \tag{57}$$

$$\lambda_t^b p_t = uc_t^b, \tag{58}$$

$$\lambda_t^b q_t = \mathbb{E}_t(\beta^b \lambda_{t+1}^b q_{t+1} + \mu_t^b m_t q_{t+1} \Pi_{d,t+1}) + uh_t^b, \tag{59}$$

$$d_t \tau_t (n_t^b)^\eta = \lambda_t^b w_t^b, \tag{60}$$

$$\lambda_t^b = \mathbb{E}_t \left(\beta^b \lambda_{t+1}^b \frac{R_t}{\Pi_{d,t+1}} + \mu_t^b R_t\right). \tag{61}$$

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3.10 Government

The monetary policy adjusts interest rate according to the Taylor rule:

$$R_t = R_{t-1}^{r_R} \left[\left(\frac{\Pi_t}{\Pi} \right)^{r_\Pi} \left(\frac{y_t}{y_{t-1}} \right)^{r_y} \left(\frac{e_t}{e_{t-1}} \right)^{r_e} \right]^{1-r_R} R^{1-r_R} \exp(u_{R,t}), \tag{62}$$

where r_Π, r_y, r_e represent the adjustment strengths reacted to the inflation rate, the final good fluctuation, and the real exchange rate fluctuation, r_R is the coefficient that controls the inertia of the last term interest rate, and exp$(u_{R,t})$ is the monetary policy shock.

The government budget condition is set as

$$g_t y_t = tax_t, \tag{63}$$

where g is the proportion of output committed to government spending, and it is assumed that the government spending is financed by the taxes collected from the economy.

3.11 Market Clearing Condition

Below are the market clearing conditions for the commodity, housing, and domestic borrowing markets:

$$p_t y_t = p_t(c_t^s + c_t^b + c_t^e + i_t) + e_t(\Phi_t^{e^*} + \Phi_t^{s^*}) + p_t g_t y_t, \tag{64}$$

$$1 = h_t^s + h_t^b + h_t^e, \tag{65}$$

$$b_t^s = b_t^b + b_t^e. \tag{66}$$

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Finally, to close the economy, the balance of payment requires that the current account should be equal to the capital account:

$$e_t\left[\left(b_t^{s^*}-\frac{R_t^*}{\Pi_t^*}b_{t-1}^{s^*}\right)-\left(b_t^{e^*}-\frac{R_t^*}{\Pi_t^*}b_{t-1}^{e^*}\right)\right]=y_{x,t}-e_t y_{m,t}, \tag{67}$$

where $y_{x,t}-e_t y_{m,t}$ is the net export or balance of trade of this economy. Figure 1 illustrates relationships between the variables.

3.12 Shocks

All external shocks follow AR(1) process:

$$\log A_t = \rho_A \log A_{t-1} + \epsilon_{A,t}, \tag{68}$$

$$\log j_t = (1-\rho_j)\log j + \rho_j \log j_{t-1} + \epsilon_{j,t}, \tag{69}$$

$$\log d_t = \rho_d \log d_{t-1} + \epsilon_{d,t}, \tag{70}$$

$$\log \tau_t = \rho_\tau \log \tau_{t-1} + \epsilon_{\tau,t}, \tag{71}$$

$$\log a_t^i = \rho_{a^i} \log a_{t-1}^i + \epsilon_{a^i,t}, \tag{72}$$

$$\log g_t = (1-\rho_g)\log g + \rho_g \log g_{t-1} + \epsilon_{g,t}, \tag{73}$$

$$\log \Pi_t^* = (1-\rho_{\Pi^*})\log \Pi^* + \rho_{\Pi^*} \log \Pi_{t-1}^* + \epsilon_{\Pi^*,t}, \tag{74}$$

$$\log R_t^* = (1-\rho_{R^*})\log R^* + \rho_{R^*} \log R_{t-1}^* + \epsilon_{R^*,t}, \tag{75}$$

$$\log ex_t = \rho_{ex} \log ex_{t-1} + \epsilon_{ex,t}. \tag{76}$$

3.13 Calibration

The parameters in this models can be divided into two parts: deep parameters and structural parameters, which are listed in Table 1 and Table 2. The calibration of the parameters

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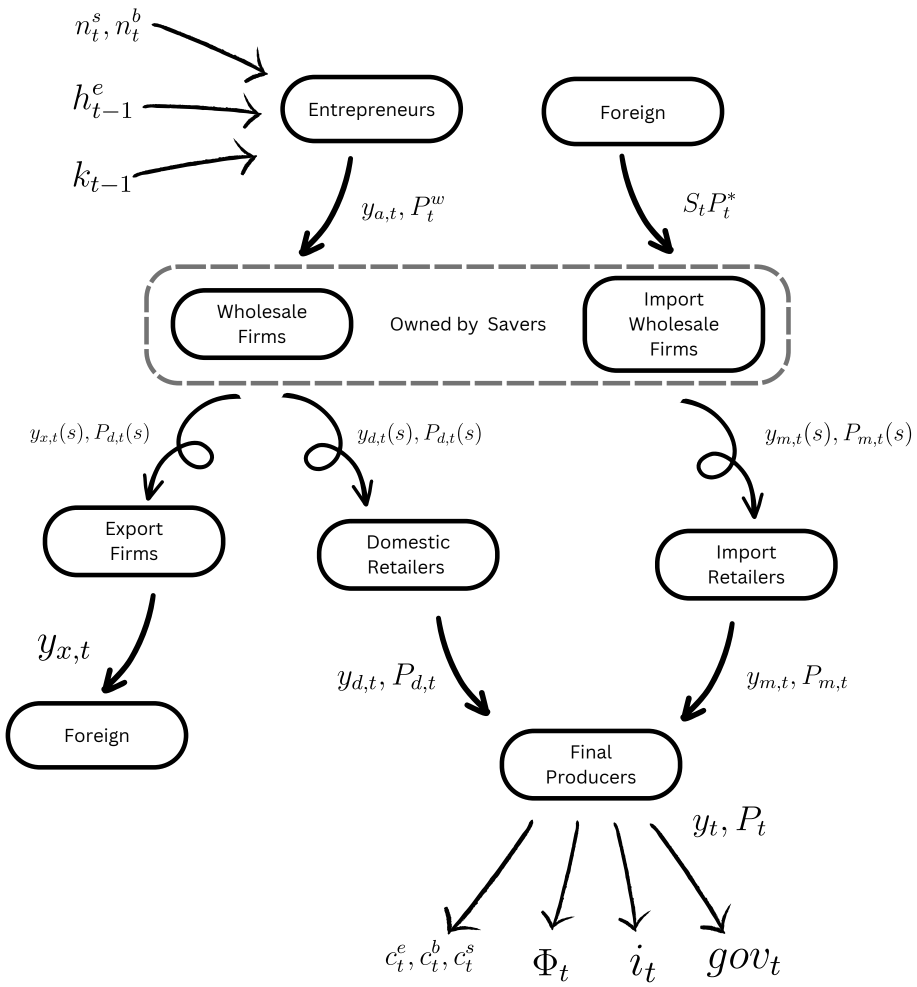

Figure 1: A simplified diagram of this small open economy. Straight arrows represent that the homogeneous goods are sold in competitive markets, whereas curved arrows sell heterogeneous products in a monopolistically competitive way. Both wholesale firms are owned by savers.

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Table 1: Deep parameters. Note: The values are taken from Tsai et al. [2022].

Deep Parameters Value
$\beta^s = 0.9978, \beta^b = \beta^e = 0.97$
$\epsilon_h = 0.0$
$\Pi_d = 1.0000$
$\omega_x = 0.6014, \omega_m = 0.6582$
$g = 0.1530$
$\delta = 0.025$
$\nu = 0.03$
$\mu = 0.3$
$m^b = m^e = 0.90$
$m^{e*} = 0.5$
$X_d = X_m = 1.2$

Table 2: Structural parameters. Note: The values are the posterior mean reported in Tsai et al. [2022].

Structural Parameters	Value
j	0.1848
η	2.6352
α	0.7926
ϵ_c	0.4216
Φ	18.4387
Φ_b	4.1898×10^{-5}
θ_d	0.4742
θ_m	0.5367
θ_w	0.5057
κ_x	3.4054
κ_z	1.6220
r_R	0.9151
r_Π	1.1955

is based on Tsai et al. [2022], where a comprehensive Bayesian estimation method was introduced to estimate the parameters. The structural parameters are listed in Table 2, which are set as the posterior mean reported in Table 6 in Tsai et al. [2022]. The deep parameters are almost the same as those in Tsai et al. [2022], with two exceptions. First, the labor union is not included here for simplicity, so relevant parameters do not appear. Second, to emphasize the trade-off between agents, it is necessarily to set the steady state of LTV ratio m higher to 0.90, as Iacoviello [2005] did, instead of 0.85 as reported in Table 5 in Tsai et al. [2022].

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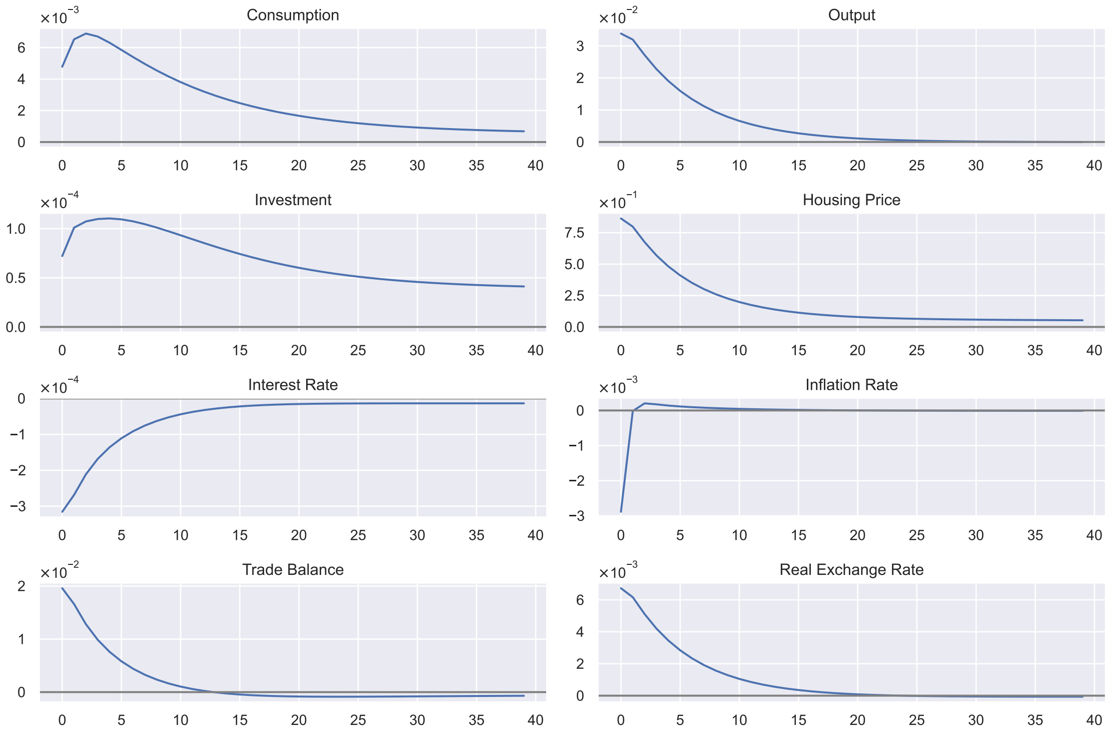

Figure 2: Positive technology shock

4 Impulse Responses

Several impulse response analyses are conducted. The analysis helps us to understand how endogenous variables change over time when the economy is subject to an external impact.

4.1 Technological Shocks

In Figure 2 shows the results of a positive technology shock on the economy. In general, a positive technology shock improves domestic economic conditions, leading to increases in consumption, investment, and output. As the positive technology shock reduces production costs, the effect will be reflected in domestic prices, causing domestic goods to gradually become cheaper and leading to a decrease in inflation. Monetary policy responds to the decrease in inflation by lowering interest rates, leading to lower domestic

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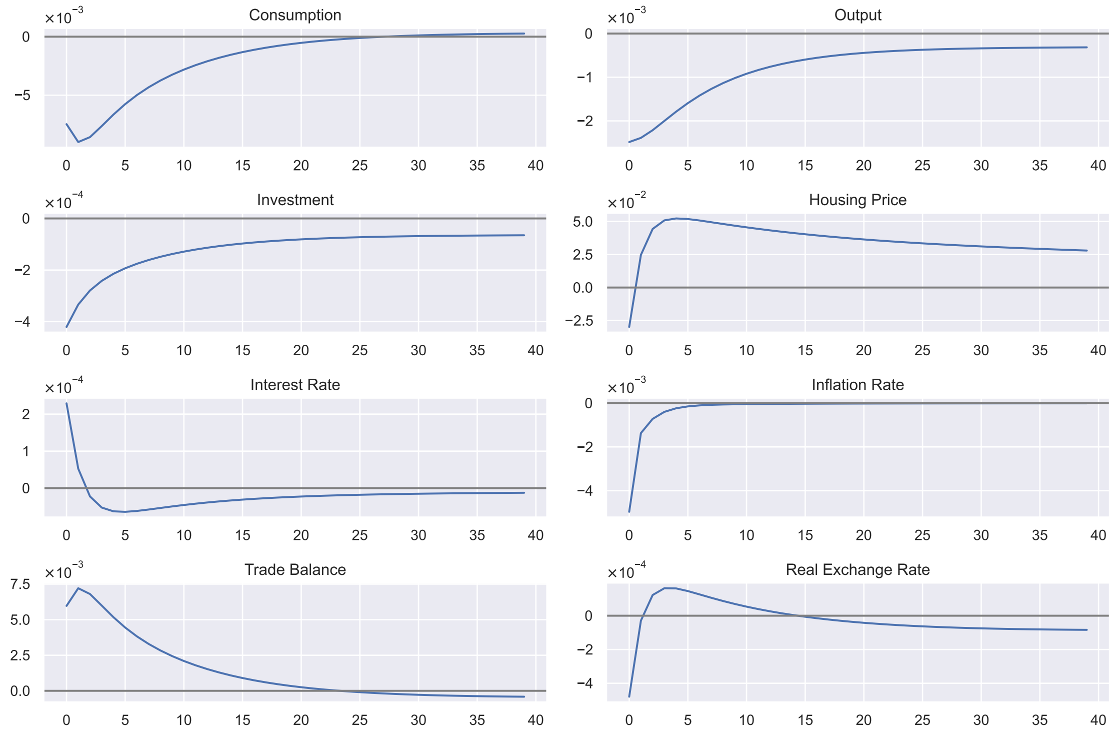

Figure 3: Negative monetary shock

interest rates compared to foreign interest rates. This prompts domestic savers to choose to lend more of their funds abroad, which, due to (67), implies a surplus in the balance of trade. Finally, due to technological advances and surge in the market demand, which leads to higher output, there is an increased demand for investment in production by entrepreneurs, leading to an increase in capital investment and a rise in the prices of houses used as collateral for production investments, causing housing prices to soar.

4.2 Monetary Shock

In Figure 3 shows the results of a negative monetary shock. Under this shock, domestic interest rates rise as the central bank adopts a contractionary monetary policy. Since foreign interest rates do not change with the increase in domestic interest rates, the domestic borrowing environment becomes relatively unfavorable. When domestic interest rate rises, it results in a reduction in consumption, investment, imports, and output. Consequently,

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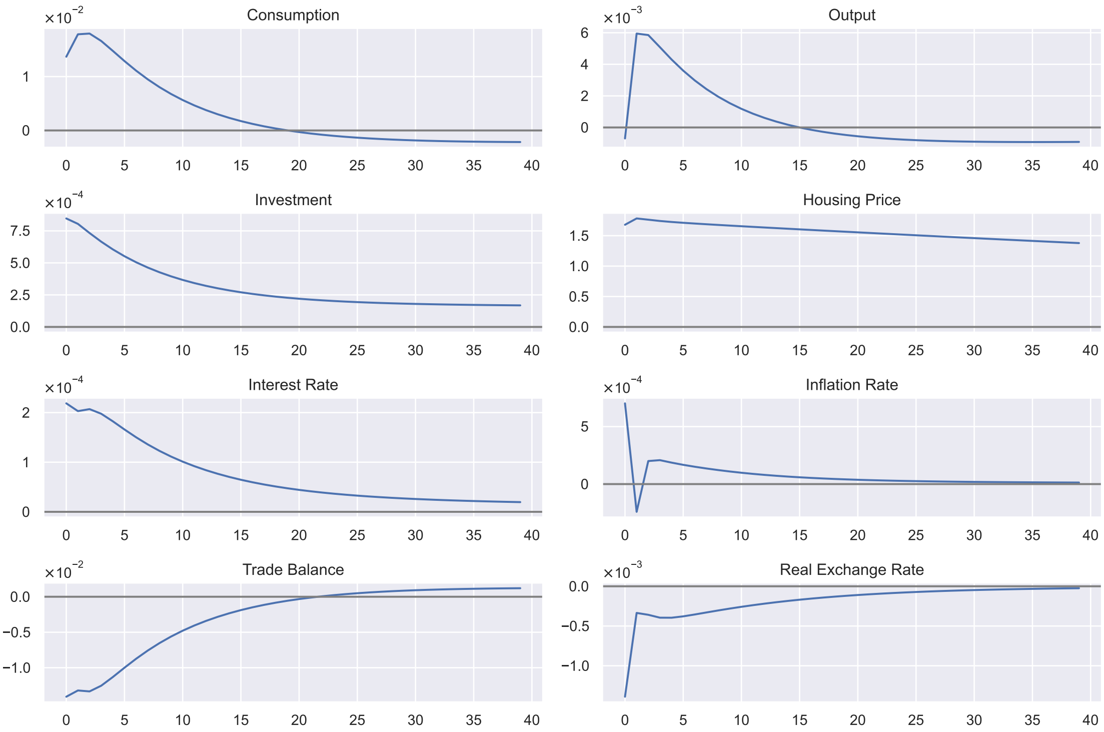

Figure 4: Housing preference shock

as imports decrease, the trade balance increases. Next, the decrease in output leads to a decrease in demand for factors of productions, i.e., low demand for investment, housing, etc., and as a result, housing prices, which serve as collateral, decrease. The decrease in demand also reduces production costs, leading to a further decrease in the inflation rate. The monetary policy will immediately lower interest rates in response to the decrease in inflation rate, so we can see in Figure 3 that the interest rate quickly returns to its original level relative to other shocks.

4.3 Housing Preference Shock

As shown in Figure 4, facing the impact of positive housing preferences, house prices would rise significantly. In this model, the persistence of housing preferences is set at 0.993, which means the rise in the housing market will last for several periods, so house prices will not decline in the short term and will maintain a high price state for several

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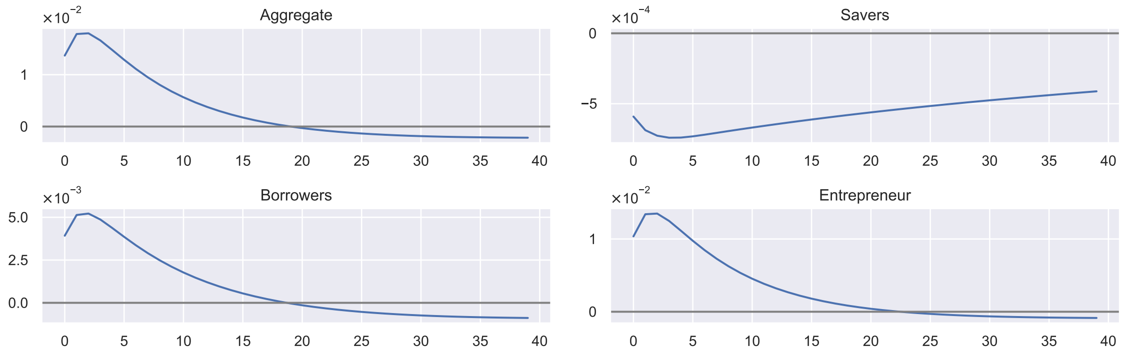

Figure 5: Shock of housing preference in consumption

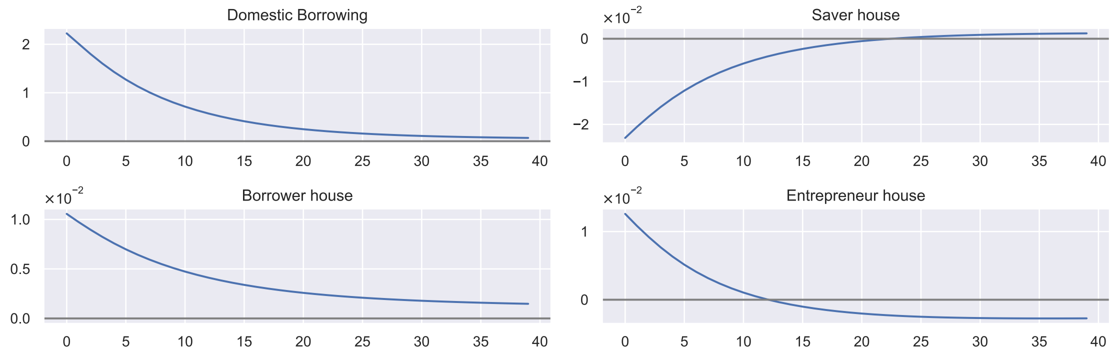

Figure 6: Shock of housing preference in housing market

periods. Due to the soaring house prices, the value of mortgage collateral has increased, raising the upper bound of the collateral constraint, which then leading to an increase in available funds for entrepreneurs and borrowers, thereby promoting investment and consumption.

From Figure 5 and Figure 6, the impact of housing preferences on aggregate consumption increases overall. Entrepreneurs and borrowers enjoy a higher level of consumption, but savers' consumption is lower. Although there is a greater need for borrowing due to higher demand for housing and the higher interest rates, excessive inflation still requires savers to give up consumption and the amount of existing housing they own.

The increase in demand for goods drives an increase in production, which in turn causes an increase in demand for factors such as investment and labor requirements, thereby pushing up production costs and inflation. As a response to the rising inflation

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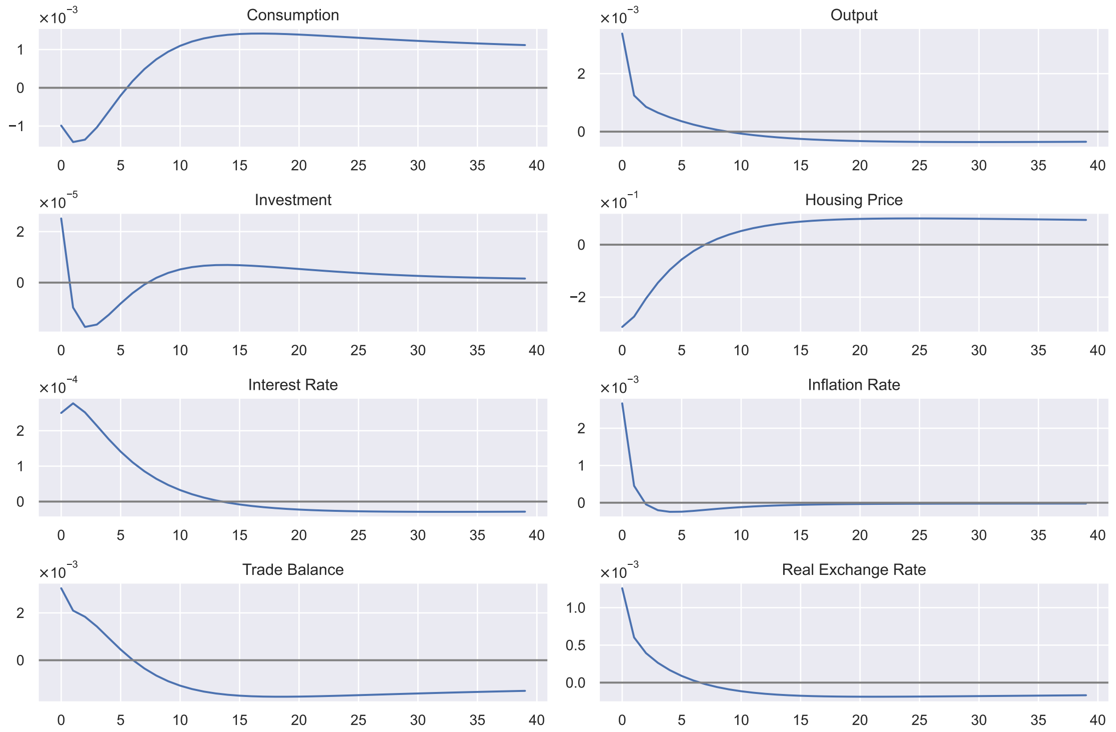

Figure 7: Negative foreign interest rate shock

rate, monetary policy adjusts interest rates upward. Finally, the domestic interest rate rises, causing foreign capital inflows, so the balance of trade decrease.

4.4 Foreign Interest Shocks

Figure 7 shows a negative foreign interest rate shock. The increase in foreign interest rates causes capital outflows from the domestic economy, resulting in a surplus in balance of trade.

On the consumption side, in Figure 8, borrowers and entrepreneurs benefit from the lower housing prices and can have more consumption, but savers are negatively impacted further, resulting in an overall decrease in the aggregate consumption level. As shown in Figure 9, due to the increase in balance of trade, exports increase significantly, leading to an increase in output by entrepreneurs, which results in an increase in investment. The higher foreign demand will increase the prices of the products sold by entrepreneurs to

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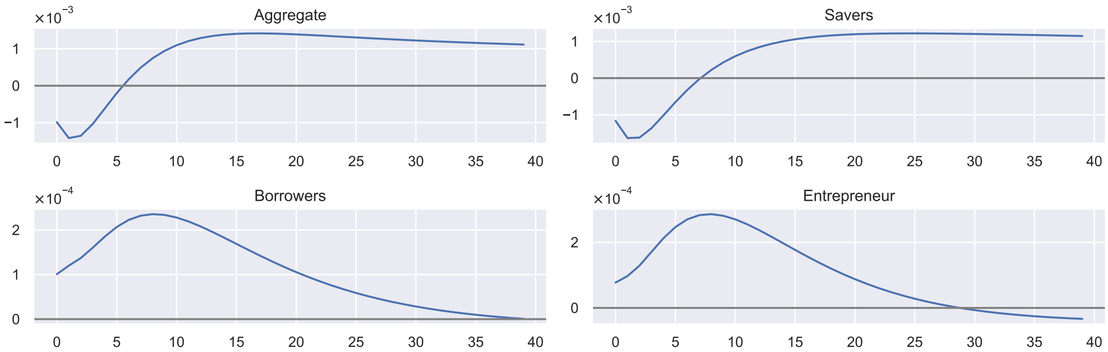

Figure 8: Shock of foreign interest rate in consumption

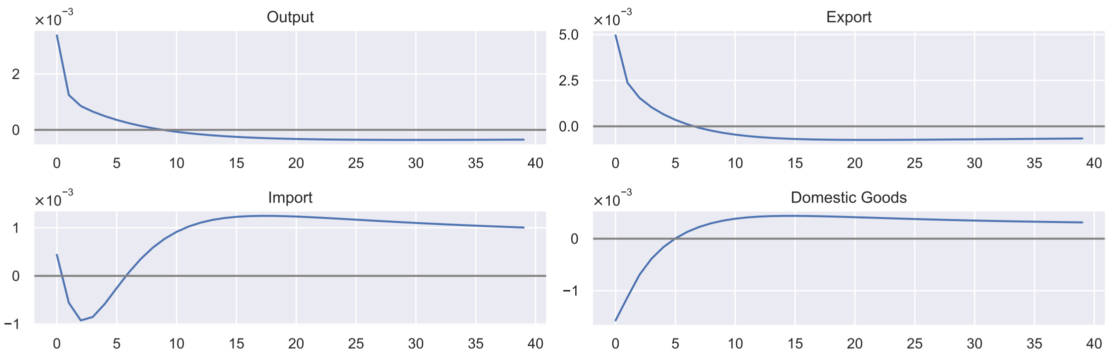

Figure 9: Foreign Interest Shock on productions

the retail industry, resulting in inflationary pressures even if the domestic demand is weak. The monetary policy raises the domestic interest rate to counter the increase in inflation rate.

5 Welfare

In the following sections, macroprudential policy and that monetary policy oversees the housing market are added to the economy. The macroprudential policy adjusts the LTV ratio by overseeing credit expansion and the housing market fluctuation

$$m_t = m \left(\frac{b_t}{b_{t-1}} \right)^{-\phi_b} \left(\frac{q_t}{q_{t-1}} \right)^{-\phi_q} . \tag{77}$$

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5.1 Welfare Measure

In order to compare whether individual and social are better-off under different policy regimes, the welfare of savers, borrowers, and entrepreneurs are defined as follows:

$$W^s = \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta^s)^t d_t \left[\log(c_t^s - \varepsilon_c c_{t-1}^s) + j_t \log(h_t^s - \varepsilon_h h_{t-1}^s) - \frac{\tau_t}{1+\eta} (n_t^s)^{1+\eta} \right], \quad (78)$$

$$W^b = \mathbb{E}_0 \sum_{t=0}^{\infty} (\beta^b)^t d_t \left[\log(c_t^b - \varepsilon_c c_{t-1}^b) + j_t \log(h_t^b - \varepsilon_h h_{t-1}^b) - \frac{\tau_t}{1+\eta} (n_t^b)^{1+\eta} \right], \quad (79)$$

$$W^e = \mathbb{E} \sum_{t=0}^{\infty} (\beta^e)^t d_t \log(c_t^e - \varepsilon_c c_{t-1}^e). \quad (80)$$

The social welfare, following Pescatori et al. [2005], is defined as

$$W = (1-\beta^s)W^s + (1-\beta^b)W^b + (1-\beta^e)W^e, \quad (81)$$

where each agent's welfare is weighted by one minus its own discount factor.

Generally, the literature indicates that macroprudential responses to external shocks can benefit certain individuals, often borrowers, but not all households or in every situation. As a result, it is important to conduct welfare comparisons not just through an arbitrary overall welfare function, but also by breaking down welfare among different agents to emphasize the potential trade-offs between them.

To make the comparison more intuitive, the consumption equivalent measure is presented. This measure calculates the fraction of consumption that households must give up to obtain the benefits of the compared policy relative to the base regime. The welfare changes in terms of consumption equivalent units for the three types of agents are derived

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as

$$CE_s = \exp[(1-\beta^s)(W^s_{test} - W^s_{base})] - 1, \tag{82}$$

$$CE_b = \exp[(1-\beta^b)(W^b_{test} - W^b_{base})] - 1, \tag{83}$$

$$CE_e = \exp[(1-\beta^e)(W^e_{test} - W^e_{base})] - 1. \tag{84}$$

Finally, the consumption equivalent of social welfare can also be derived as

$$CE_{social} = \exp[(1-\beta^s)(W^{social}_{test} - W^{social}_{base})] - 1. \tag{85}$$

5.2 Welfare Trade-offs

In this section, the individual welfare and social welfare are first computed when a static LTV is present, without the macroprudential policy. Second, the welfare gains are evaluated when the macroprudential policy is introduced by changing its reaction parameters ϕ_b and ϕ_q.

In Figure 10, the absence of macroprudential policy leads to an increase in social welfare as the LTV ratio increases, reaching a maximum at LTV=0.85, with optimality existing through LTV=0 to LTV=1. An increase in LTV ratio, as stated in Rubio and Carrasco-Gallego [2014], may harm borrowers and entrepreneurs, and the effect of over-indebtedness may dominate after LTV increases further. However, the model does not exhibit over-indebtedness as a concern for borrowers, as they can still benefit from the income effect of receiving higher salaries from entrepreneurs due to increased demand, even when excessive borrowing has occurred.

In Figure 11, the scenario where macroprudential enters the economy by overseeing

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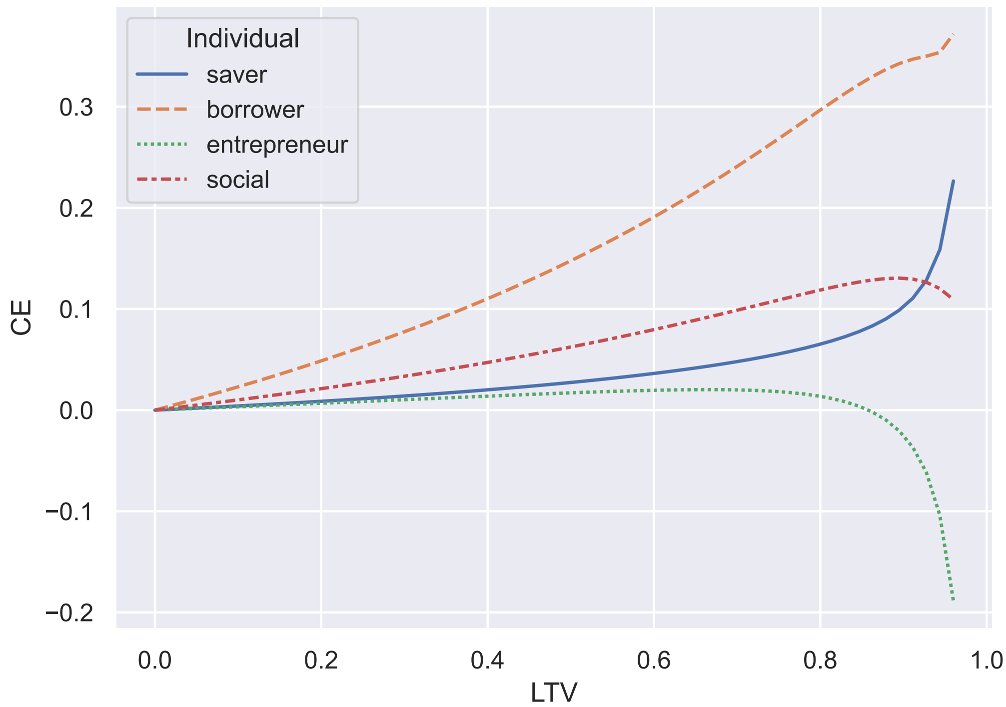

Figure 10: No macroprudential, changing LTV

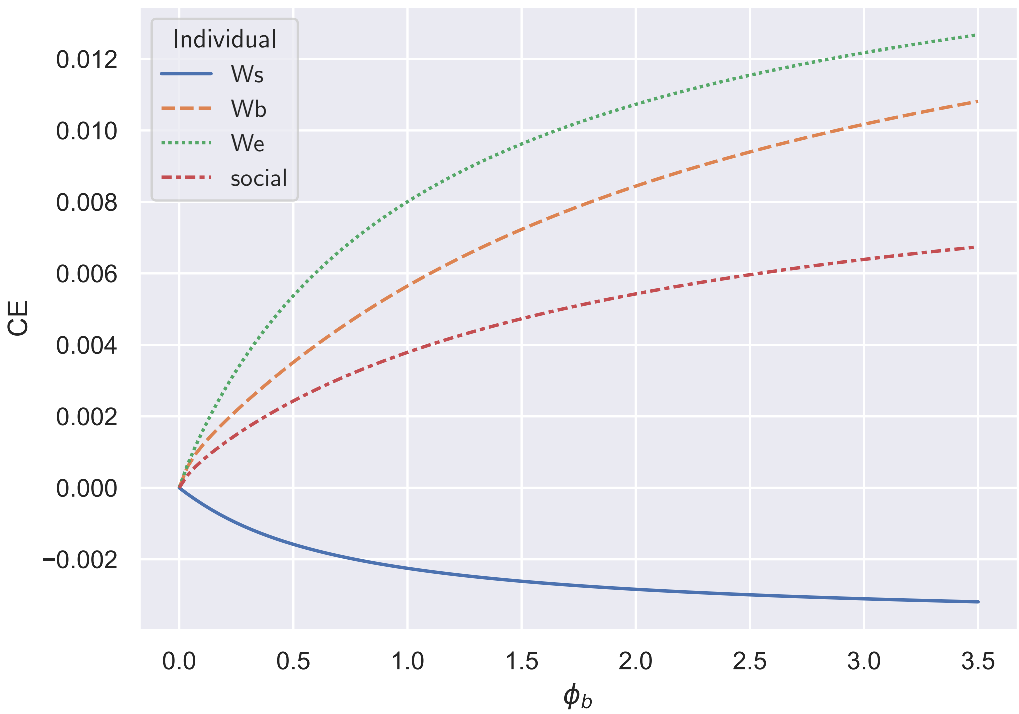

Figure 11: Macroprudential oversees the fluctuations in credit expansion.

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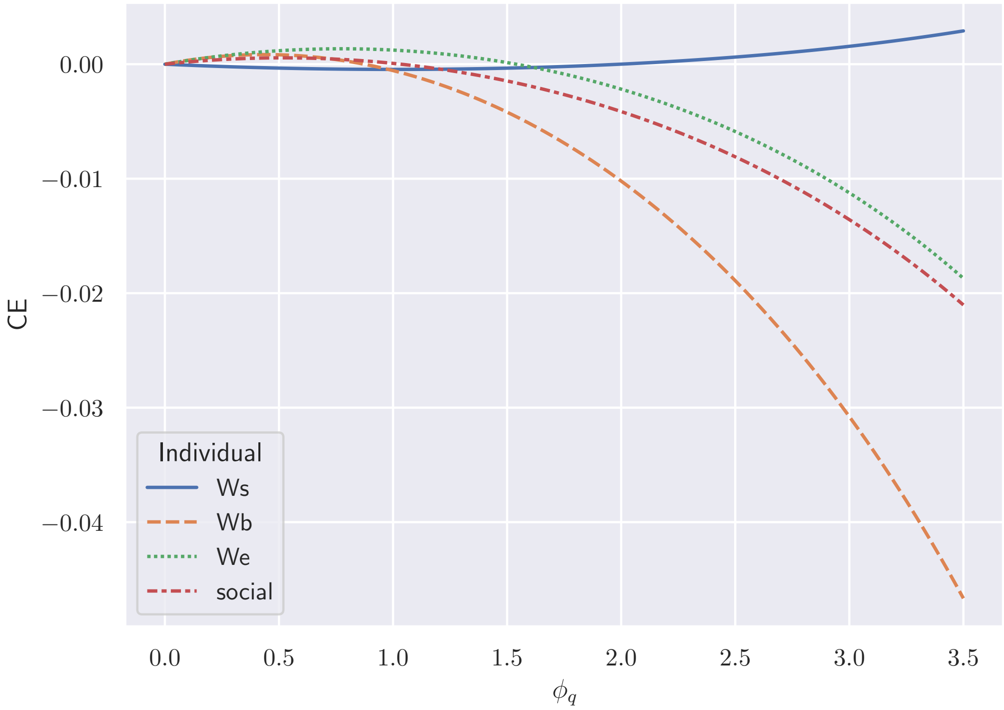

Figure 12: Macroprudential oversees the fluctuations in housing market.

the domestic credit expansion, social welfare increases as regulatory strength ϕ_b increases. Borrowers and entrepreneurs enjoy a more stable lending environment, leading to an increase in welfare, while savers perform worse as regulatory strength increases, and this result is inline with that of Rubio and Carrasco-Gallego [2014].

In Figure 12, the case where macroprudential regulation only focuses on the housing market, social welfare improves before $\phi_q = 1$ and gradually decreases as regulatory strength increases. Borrowers and entrepreneurs can still benefit from appropriate regulation, but both will suffer when the regulation is excessive. Savers' welfare slightly decreases when regulatory strength is weak, but increases as housing prices become more highly regulated.

Macroprudential policy stabilizes the housing market during external shocks by initiating an increase in LTV ratio. This increases the borrowing capacity of borrowers and

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entrepreneurs, allowing them to purchase houses and bolstering housing market demand. However, it may take longer for house price to return to normal levels after external shocks, causing elevated housing prices to persist. This can lead to a decline in borrowers' and entrepreneurs' welfare, ultimately resulting in reduced social welfare. Incidentally, borrowers experience a faster decline in welfare than entrepreneurs because they have lower income as ϕ_q increases.

To summarize, macroprudential policy monitoring of housing prices can decrease social welfare unless properly controlled, while monitoring domestic credit expansion improves social welfare monotonically.

6 Optimal Policy Analysis

6.1 Loss Function

In order to rationalize the Taylor rule of the macroprudential policy and monetary policy, this study proposes a cooperative loss function, which accounts for the volatility of output, real exchange rate, house prices, inflation, and borrowing:

$$L = \frac{\sigma_y}{\mu_y} + \frac{\sigma_s}{\mu_s} + \frac{\sigma_q}{\mu_q} + \frac{\sigma_\pi}{\mu_\pi} + \frac{\sigma_{bs}}{\mu_{bs}}. \tag{86}$$

Both macroprudential and monetary policies adjust their exploitable parameters to minimize the loss function under different policy regimes.

Unlike Angelini et al. [2011], which focus on a limited number of variables and use weighted loss function settings, this model adopts a unit-free quantity approach, which employs standard deviation divided by the average for each variable's level. Additionally, house prices and real exchange rates are included in the model to reflect the Taylor rule's

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real exchange rates and the importance of fluctuations in the housing market. Since there is no prior knowledge or preference on each variable, no weights are assigned to any of them, ensuring that each variable is considered equally important.

Svensson [2012] argues that combining monetary and fiscal policies for minimizing a loss function is inappropriate, and the two sectors should find their optimal parameters based on others' strategy, resulting in a Nash equilibrium in the parameter space. However, the difficulty in finding a Nash equilibrium arises due to the curse of dimensionality, as there are four parameters for monetary policy and two parameters for macroprudential policy, which would require an excessive amount of time and computational resources to optimize. Therefore, the cooperative approach is used as a proxy for the preferable non-cooperative solution. Although it may not provide optimal parameter settings under a particular policy regime, it is sufficient to provide insights for comparison purposes.

6.2 Optimal Parameters

To incorporate housing regulation for monetary policy, (62) becomes

$$R_t = R_{t-1}^{r_R} \left[\left(\frac{\Pi_t}{\Pi} \right)^{r_\Pi} \left(\frac{y_t}{y_{t-1}} \right)^{r_y} \left(\frac{e_t}{e_{t-1}} \right)^{r_e} \left(\frac{q_t}{q_{t-1}} \right)^{r_q} \right]^{1-r_R} R^{1-r_R} \exp(u_{R,t}), \qquad (87)$$

The inertia parameter $r_R = 0.9151$ remains constant for all experiments. The search range for monetary policy parameters is set as $r_\Pi, r_y, r_q \in [0, 20]$, and $r_e \in [-20, 20]$. To ensure a similar range of manipulation as the interest rate, $(1 - 0.9151) \cdot 20 \approx 2$, the parameters of macroprudential policy, ϕ_b and ϕ_q, are searched within the range of $\phi_b, \phi_q \in [0, 2]$.

Table 3 shows results of minimizing the loss function, where X indicates a variable that is not subject to regulatory control and is fixed at 0. Monetary policy is set to always

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Table 3: Optimal parameter settings for minimizing the loss function under six different policy regimes. In all regimes, monetary policy regulates inflation, real exchange rate, and output. The six regimes are:

1. Benchmark - no macroprudential policy,
2. Macroprudential oversees credit expansion,
3. Macroprudential oversees housing market,
4. Macroprudential oversees credit expansion and housing market,
5. Monetary policy oversees housing market,
6. Monetary policy oversees housing market and macroprudential oversees credit expansion.

The optimal values are obtained using the particle swarm method in the Matlab Global optimization toolbox. The X symbol indicates that the corresponding variable is not subject to regulatory control and is fixed at 0.

	1.	2.	3.	4.	5.	6.
r_π	4.48	2.89	4.46	3.06	20.0	18.23
r_s	0.84	0.13	0.5	0.16	-6.71	-6.09
r_y	7.51	6.65	6.77	5.6	1.42	2.51
r_q	X	X	X	X	15.79	15.17
ϕ_q	X	X	0.36	2.0	X	X
ϕ_b	X	2.0	X	2.0	X	2.0
Loss	0.54	0.4	0.53	0.38	0.31	0.29

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regulate inflation rates, real exchange rates, and output.

For column 1 and 4, monetary policy has a significant impact on the loss function, dropping from 0.54 to 0.31 when regulating the housing market. Relative to column 2 and 3, macroprudential policy can also reduce the loss function but to a lesser extent. Column 1 and 4 also show that when monetary policy oversees the housing market, responses to inflation and real exchange rates are more drastic, while output turns towards moderation.

For column 2 and 4, ϕ_b always finds a corner solution, implying that macroprudential policy should be responded to credit expansion with a greater magnitude of change. A larger value of ϕ_b is better, while in column 3, ϕ_q reaches an optimal in an interior point.

Column 2 and 3 show that macroprudential policy regulates house prices have little impact on reducing the loss function compared to regulating credit expansion. It is worth noting that, when introducing macroprudential policy to regulate the housing market conditional on monetary policy overseeing housing market, it reduces to the case of column 6. It seems that no action on housing market for macroprudential policy is the best course of action as monetary interest rate policy measure is more powerful than macroprudential LTV policy measure and can dominate or even weaken its effectiveness.

It is worth noting the comparison with the findings in Wang [2021]. Both studies have identified the optimality of assigning oversight of a variable to a single specific institute, which is the reason why a full comparison of all possible combinations was not conducted, as they would ultimately reduce to the six regimes listed above. However, in Wang [2021], the author found that the best policy corresponds to the third regime, indicating the effectiveness of cooperative efforts between macroprudential and monetary policies. The disparity in results can be attributed to several factors. Firstly, I did not allow for the freedom to adjust the inertia parameter r_R, which is a more realistic assump-

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Table 4: The consumption equivalent comparisons between different regimes in ‰

	1.	2.	3.	4.	5.	6.
CEs	0.0	-0.85	-0.14	-1.07	-8.84	-8.75
CEb	0.0	3.66	1.22	5.75	-0.98	-2.21
CEe	0.0	4.73	0.53	5.60	21.06	21.12
CEsocial	0.0	2.50	0.50	3.40	3.70	3.30

tion. Additionally, the search space for the parameters and the objective function differ between the two studies. In Wang [2021], the welfare is maximized, whereas I utilized a loss function minimization approach.

6.3 Welfare Comparisons

Table 4 displays the changes in the welfare of savers, borrowers, and entrepreneurs, as well as social welfare in units of one-thousandth under optimal parameter settings. Through all columns, savers worsened in all cases, and this situation was further exacerbated when monetary policy regulated the housing market (column 5 and 6). Entrepreneurs, on the other hand, experienced an opposite situation, and their welfare improved in all six cases, with a substantial increase when monetary policy regulated the housing market. Borrowers' welfare improved when monetary policy did not regulate the housing market (column 1 to 4), but once it intervened, their welfare became negative.

Column 2 shows the findings are consistent with Rubio and Carrasco-Gallego [2014], which suggests that the introduction of macroprudential regulation helps stabilize the financial market, benefiting borrowers and entrepreneurs in the economy and increasing their welfare, while decreasing savers' welfare. However, there is also made another finding in column 6: when monetary policy decides to regulate the housing market, the introduction of macroprudential regulation treats borrowers and entrepreneurs asymmetrically. Entrepreneurs will continue to increase their welfare, while borrowers will dete-

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riorate. This kind of asymmetry also appeared in Figure 10, highlighting the fundamental differences between borrowers and entrepreneurs. This indicates that blindly implementing macroprudential regulation may not necessarily improve the welfare of borrowers and entrepreneurs and it may even decrease social welfare. Therefore, the consideration of monetary policy must be taken into account.

It is important to note that in all six regimes analyzed, all achieving Pareto improvements, indicating the existence of trade-offs when implementing these policies. In terms of social welfare comparison, the results in column 5 suggest that monetary policy should be used to regulate the housing market, while macroprudential regulation should not exist to achieve maximum welfare. Although the welfare of savers may decrease as a result of the monetary policy regulation, the substantial increase in entrepreneurs' welfare significantly contributes to overall social welfare. Any reduction in welfare experienced by savers and borrowers can potentially be compensated through transfer payment subsidies.

If the implementation of such subsidies is costly or may introduce additional distortions, the approach in column 4 represents a second-best option, which minimally affects savers. This suggests that macroprudential policies should focus on regulating the housing market and credit expansion, aligning with the coordination findings presented in Wang [2021].

6.4 Behavior of Endogenous Variables

Table 5 displays the means per thousand of endogenous variables in a second order perturbation. Table 6 reports the relative change of standard deviations of these variables as a percentage compared to the base case.

In Table 5, the consumption and housing for entrepreneurs increase in columns 2-4,

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Table 5: Endogenous variables mean after perturbation in ‰

	1.	2.	3.	4.	5.	6.
y	0.0	-0.79	0.12	-0.62	-8.56	-8.80
i	0.0	-6.85	-0.09	-7.32	-45.21	-45.94
k	0.0	-6.85	-0.09	-7.31	-45.20	-45.93
q	0.0	-3.36	-0.02	-3.00	-9.40	-10.05
c^e	0.0	4.91	0.74	5.92	15.37	15.27
c^s	0.0	-1.16	-0.04	-1.17	-9.05	-9.16
c^b	0.0	0.22	0.22	0.38	-6.74	-6.79
tb	-0.0	-1.14	1.15	0.12	-3.18	-4.55
h^e	0.0	6.98	0.55	16.06	118.28	119.47
h^s	0.0	-1.31	-0.27	-2.68	-12.89	-12.87
h^b	0.0	12.34	3.63	22.90	58.94	57.27
n^s	0.0	0.03	0.11	0.18	-0.39	-0.51
w^s	0.0	-1.14	0.20	-0.84	-11.81	-12.15
n^b	0.0	-0.03	-0.08	-0.15	-1.39	-1.30
w^b	0.0	-0.96	0.24	-0.61	-11.07	-11.40
b^e	0.0	-4.55	1.08	4.94	76.99	74.62
b^{e*}	0.0	9.54	-7.71	-4.77	-11.85	1.87
b^s	0.0	-1.33	1.90	7.15	46.51	43.81
b^{s*}	0.0	-0.02	-0.03	-0.03	1.07	1.10
b^b	0.0	2.00	2.76	9.43	14.99	11.96

Table 6: Endogenous variables variations after perturbation in %

	1.	2.	3.	4.	5.	6.
y	0.0	-3.59	3.44	1.84	32.61	27.38
i	0.0	-9.04	-0.28	-10.33	-58.88	-61.41
k	0.0	-8.15	-0.15	-9.29	-58.39	-61.09
q	0.0	-0.34	-0.16	-0.70	2.64	2.74
c^e	0.0	1.65	1.39	2.59	-45.14	-47.05
c^s	0.0	-1.09	-0.32	-1.51	8.73	8.22
c^b	0.0	5.91	-0.80	1.98	-0.76	1.76
tb	0.0	1.78	-0.84	1.31	7.72	7.96
h^e	0.0	-19.98	-1.84	-20.97	-7.27	-7.47
h^s	0.0	-46.02	-3.24	-50.13	-45.17	-46.40
h^b	0.0	-17.85	-1.09	-19.06	-47.81	-48.87
n^s	0.0	-0.22	0.20	-0.06	1.54	1.17
w^s	0.0	0.37	-0.59	-1.05	8.65	9.74
n^b	0.0	1.95	-1.23	0.22	-3.23	-1.15
w^b	0.0	-0.43	-1.44	-3.56	8.71	10.66
b^e	0.0	-41.11	-3.15	-43.64	-31.37	-33.06
b^{e*}	0.0	237.35	27.33	276.92	-7.08	16.92
b^s	0.0	-42.20	-2.78	-46.65	-74.44	-81.68
b^{s*}	0.0	-0.32	-0.24	-0.15	10.70	9.56
b^b	0.0	-11.10	-0.61	-12.20	-32.97	-34.03

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and show a significant leap in columns 5-6. Conversely, savers move in the opposite direction, experiencing a small decline in columns 2-4, and a substantial decline in columns 5-6. As for borrowers, their consumption increases only slightly in columns 2-4 and decreases in columns 5-6. The behavior regarding housing consumption is similar to that of entrepreneurs, with a small increase under macroprudential policy and a significant increment once monetary policy oversees the housing market. This allows us to take a deeper look for the consumption equivalence behavior of Table 4.

Moreover, Table 5 provides an explanation as to why the introduction of macroprudential policy under column 6, within the monetary policy framework, leads to a reduction in borrower welfare compared to column 5. Firstly, under monetary policy regulations governing the housing market, the additional introduction of macroprudential policy causes a decrease in domestic borrowing by both borrowers and entrepreneurs (from 14.99 to 11.96 and 76.99 to 74.62, respectively), thereby limiting their credit expansion. Furthermore, the subdued economic environment resulting from the monetary policy regulations significantly reduces borrowers' real wages, surpassing the benefits derived from financial market stability. As a result, the decrease in their income effect outweighs any welfare benefits, leading to a decline in borrower welfare. In times of economic downturns, further restrictions on domestic borrowing through the introduction of macroprudential regulations do not lead to welfare improvement but rather a decline.

Secondly, the welfare of entrepreneurs improves not only due to the subdued economic conditions reducing salary expenditures but also because they have access to foreign capital markets, allowing them to maintain their income levels and continue acquiring properties in the market. On the other hand, borrowers in the model do not have access to foreign capital, limiting their opportunities to borrow from external sources during economic dif-

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ficulties and resulting in a decrease in their welfare.

This finding aligns to some extent with the empirical findings of Cerutti et al. [2016], which suggest that the effective impact of macroprudential policy is relatively small during economic downturns and for open economies, although their focus is on the stability of the financial market rather than the welfare implications discussed here.

Table 6 shows that macroprudential monitoring of the lending market helps to mitigate (b^b, b^e) fluctuations in lending volume. However, it also shows that monetary policy is more effective. For example, the introduction of macroprudential regulation reduces the standard deviation relative to the baseline of b^b by 11, while the introduction of monetary policy directly reduces it by 33.

One might observe that once monetary policy oversees the housing market, the variability in y and q rises even more than in the base case. This could be resolved by referring to Table 7, which decomposes the loss function of each policy regime. The trade-off occurs among y, q, and b. With monetary policy overseeing the housing market, it allows for a slightly higher variability in y and q, resulting in a substantial reduction in the variability of b. Although it may appear contradictory that overseeing on the housing market increases the volatility, it actually provides the central bank with an additional instrument to minimize the overall loss function. Further research or practitioners can adjust the loss function so that to mitigate the undesirable trade-off in the housing market. Indeed, despite the theoretical importance of both markets, stabilizing the housing market seems to have a more tangible impact on the economy for ordinary people compared to the financial market.

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Table 7: Loss function decomposition

	1.	2.	3.	4.	5.	6.
$\frac{\sigma_\pi}{\mu_\pi}$	0.01	0.01	0.01	0.01	0.01	0.01
$\frac{\sigma_e}{\mu_e}$	0.03	0.03	0.03	0.03	0.03	0.03
$\frac{\sigma_y}{\mu_y}$	0.03	0.03	0.03	0.03	0.04	0.04
$\frac{\sigma_{b^s}}{\mu_{b^s}}$	0.32	0.19	0.31	0.17	0.08	0.06
$\frac{\sigma_q}{\mu_q}$	0.14	0.14	0.14	0.14	0.15	0.15

7 Conclusion

After conducting an analysis of the impact of monetary policy and macroprudential policy on the housing market in Taiwan, several conclusions can be drawn. Firstly, using monetary policy rather than macroprudential policy, which controls the economy's LTV ratio, can achieve stability and maximize social welfare, thereby rendering the need for a unnecessary of macroprudential policy. Secondly, the Central bank, which executes monetary policy in Taiwan, should actively monitor the fluctuation of the housing market using interest rate adjustment to achieve a more stable economy and better welfare improvement. Thirdly, if macroprudential policy is to be used, the regulation of LTV based on domestic credit expansion should be accompanied by regulation of housing prices. Relying solely on the macroprudential policy to regulate housing prices does not significantly increase social welfare and must be paired with credit expansion monitoring to achieve optimal results. Fourthly, when monetary policy regulates housing prices, savers' welfare is most affected, while entrepreneurs benefit the most. A transfer policy subsidy can be used to compensate losses occurred on savers. Finally, due to the ability to reach overseas funds, entrepreneurs are less affected than borrowers when facing a poor domestic borrowing environment.

Despite the above conclusions, there are several areas for improvement in this paper. Firstly, the welfare comparison is sensitive to the parameters and model settings. There-

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fore, some robustness and sensitivity checks should be conducted to obtain more reliable results. Secondly, the impact of labor unions in delaying wage changes was not included in the analysis, leading to excessive changes in saver and borrower welfare. Thirdly, the impact of taxation, including housing transaction taxes and property taxes, on changes in the economy's welfare, could be included to provide a more comprehensive discussion. Fourthly, including housing producers in the model can create more complex variations and discussions on welfare. Fifthly, a more efficient algorithm can be developed to find the best mutual coordination parameters for the non-cooperative game between monetary policy and macroprudential policy. Finally, parameter estimation can be re-evaluated to obtain an updated, more accurate, and representative model of Taiwan's current situation.

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