# Optimal Macro-prudential Policies in a DSGE Model: The Case of Taiwan*

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## Abstract

We develop a small open economy DSGE model featuring collateral constraint following Iacoviello and Neri (2010) and Lambertini et al. (2013) with open economy framework à la Kollmann (2002). To investigate the optimal macro-prudential policy of the Taiwanese economy, several versions of interest rate rules and loan-to-value (LTV) ratio rules are discussed. This paper finds that the interest rate rule leaning against the wind of housing price has the best effect on mitigating the volatility of major macroeconomic variables and improving social welfare function, while the LTV rule responding to domestic credit has the best performance.

Keywords: Dynamic Stochastic General Equilibrium Model, Collateral Constraint, Monetary Policy, Macro-prudential Policy, Loan-to-value Ratio

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# 1 Introduction

The devastating aftermath of the 2007–2009 global financial crisis has prompted central banks to reconsider their roles in maintaining and promoting financial stability. In addition to traditional monetary policies and supervisory regulations that target at soundness of individual financial institutions, monetary policies taking into account of financial variables and a variety of macro-prudential policies and tools have been proposed to strengthen the capabilities of central banks to contain systemic risk of the financial sector.

Macro-prudential policies are designed to mitigate the systemic risk and aim to enhance stability in the financial system. Several types of instruments or tools have been proposed, for instance, loan-to-value (LTV) ratio, credit-to-GDP ratio, debt-to-income ratio, or leverage ratio. However, there is no agreement about which measure can best maintain financial stability and/or macroeconomic aggregates. In this paper, we develop a DSGE framework to study the effects of macro-prudential policies on a small open economy such as Taiwan. More specifically, we evaluate welfare implications for various interest rate rules and LTV ratio rules in a small open economy, calibrated to Taiwan's data. For this purpose, we combine the model featuring collateral constraints from Iacoviello and Neri (2010) and Lambertini et al. (2013) with foreign markets setup à la Kollmann (2002). The main features of the model are as follows.

First, there are heterogenous agents in this economy, i.e., households are divided into patient and impatient. Then, following Kiyotaki and Moore (1997), we incorporate credit market frictions by introducing collateral constraints on impatient households' borrowing, which acts as a propagation mechanism to amplify and propagate credit shocks to the macro-economy. Therefore, holding housing assets not only provides impatient households housing services but also helps relax their credit limits.

Second, this model considers various real and nominal rigidities including investment adjustment costs, foreign bond adjustment costs, utilization adjustment costs, habit formation in consumption, sticky price, and wage stickiness. All adjustment costs are assumed to face convex costs to guarantee stationarity. Staggered prices and wages are incorporated à la Calvo (1983). This model is also equipped with a lot of structural shocks to capture the exogenous fluctuation of the Taiwanese economy.

Third, we extend the structural model developed by Iacoviello and Neri (2010) to a small open economy model following Kollmann (2002). The economy produces tradable intermediate goods for domestic uses and exports, and also imports foreign intermediate goods. Then, perfectly competitive firms use these intermediate goods to produce non-tradable final goods used for domestic consumption and investment.

Forth, there is a two-sector structure of production: the tradable intermediate goods sector and the housing sector. For tradable intermediate goods, we simply assume that the technology follows Cobb-Douglas production functions and uses labor and capital as inputs. As for housing, the production process is assumed to follow a more complex Cobb-Douglas form and use not only labor and capital, but also land and intermediate goods to capture the behaviors of housing production in the real world.

Finally, we analyze two groups of central bank policies. First, given a constant LTV ratio, we consider interest rate rules incorporating financial variables. Central bank sets the nominal interest rate following the Taylor rule leaning against the wind by reacting to not only inflation gap and output gap, but also either domestic credit, housing price, or exchange rate. Second, given the baseline Taylor rule, LTV rules reacting counter-cyclically to asset price or domestic credit are also considered. Moreover, the level effects and stabilization effects on major macroeconomic variables of these policies would be discussed.

We find that the interest rate rule responding to housing price has the best effect on stabilizing the economy and enhancing the social welfare function, and for the LTV ratio rules the one reacting to domestic credit is the best.

This paper is close to the work of Lambertini et al. (2013), which also uses the same model developed by Iacoviello and Neri (2010) to discuss monetary and macro-prudential policies. They find that for the case of the United States no matter interest rate rules or LTV ratio rules, the policy responding to domestic credit is always socially optimal, and if the monetary authority further considers the implementation of both types of policies, heterogeneity plays a paramount role in determining the optimal policy instrument. Our model deviates from Lambertini et al. (2013) by incorporating foreign markets setup à la Kollmann (2002).

Angelini et al. (2012) considers a closed economy DSGE model with a banking sector and introduces financial frictions by collateral constraints to assess macro-prudential policies. They find that paying attention to macro-prudential policies can help central banks improve overall economic stability, and the ranking of policy regimes relies on the total effect of both supply and financial shocks.

Medina and Roldós (2014) combines the financial accelerator framework developed by Bernanke et al. (1999) with the mechanism in Choi and Cook (2012), which introduces fire sales to amplify the financial accelerator mechanism, to study the interaction between monetary and macro-prudential policies. They find that taking counter-cyclically macro-prudential instruments into account can improve welfare and has crucial implications for the design of monetary policies.

To analyze the effects of macro-prudential policies, Quint and Rabanal (2014) considers an estimated two-country model of the euro area and uses financial accelerator to feature financial frictions. They find that introducing macro-prudential rules can mitigate macroeconomic volatility, enhance households' welfare, and supplement the lacks of traditional policies. They also indicates that macro-prudential policies, in their framework, always increase savers' welfare. But for borrowers, the types of exogenous shocks are the key factor to determine the effects.

The paper is structured as follows. Section 2 describes the small open economy DSGE model. Section 3 discusses empirical methodology and demonstrates properties of the model. Monetary and macro-prudential policies are presented in section 4. Section 5 concludes.

## 2 The Model

We develop a small open economy DSGE model in which the main structure follows Iacoviello and Neri (2010) and the foreign markets are included à la Kollmann (2002).[1] There are seven types of

[1]Closed economy DSGE models can be extended to open economies in several ways. First, a closed economy model can be extended to be a small open economy model by modeling the foreign variables as exogenous processes from the demand side, such as Galí and Monacelli (2005), Adolfson et al. (2007), and Teo (2009). Second, we can incorporate foreign variables as exogenous processes from supply side. For example, see Kollmann (2001, 2002). Third, a two-country model could be considered as in Lubik and Schorfheide (2006), in which all variables in the foreign markets are endogenously determined. Since in this paper we consider a heterogeneous agent model, extending this framework into open economy from demand side could be very complicated. Therefore, we decided to incorporate foreign markets à la Kollmann (2002).

agents in this model: patient households, impatient households, intermediate goods firms, final goods firms, house-producing firms, labor unions, and a central bank. In the following, these agents are sequentially discussed.

## 2.1 Patient Households

A representative patient household's lifetime utility function is given by:

$$E_0 \sum_{t=0}^{\infty} z_t \beta^t \Big( \Gamma_c \ln(C_t - \varepsilon C_{t-1}) + j_t \ln h_t - \frac{\tau_t}{1+\eta} (n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi})^{\frac{1+\eta}{1+\xi}} \Big),$$

where $z_t$ captures the intertemporal preferences shock, $\beta$ is the discount factor of patient households, $\Gamma_c = (1-\varepsilon)/(1-\beta\varepsilon)$ is the scaling factor which ensures that the marginal utility of consumption is $1/C$ in the steady state, $\varepsilon$ measures the habit formation in consumption, $j_t$ captures the housing preferences shock, and $\tau_t$ captures the labor supply shock. Patient households maximize their expected lifetime utility subject to the following budget constraint:

$$\begin{aligned} \frac{p_t}{p_{d,t}} \Big[ C_t + I_{c,t} + I_{h,t} + k_{b,t} \Big] + q_t h_t + p_{l,t} l_t + \Big[ B_t - \frac{R_{t-1}}{\pi_{d,t}} B_{t-1} \Big] + \frac{p_t}{p_{d,t}} \Phi_t \\ = \frac{w_{c,t} n_{c,t}}{X_{wc,t}} + \frac{w_{h,t} n_{h,t}}{X_{wh,t}} + R_{c,t} z_{c,t} K_{c,t-1} + R_{h,t} z_{h,t} K_{h,t-1} + p_{b,t} k_{b,t} \\ + q_t (1-\delta_h) h_{t-1} + (p_{l,t} + R_{l,t}) l_{t-1} + \frac{e_t p^*}{p_{d,t}} \Big[ B_t^* - \frac{R^*}{\pi^*} B_{t-1}^* \Big] + DIV_t, \end{aligned} \tag{2.1.1}$$

where

$$K_{c,t} = (1-\delta_k) K_{c,t-1} + A_{k,t} I_{c,t}, \tag{2.1.2}$$

$$K_{h,t} = (1-\delta_k) K_{h,t-1} + I_{h,t}, \tag{2.1.3}$$

$$\begin{aligned} \Phi_t = \frac{\Phi_{kc}}{2} \frac{(K_{c,t} - K_{c,t-1})^2}{K_{c,t-1}} + \frac{\mathcal{A}(z_{c,t}) K_{c,t-1}}{A_{k,t}} + \frac{\Phi_{kh}}{2} \frac{(K_{h,t} - K_{h,t-1})^2}{K_{h,t-1}} + \mathcal{A}(z_{h,t}) K_{h,t-1} \\ + \frac{e_t p^*}{p_t} \frac{\Phi_{B^*}}{2} (B_t^* - B^*)^2, \end{aligned} \tag{2.1.4}$$

$$\mathcal{A}(z_{c,t}) = R_c \left[ \frac{1}{2} \bar{\varphi} z_{c,t}^2 + (1-\bar{\varphi}) z_{c,t} + (\frac{\bar{\varphi}}{2} - 1) \right], \tag{2.1.5}$$

$$\mathcal{A}(z_{h,t}) = R_h \left[ \frac{1}{2} \bar{\varphi} z_{h,t}^2 + (1-\bar{\varphi}) z_{h,t} + (\frac{\bar{\varphi}}{2} - 1) \right]. \tag{2.1.6}$$

Precisely, patient households choose consumption $C_t$, housing $h_t$, domestic-currency bonds $B_t$, foreign-currency bonds $B_t^*$, working hours in the intermediate goods sector $n_{c,t}$, working hours in the housing sector $n_{h,t}$, capital in the intermediate goods sector $K_{c,t}$, capital in the housing sector $K_{h,t}$, intermediate inputs in the housing sector $k_{b,t}$, land $l_t$, capital utilization rate of capital in the intermediate goods sector $z_{c,t}$, and capital utilization rate of capital in the housing sector $z_{h,t}$, subject to (2.1.1).[2]

$p_t/p_{d,t}$, $p_{m,t}/p_{d,t}$, and $e_t p^*/p_{m,t}$ are the relative prices of final goods to domestic goods, imported goods to domestic goods, and foreign goods to domestic goods, respectively.[3] $q_t$ denotes the real

[2] To guarantee stationarity, patient households face convex costs of foreign-currency bonds in quantities different from its steady state à la Schmitt-Grohé and Uribe (2003).

[3] According to Teo (2009), the effects of foreign variables on Taiwanese economy are relatively small, so for simplicity foreign inflation rate and foreign price level are assumed to be constants.

housing price. $p_{b,t}$ and $p_{l,t}$ are the real prices of intermediates goods and land. Real wages in the intermediate goods sector and housing sector are denoted by $w_{c,t}$ and $w_{h,t}$, real rental rates of capital in the intermediate goods sector and housing sector by $R_{c,t}$ and $R_{h,t}$, and real rental rate of land in the housing sector by $R_{l,t}$. $X_{wc,t}$ and $X_{wh,t}$ denote the markups between the wage paid by firms and the wage paid to the patient households for intermediate goods sector and housing sector, respectively. $R_t$ and $R^*$ denote the nominal interest rates of domestic bonds and foreign bonds, respectively. $\pi_{d,t} = p_{d,t}/p_{d,t-1}$ is the domestic inflation rate. $\delta_k$ and $\delta_h$ are depreciation rates. $\mathcal{A}(z_{c,t})$ and $\mathcal{A}(z_{h,t})$ are the adjustment costs for utilization rates. $\Phi_{kc}$, $\Phi_{kh}$, and $\Phi_{B^*}$ are the adjustment costs of capital in the intermediate goods sector, capital in the housing sector, and foreign bonds, respectively. $DIV_t$ is the lump-sum transfer from domestic intermediate goods firms, imported intermediate goods firms, and labor unions.

Patient households choose $\{C_t, h_t, B_t, B_t^*, n_{c,t}, n_{h,t}, K_{c,t}, K_{h,t}, k_{b,t}, l_t, z_{c,t}, z_{h,t}\}_{t=0}^{\infty}$ to maximize their expected lifetime utility subject to (2.1.1). The following equations are the first-order conditions of this maximization problem:

$$z_t \Gamma_C \left( \frac{1}{C_t - \varepsilon C_{t-1}} - \frac{\beta \varepsilon}{C_{t+1} - \varepsilon C_t} \right) = \lambda_t \frac{p_t}{p_{d,t}}, \tag{2.1.7}$$

$$\lambda_t q_t = z_t \frac{j_t}{h_t} + \beta \mathrm{E}_t \left( \lambda_{t+1} q_{t+1} (1 - \delta_h) \right), \tag{2.1.8}$$

$$\lambda_t = \beta \mathrm{E}_t \left[ \lambda_{t+1} \frac{R_t}{\pi_{d,t+1}} \right], \tag{2.1.9}$$

$$\lambda_t \frac{e_t p^*}{p_{d,t}} \left[ 1 - \Phi_{B^*} (B_t^* - B^*) \right] = \beta \mathrm{E}_t \left[ \lambda_{t+1} \frac{e_{t+1} p^*}{p_{d,t+1}} \frac{R^*}{\pi^*} \right], \tag{2.1.10}$$

$$z_t \tau_t (n_{c,t})^{\xi} \left[ (n_{c,t})^{1+\xi} + (n_{h,t})^{1+\xi} \right]^{\frac{\eta - \xi}{1+\xi}} = \lambda_t \frac{w_{c,t}}{X_{wc,t}}, \tag{2.1.11}$$

$$z_t \tau_t (n_{h,t})^{\xi} \left[ (n_{c,t})^{1+\xi} + (n_{h,t})^{1+\xi} \right]^{\frac{\eta - \xi}{1+\xi}} = \lambda_t \frac{w_{h,t}}{X_{wh,t}}, \tag{2.1.12}$$

$$\begin{aligned} &\lambda_t \frac{p_t}{p_{d,t}} \left( \frac{1}{A_{kt}} + \Phi_{kc} \left( \frac{K_{c,t} - K_{c,t-1}}{K_{c,t-1}} \right) \right) \\ = \beta \mathrm{E}_t &\left[ \lambda_{t+1} \frac{p_{t+1}}{p_{d,t+1}} \left( \frac{p_{d,t+1}}{p_{t+1}} R_{c,t+1} z_{c,t+1} - \frac{\mathcal{A}(z_{c,t+1})}{A_{k,t+1}} + \frac{1 - \delta_k}{A_{k,t+1}} - \frac{\Phi_{kc}}{2} \left( 1 - \frac{K_{c,t+1}^2}{K_{c,t}^2} \right) \right) \right], \end{aligned} \tag{2.1.13}$$

$$\begin{aligned} &\lambda_t \frac{p_t}{p_{d,t}} \left( 1 + \Phi_{kh} \left( \frac{K_{h,t} - K_{h,t-1}}{K_{h,t-1}} \right) \right) \\ = \beta \mathrm{E}_t &\left[ \lambda_{t+1} \frac{p_{t+1}}{p_{d,t+1}} \left( \frac{p_{d,t+1}}{p_{t+1}} R_{h,t+1} z_{h,t+1} - \mathcal{A}(z_{h,t+1}) + (1 - \delta_k) - \frac{\Phi_{kh}}{2} \left( 1 - \frac{K_{h,t+1}^2}{K_{h,t}^2} \right) \right) \right], \end{aligned} \tag{2.1.14}$$

$$p_{b,t} = \frac{p_t}{p_{d,t}}, \tag{2.1.15}$$

$$\lambda_t p_{l,t} = \beta \mathrm{E}_t \Big( \lambda_{t+1} (p_{l,t+1} + R_{l,t+1}) \Big), \tag{2.1.16}$$

$$R_{ct} = \frac{p_t}{p_{d,t}} \frac{R_c \Big( \bar{\varphi} z_{c,t} + (1 - \bar{\varphi}) \Big)}{A_{kt}}, \tag{2.1.17}$$

$$R_{ht} = \frac{p_t}{p_{d,t}} R_h \Big( \bar{\varphi} z_{h,t} + (1 - \bar{\varphi}) \Big), \tag{2.1.18}$$

where $\lambda_t$ is the Lagrange multiplier of budget constraint.

## 2.2 Impatient Households

Compared to patient household's variables, variables with prime refer to impatient households. A representative impatient household's lifetime utility function is given by:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} z_t (\beta')^t \Big( \Gamma'_C \ln(C'_t - \varepsilon' C'_{t-1}) + j_t \ln h'_t - \frac{\tau_t}{1+\eta'} \big( (n'_{c,t})^{1+\xi'} + (n'_{h,t})^{1+\xi'} \big)^{\frac{1+\eta'}{1+\xi'}} \Big),$$

where $\beta'$ is the discount factor of impatient households and $\beta' < \beta$ which ensures that impatient households are net borrowers, $\Gamma'_c = (1 - \varepsilon')/(1 - \beta' \varepsilon')$ is the scaling factor which ensures that the marginal utility of consumption is $1/C'$ in the steady state, and $\varepsilon'$ measures the habit formation in consumption. Impatient households maximize their expected lifetime utility subject to the budget constraint:

$$\frac{p_t}{p_{d,t}} C'_t + q_t h'_t = \frac{w'_{c,t} n'_{c,t}}{X'_{wc,t}} + \frac{w'_{h,t} n'_{h,t}}{X'_{wh,t}} + q_t (1 - \delta_h) h'_{t-1} + \Big[ B'_t - \frac{R_{t-1}}{\pi_{d,t}} B'_{t-1} \Big] + DIV'_t, \tag{2.2.1}$$

and to the collateral constraint:

$$R_t B'_t \leq m \mathrm{E}_t \Big( q_{t+1} h'_t \pi_{d,t+1} \Big), \tag{2.2.2}$$

where $m$ represents the loan-to-value (LTV) ratio. $X'_{wc,t}$ and $X'_{wh,t}$ denote the markup between the wage paid by firms and the wage paid to the impatient households for intermediate goods sector and housing sector, respectively. $DIV_t$ is the lump-sum transfer from labor unions. The borrowing constraint implies that for impatient households housing plays a dual role: offering housing services and serving as collateral for borrowing.[4]

Impatient households choose consumption $C'_t$, housing $h'_t$, domestic-currency bonds $B'_t$, working hours in the intermediate goods sector $n_{c,t}$, and working hours in the housing sector $n_{h,t}$, subject to (2.2.1) and (2.2.2).

Therefore, impatient households choose $\{C'_t, h'_t, B'_t, n'_{c,t}, n'_{h,t}\}_{t=0}^{\infty}$ to maximize their expected lifetime utility subject to (2.2.1) and (2.2.2). The following equations are the first-order conditions of this

[4] There are two popular ways to incorporate financial frictions into traditional DSGE models. First, we can introduce financial accelerator originally proposed by Bernanke and Gertler (1989) and Bernanke et al. (1999), which emphasize on the relationship between external finance premium and the net worth of borrowers. Second, we can include collateral constraint developed by Kiyotaki and Moore (1997), which uses durable goods as a collateral for borrowing. Both of them can amplify and propagate credit shocks to the macroeconomy, but the framework of financial accelerator implies that the changes in asset price is backward-looking, while the model with collateral constraint indicates that the changes in asset price is forward-looking, and therefore is able to generate richer dynamics of macroeconomic aggregates. This paper chooses collateral constraint to incorporate financial frictions following the structure of Iacoviello and Neri (2010).

maximization problem:

$$z_t\Gamma'_C\left(\frac{1}{C'_t-\varepsilon' C'_{t-1}}-\frac{\beta'\varepsilon'}{C'_{t+1}-\varepsilon' C'_t}\right)=\lambda'_t\frac{p_t}{p_{d,t}}, \tag{2.2.3}$$

$$\lambda'_t q_t = z_t\frac{j_t}{h'_t}+\beta'\mathrm{E}_t\left(\lambda'_{t+1}q_{t+1}(1-\delta_h)\right)+\psi'_t\mathrm{E}_t\left[\frac{m q_{t+1}\pi_{d,t+1}}{R_t}\right], \tag{2.2.4}$$

$$\lambda'_t=\beta'\mathrm{E}_t\left[\lambda'_{t+1}\frac{R_t}{\pi_{d,t+1}}\right]+\psi'_t, \tag{2.2.5}$$

$$z_t\tau_t(n'_{c,t})^{\xi'}\left[(n'_{c,t})^{1+\xi'}+(n'_{h,t})^{1+\xi'}\right]^{\frac{\eta'-\xi'}{1+\xi'}}=\lambda'_t\frac{w'_{c,t}}{X'_{wc,t}}, \tag{2.2.6}$$

$$z_t\tau_t(n'_{h,t})^{\xi'}\left[(n'_{c,t})^{1+\xi'}+(n'_{h,t})^{1+\xi'}\right]^{\frac{\eta'-\xi'}{1+\xi'}}=\lambda'_t\frac{w'_{h,t}}{X'_{wh,t}}, \tag{2.2.7}$$

where $\lambda'_t$ and $\psi'_t$ are the Lagrange multipliers of budget constraint and collateral constraint, respectively.

## 2.3 Intermediate Goods Firms

### 2.3.1 Domestic Intermediate Goods Firms

There are a continuum of monopolistically competitive intermediate goods producers indexed by $s\in[0,1]$. The domestic producer uses labors, $n_{c,t}(s)$ and $n'_{c,t}(s)$, and capital in intermediate goods sector $K_{c,t-1}(s)$, to produce differentiated intermediate goods $y_{a,t}(s)$. The production technology is given by:

$$y_{a,t}(s)=\left[A_{c,t}\left(n_{c,t}(s)^{\alpha}n'_{c,t}(s)^{1-\alpha}\right)\right]^{1-\mu_c}\left[z_{c,t}K_{c,t-1}(s)\right]^{\mu_c}, \tag{2.3.1}$$

where $A_{c,t}$ is an aggregate exogenous technology shock for all domestic producers. These differentiated intermediate goods are divided into domestic use, $y_{d,t}(s)$, and exports, $y_{x,t}(s)$, that is,

$$y_{a,t}(s)=y_{d,t}(s)+y_{x,t}(s). \tag{2.3.2}$$

Because in a small open economy domestic producers are price-takers on exports, the export price is simply $p_{d,t}/e_t$, where $e_t$ is the exchange rate expressed as the price of the foreign currency in terms of domestic currency. As in Dib (2011), we assume that total foreign demand function for exports is:

$$y_{x,t}=\bar{\omega}\left[\frac{p_{d,t}}{e_t p^*}\right]^{-\nu_x}, \tag{2.3.3}$$

where $\bar{\omega}$ is a parameter determining the steady-state level of total exports, $\nu_x$ is the price elasticity of demand for domestic goods by foreigners, and $p^*$ is the world price level denominated in foreign currency.

The cost minimization problem for domestic producer is given by:

$$\min_{\{n_{c,t}(s),n'_{c,t}(s),K_{c,t-1}(s)\}} W_{c,t}n_{c,t}(s)+W'_{c,t}n'_{c,t}(s)+R_{c,t}K_{c,t-1}(s),$$

subject to (2.3.1), where $W_{c,t}$ and $W'_{c,t}$ are nominal wage rates, and $R_{c,t}$ is nominal rental rate of capital in intermediate goods sector. Taking first-order conditions with respect to $n_{c,t}(s)$, $n'_{c,t}(s)$, and $K_{c,t-1}(s)$ yields:

$$W_{c,t} = MC_t \alpha(1-\mu_c)\frac{y_{a,t}(s)}{n_{c,t}(s)}, \tag{2.3.4}$$

$$W'_{c,t} = MC_t(1-\alpha)(1-\mu_c)\frac{y_{a,t}(s)}{n'_{c,t}(s)}, \tag{2.3.5}$$

$$R_{c,t} = MC_t \mu_c \frac{y_{a,t}(s)}{z_{c,t}K_{c,t-1}(s)}, \tag{2.3.6}$$

where $MC_t$ is the Lagrange multiplier and can be interpreted as nominal marginal cost. Combining (2.3.4), (2.3.5), and (2.3.6) yields:

$$MC_t = \frac{1}{(1-\mu_c)^{1-\mu_c}}\frac{1}{(\mu_c)^{\mu_c}}\left[\frac{1}{A_{c,t}}\left(\frac{W_{c,t}}{\alpha}\right)^{\alpha}\left(\frac{W'_{c,t}}{1-\alpha}\right)^{(1-\alpha)}\right]^{1-\mu_c}\left(\frac{R_{K,t}}{z_{c,t}}\right)^{\mu_c}. \tag{2.3.7}$$

The domestic producers set prices in a staggered fashion à la Calvo (1983). Each period, a fraction $(1-\theta_d)$ of producers can reset a new optimal price, $p_{d,t}(s) = \widehat{p_{d,t}}(s)$, while a fraction $\theta_d$ of producers cannot do so. If a producer cannot reset its price, its last period price is updated by multiplying the previous period inflation rate with an elasticity equal to $\iota_d$; that is, $p_{d,t}(s) = p_{d,t-1}(s)\pi_{d,t-1}^{\iota_d}$. Therefore, the maximization problem for a producer in period $t$ is given by:

$$\max_{\widehat{p_{d,t}}(s)} \mathrm{E}_t \sum_{j=0}^{\infty}(\beta\theta_d)^j \mathcal{V}_{t,t+j}\left\{\left(p_{d,t+j}(s) - MC_{t+j}\right) y_{a,t+j}(s)\right\},$$

subject to the evolution of domestic price:

$$p_{d,t+j}(s) = \widehat{p_{d,t}}(s)\left[\prod_{l=1}^{j}\pi_{d,t+l-1}\right]^{\iota_d}, \tag{2.3.8}$$

and to the following demand functions:

$$y_{a,t+j}(s) = \left[\frac{p_{d,t+j}(s)}{p_{d,t+j}}\right]^{-\nu_d} y_{a,t+j}. \tag{2.3.9}$$

The first-order condition is given by:

$$\widehat{p_{d,t}}(s) = \frac{\nu_d}{\nu_d - 1}\frac{\mathrm{E}_t \sum_{j=0}^{\infty}(\beta\theta_d)^j \mathcal{V}_{t,t+j} MC_{t+j} y_{a,t+j}(s)}{\mathrm{E}_t \sum_{j=0}^{\infty}(\beta\theta_d)^j \mathcal{V}_{t,t+j} \mathcal{Q}_{t+j}^d y_{a,t+j}(s)}, \tag{2.3.10}$$

where $\mathcal{Q}_{t+j}^d = \left(\prod_{l=1}^{j}\pi_{d,t+l-1}\right)^{\iota_d}$. Furthermore, the aggregate domestic price is:

$$p_{d,t} = \left[\theta_d\left(p_{d,t-1}\pi_{d,t-1}^{\iota_d}\right)^{1-\nu_d} + (1-\theta_d)\widehat{p_{d,t}}^{1-\nu_d}\right]^{\frac{1}{1-\nu_d}}. \tag{2.3.11}$$

Combining (2.3.10) and (2.3.11) yields the following domestic sector Phillips curve:

$$\ln \pi_{d,t} - \iota_d \ln \pi_{d,t-1} = \beta(\mathrm{E}_t \ln \pi_{d,t+1} - \iota_d \ln \pi_{d,t}) - \varepsilon_d \ln(X_{d,t}/X_d) + u_{d,t}, \tag{2.3.12}$$

where $\varepsilon_d = (1-\theta_d)(1-\beta\theta_d)/\theta_d$, $X_{d,t} = p_{d,t}/MC_t$, and $X_d$ is the steady-state of $X_{d,t}$.

### 2.3.2 Imported Intermediate Goods Firms

A continuum of monopolistically competitive intermediate goods importers, indexed by $s \in [0,1]$, import homogeneous intermediate goods at price $e_t p_t^*$ and then transform them into differentiated intermediate goods. The importers set prices in a staggered fashion à la Calvo (1983). Each period, a fraction $(1-\theta_m)$ of importers can reset a new optimal price, $p_{m,t}(s) = \widehat{p_{m,t}}(s)$, while a fraction $\theta_m$ of importers cannot do so. If a importer cannot reset its price, its last period price is updated by multiplying the previous period inflation rate with an elasticity equal to $\iota_m$; that is, $p_{m,t}(s) = p_{m,t-1}(s)\pi_{m,t-1}^{\iota_m}$, Therefore, the maximization problem for an importer, s, in period t is given by:

$$\max_{\widehat{p_{m,t}}(s)} \mathrm{E}_t \sum_{j=0}^{\infty} (\beta\theta_m)^j \mathcal{V}_{t,t+j} \left\{ \left( p_{m,t+j}(s) - e_{t+j} p_{t+j}^* \right) y_{m,t+j}(s) \right\},$$

subject to the evolution of importing price:

$$p_{m,t+j}(s) = \widehat{p_{m,t}}(s) \left[ \prod_{l=1}^{j} \pi_{m,t+l-1} \right]^{\iota_m}, \tag{2.3.13}$$

and to the following demand functions:

$$y_{m,t+j}(s) = \left[ \frac{p_{m,t+j}(s)}{p_{m,t+j}} \right]^{-\nu_m} y_{m,t+j}. \tag{2.3.14}$$

The first-order condition is given by:

$$\widehat{p_{m,t}}(s) = \frac{\nu_m}{\nu_m - 1} \frac{\mathrm{E}_t \sum_{j=0}^{\infty} (\beta\theta_m)^j \mathcal{V}_{t,t+j} e_{t+j} p_{t+j}^* y_{m,t+j}(s)}{\mathrm{E}_t \sum_{j=0}^{\infty} (\beta\theta_m)^j \mathcal{V}_{t,t+j} \mathcal{Q}_{t+j}^m y_{m,t+j}(s)}, \tag{2.3.15}$$

where $\mathcal{Q}_{t+j}^m = \left( \prod_{l=1}^{j} \pi_{m,t+l-1} \right)^{\iota_m}$. Furthermore, the aggregate importing price is:

$$p_{m,t} = \left[ \theta_m \left( p_{m,t-1} \pi_{m,t-1}^{\iota_m} \right)^{1-\nu_m} + (1-\theta_m) \widehat{p_{m,t}}^{1-\nu_m} \right]^{\frac{1}{1-\nu_m}}. \tag{2.3.16}$$

Combining (2.3.15) and (2.3.16) yields the following importing Phillips curve:

$$\ln \pi_{m,t} - \iota_m \ln \pi_{m,t-1} = \beta(\mathrm{E}_t \ln \pi_{m,t+1} - \iota_m \ln \pi_{m,t}) - \varepsilon_m \ln(X_{m,t}/X_m) + u_{m,t}, \tag{2.3.17}$$

where $\varepsilon_m = (1-\theta_m)(1-\beta\theta_m)/\theta_m$, $X_{m,t} = p_{m,t}/(e_t p^*)$, and $X_m$ is the steady-state of $X_{m,t}$.

## 2.4 Final Goods Firms

Final goods firm transforms differentiated domestic and imported intermediate goods into composite goods and then turn these composite goods into final goods, which are used for domestic consumption and investment.

The composite domestic and imported intermediate goods, $y_{d,t}$ and $y_{m,t}$, are produced using a continuum of differentiated domestic and imported intermediate goods, $y_{d,t}(s)$ and $y_{m,t}(s)$, respectively. The aggregate technologies are:

$$y_{d,t} = \left[ \int_0^1 y_{d,t}(s)^{\frac{\nu^d - 1}{\nu^d}} \mathrm{d}s \right]^{\frac{\nu^d}{\nu^d - 1}}, \tag{2.4.1}$$

$$y_{m,t} = \left[ \int_0^1 y_{m,t}(s)^{\frac{\nu^m - 1}{\nu^m}} \mathrm{d}s \right]^{\frac{\nu^m}{\nu^m - 1}}, \tag{2.4.2}$$

where $\nu^d$ and $\nu^m$ are the constant elasticity of substitution between different domestic and imported intermediate goods, respectively.

The final goods $Y_t$ are produced using the composite domestic and imported intermediate goods, $y_{d,t}$ and $y_{m,t}$, and the aggregate technology is:

$$Y_t = \left[ (1-\omega_m)^{\frac{1}{\nu}} y_{d,t}^{\frac{\nu-1}{\nu}} + \omega_m^{\frac{1}{\nu}} y_{m,t}^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}, \tag{2.4.3}$$

where $\omega_m$ denotes a positive share of imported intermediate goods in the production of final goods, and $\nu$ is the constant elasticity of substitution between domestic and imported intermediate goods.

Given the price level of the final good, $p_t$, of domestic intermediate goods, $p_{d,t}$, and of imported intermediate goods, $p_{m,t}$, final goods firm maximizes its profit by choosing the optimal quantities of $y_{d,t}$ and $y_{m,t}$. Hence, final goods firm faces the following maximization problem:

$$\max_{\{y_{d,t}, y_{m,t}\}} p_t Y_t - (p_{d,t} y_{d,t} + p_{m,t} y_{m,t}),$$

subject to (2.4.3). This maximization problem implies the demand functions for domestic and imported intermediate goods are respectively given by:

$$y_{d,t} = (1-\omega_m) \left[ \frac{p_{d,t}}{p_t} \right]^{-\nu} Y_t, \tag{2.4.4}$$

$$y_{m,t} = \omega_m \left[ \frac{p_{m,t}}{p_t} \right]^{-\nu} Y_t. \tag{2.4.5}$$

In addition, the zero profit condition implies the price level of the final good is a price index given by:

$$p_t = \left[ (1-\omega_m) p_{d,t}^{1-\nu} + \omega_m p_{m,t}^{1-\nu} \right]^{\frac{1}{1-\nu}}. \tag{2.4.6}$$

## 2.5 House-producing Firms

The housing firm uses labors, $n_{h,t}$ and $n'_{h,t}$, capital in the housing sector, $K_{h,t-1}$, intermediate goods, $k_{b,t}$, and land, $l_{t-1}$, to produce new houses, $IH_t$. The production technology is:

$$IH_t = \left( A_{h,t} (n_{h,t}^{\alpha} n_{h,t}'^{1-\alpha}) \right)^{1-\mu_h-\mu_b-\mu_l} \left( z_{h,t} K_{h,t-1} \right)^{\mu_h} \left( k_{b,t} \right)^{\mu_b} \left( l_{t-1} \right)^{\mu_l}, \tag{2.5.1}$$

where $A_{h,t}$ is an exogenous shock to housing technology. The maximization problem for housing firm is given by:

$$\max_{\{n_{h,t}, n'_{h,t}, K_{h,t-1}, k_{b,t}, l_{t-1}\}} q_t IH_t - (w_{h,t} n_{c,t}(s) + w'_{h,t} n'_{h,t}(s) + R_{h,t} K_{h,t-1} + p_{b,t} k_{b,t} + R_{l,t} l_{t-1}),$$

subject to (2.5.1), where $q_t$ is the real housing price, $w_{h,t}$ and $w'_{h,t}$ are real wage rates, $R_{h,t}$ and $R_{l,t}$ are the real rental rate of capital in the housing sector and of land, and $p_{b,t}$ is the real price of intermediate goods. The following equations are the first-order conditions of this maximization problem:

$$\alpha(1-\mu_h-\mu_b-\mu_l)\frac{q_t IH_t}{n_{h,t}} = w_{h,t}, \tag{2.5.2}$$

$$(1-\alpha)(1-\mu_h-\mu_b-\mu_l)\frac{q_t IH_t}{n'_{h,t}} = w'_{h,t}, \tag{2.5.3}$$

$$\mu_h\frac{q_t IH_t}{K_{h,t-1}} = R_{h,t}z_{h,t}, \tag{2.5.4}$$

$$\mu_b\frac{q_t IH_t}{k_{b,t}} = p_{b,t}, \tag{2.5.5}$$

$$\mu_l\frac{q_t IH_t}{l_{t-1}} = R_{l,t}. \tag{2.5.6}$$

## 2.6 Labor Unions

The way we model sticky wage is analogous to domestic price setting. The processes of wage setting are described as follows. First, patient and impatient households provide homogeneous labor supply to unions. Second, the unions differentiate these labor supply, set wages subject to a Calvo scheme, and offer them to labor packers. Third, labor packers reassemble these differentiated labor supply into homogeneous labor composites, $n_{c,t}$, $n_{h,t}$, $n'_{c,t}$, and $n'_{h,t}$. Finally, domestic intermediate goods firms and housing firm hire labor from these packers.

Under the Calvo price setting with partial indexation to past domestic inflation, the result resembles the sticky price for domestic price setting, leading to four wage Phillips curves that are isomorphic to the domestic price Phillips curves. The four wage Phillips curves are:

$$\ln\hat{w}_{c,t} - \iota_{wc}\ln\hat{w}_{c,t-1} = \beta(\mathrm{E}_t\ln\hat{w}_{c,t+1} - \iota_{wc}\ln\hat{w}_{c,t}) - \varepsilon_{wc}\ln(X_{wc,t}/X_{wc}), \tag{2.6.1}$$

$$\ln\hat{w}_{h,t} - \iota_{wh}\ln\hat{w}_{h,t-1} = \beta(\mathrm{E}_t\ln\hat{w}_{h,t+1} - \iota_{wh}\ln\hat{w}_{h,t}) - \varepsilon_{wh}\ln(X_{wh,t}/X_{wh}), \tag{2.6.2}$$

$$\ln\hat{w'}_{c,t} - \iota_{wc}\ln\hat{w'}_{c,t-1} = \beta'(\mathrm{E}_t\ln\hat{w'}_{c,t+1} - \iota_{wc}\ln\hat{w'}_{c,t}) - \varepsilon'_{wc}\ln(X'_{wc,t}/X'_{wc}), \tag{2.6.3}$$

$$\ln\hat{w'}_{h,t} - \iota_{wh}\ln\hat{w'}_{h,t-1} = \beta'(\mathrm{E}_t\ln\hat{w'}_{h,t+1} - \iota_{wh}\ln\hat{w'}_{h,t}) - \varepsilon'_{wh}\ln(X'_{wh,t}/X'_{wh}), \tag{2.6.4}$$

where $\hat{w}_{i,t} = (w_{i,t}\pi_{d,t})/w_{i,t-1}$ denotes the nominal wage inflation, $\iota_{wi}$ is the partial indexation to past wage inflation, $\varepsilon_{wi} = (1-\theta_{wi})(1-\beta\theta_{wi})/\theta_{wi}$, and $X_{wi,t}$ is the markup between the wage paid by firms and the wage paid to the patient or impatient households for intermediate goods sector and housing sector, resepctively.

## 2.7 The Central Bank

As in Iacoviello and Neri (2010), we assume that the central bank sets the interest rates, $R_t$, according to a Taylor rule given by:

$$R_t = R_{t-1}^{r_R}\pi_{d,t}^{(1-r_R)r_\pi}\left(\frac{GDP_t}{GDP_{t-1}}\right)^{r_Y(1-r_R)} R^{(1-r_R)}\frac{\exp(u_{R,t})}{A_{s,t}}, \tag{2.7.1}$$

where $R$ is the steady-state value of nominal interest rate; $r_R$, $r_\pi$, and $r_Y$ are policy parameters corresponding to nominal interest rate, domestic inflation rate, and GDP, respectively. $u_{R,t}$ is an independently and identically distributed monetary shock with variance, $\sigma^2_{u_R}$; $A_{s,t}$ is a persistent shock aiming to capture long-term deviation of inflation from its steady-state value.

## 2.8 Exogenous Processes

There are seven persistent exogenous shocks: shock to the intertemporal preferences $z_t$, shock to the housing preferences $j_t$, shock to the labor supply $\tau_t$, shock to investment-specific technology $A_{k,t}$, shock to production technology of domestic intermediate goods $A_{c,t}$, shock to the housing technology $A_{h,t}$, and shock to the deviation of domestic inflation rate $A_{s,t}$; For simplicity, the persistent exogenous processes are assumed to evolve according to first-order autoregressive processes:

$$\mathcal{E}_t = (1 - \rho_{\mathcal{E}})\mathcal{E} + \rho_{\mathcal{E}}\mathcal{E}_{t-1} + \epsilon_{\mathcal{E},t},$$

$\mathcal{E} \in \{z, j, \tau, A_k, A_c, A_h, A_s\}$, and $\epsilon_{\mathcal{E},t}$ is i.i.d. shock with zero mean and standard deviation, $\sigma_{\mathcal{E}}$. Also, there are four temporary exogenous shocks in this model: shock to nominal interest rate $u_{R,t}$, shock to the cost of domestic intermediate goods $u_{d,t}$, shock to the cost of imported intermediate goods $u_{m,t}$, and shock to LTV ratio $u_{l,t}$, which aims to capture the exogenous fluctuation of LTV ratio. That is,

$$m_t = m + u_{l,t},$$

where $m$ is the steady-state value of LTV ratio. The temporary shocks, $u_R$, $u_l$, $u_d$, and $u_m$, are simply assigned independently and identically distributions with mean of zero and variance of $\sigma^2_{u_i}$.

## 2.9 Market Clearing Conditions

Market clearing conditions for final goods, intermediate goods, houses, labor, land, domestic bonds, and foreign assets (foreign bonds, imports, and exports) are listed respectively as follows:

$$C_t + C'_t + IK_t + k_{b,t} = Y_t - \Phi_t, \tag{2.9.1}$$

where $IK_t = I_{c,t} + I_{h,t}$ denotes business investment and $\Phi_t$ is the total adjustment cost of capitals, utilization rates, and foreign bonds;

$$y_{d,t} + y_{x,t} = y_{a,t}, \tag{2.9.2}$$

$$h_t + h'_t - (1 - \delta_h)(h_{t-1} + h'_{t-1}) = IH_t, \tag{2.9.3}$$

$$n^s_t = n^d_t, \tag{2.9.4}$$

$$l_t = 1, \tag{2.9.5}$$

$$B_t = B'_t, \tag{2.9.6}$$

$$TB_t = -\frac{e_t p^*}{p_{d,t}}\left[B^*_t - \frac{R^*}{\pi^*}B^*_{t-1}\right] = y_{x,t} - \left[\frac{p_{m,t}}{p_{d,t}}\right] y_{m,t}, \tag{2.9.7}$$

where $TB_t$ denotes trade balance. Then, real gross domestic product $GDP_t$ can be defined as the sum of final goods at the relative price of final goods to domestic goods, new houses generated in period t at steady-state real housing price, and trade balance, i.e.,

$$GDP_t = \left[\frac{p_t}{p_{d,t}}\right] Y_t + qIH_t + TB_t. \tag{2.9.8}$$

# 3 Empirical Methodology

## 3.1 Data

Domestic consumer price index, real gross domestic product, nominal interest rate, real consumption, and real consumption investment are obtained from the Taiwan Economic Journal database. Real residential investment and real trade balance are obtained from the Directorate General of Budget, Accounting and Statistics (DGBAS), Executive Yuan, Taiwan. Real housing price is obtained from SINYI Research Center for Real Estate. Except for nominal interest rate, all time series are taken logs, adjusted using the US Census Bureau's X12 seasonal adjustment program in Eviews, and detrended using Hodrick-Prescott filter program in Matlab. Figure 1 plots the series form 1992Q1 to 2012Q4.

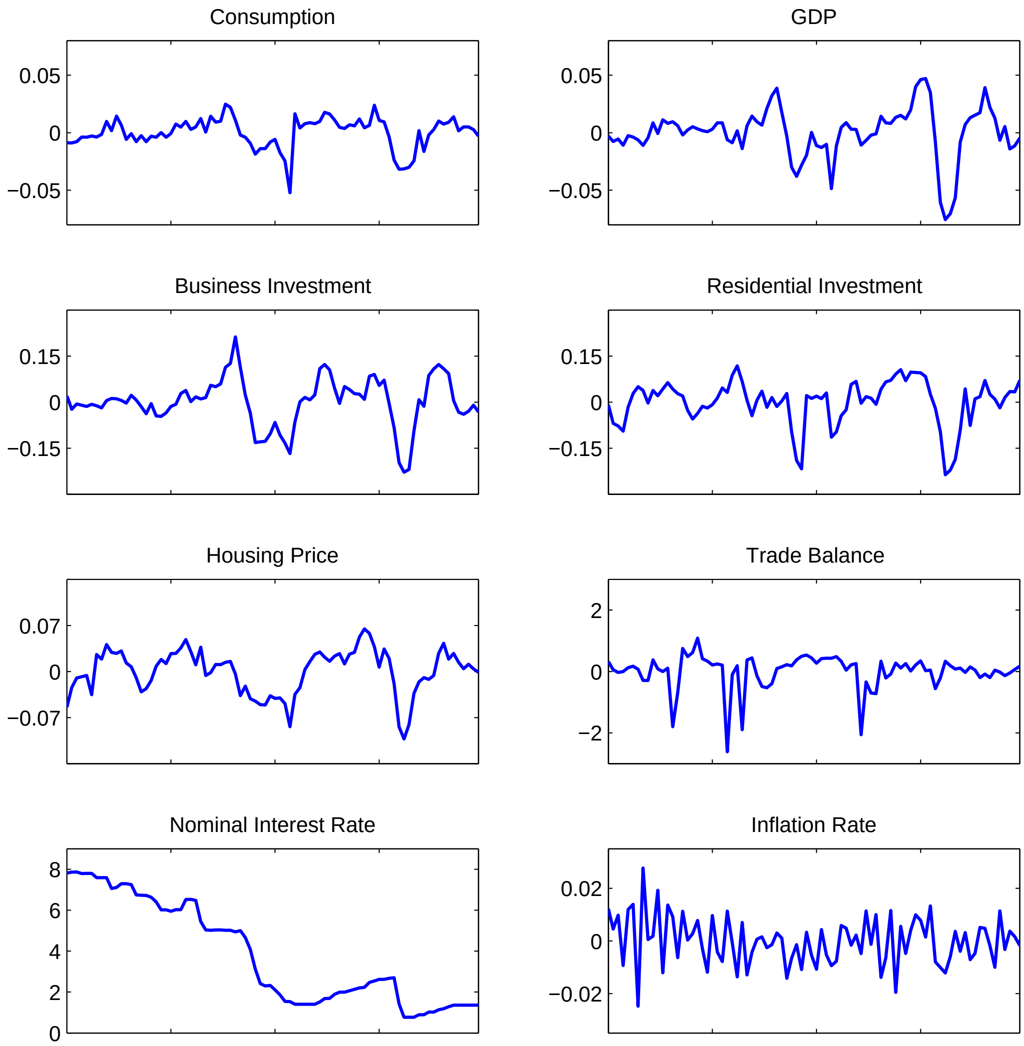


Figure 1: Data

## 3.2 Calibration

We set $\beta = 0.99$, which implies that the steady-state annual real interest rate is about 4 percent, and $\beta' = 0.97$, which ensures that patient households are net lenders and impatient households are net borrowers in domestic bond market. Following Iacoviello and Neri (2010), habit formation in consumption of patient households ($\varepsilon$) and impatient households ($\varepsilon'$) are, respectively, 0.32 and 0.58. Labor supply elasticity of patient households ($\eta$) and impatient households ($\eta'$) are, respectively, 0.52 and 0.51. Patient households' disutility of labor across sector ($\xi$) is set at 0.66. Impatient households' disutility of labor across sector ($\xi'$) is set at 0.97. For capital depreciation rate ($\delta_k$) and housing depreciation rate ($\delta_h$), we choose $\delta_k = 0.03$ and $\delta_h = 0.01$. Labor income share of patient households ($\alpha$) is set to be 0.79. The capital share in the goods production function ($\mu_c$) is taken to be 0.35. In the housing production function, capital share, land share, and intermediate goods share are all set to be 0.1, and therefore the labor share is 0.7. We choose both price elasticity of exports ($\nu_x$) and imports ($\nu$) equal to 0.6, as in Kollmann (2002).

For simplicity, the steady states of domestic inflation rate ($\pi_d$), importing inflation rate ($\pi_m$), foreign inflation rate ($\pi^*$), the relative price of domestic price to aggregate price ($\gamma_{pdp} = p_d/p$), and the relative price of domestic price to importing price ($\gamma_{pdpm} = p_d/p_m$) are all set to be 1. As in Iacoviello and Neri (2010), we fix $X_d = 1.15$, which implies a steady-state markup of 15 percent in the goods production sector. Similarly, we set $X_{wc} = X_{wh} = 1.15$. But for importing price markup, we set $X_m = 1$, which ensures that $\bar{\omega}$ can solely determine the steady state of exports. The steady state preference on house in the utility function is set at $j = 0.12$. The Loan-to-value ratio ($m$) equals 0.85. To match the actual data, we set $\omega_m = 0.6169$ and $\bar{\omega} = 1.4769$, ensuring that the steady-state ratio of exports to gross domestic product ($y_x/GDP$) and imports to gross domestic product ($y_m/GDP$) are 0.6069 and 0.5669, respectively.

For the part of Phillips curve, the nominal stickiness ($\theta$) and indexation ($\iota$) of domestic price, nonhousing sector wage, and housing sector wage are respectively set at $\theta_d = 0.83$, $\iota_d = 0.69$, $\theta_{wc} = 0.79$, $\iota_{wc} = 0.08$, $\theta_{wh} = 0.91$, and $\iota_{wh} = 0.40$, as in Iacoviello and Neri (2010). Following Teo (2009), the nominal stickiness and indexation of importing price are chosen to be $\theta_m = 0.50$ and $\iota_m = 0.50$. The adjustment cost of foreign bonds ($\Phi_{B^*}$) is set at 0.00079, which is estimated by Cheng et al. (2008). The adjustment cost of capital in the intermediate goods sector and in the housing sector are set at $\Phi_{kc} = 6.05$ and $\Phi_{kh} = 5$ to capture the standard deviation of business investment in the data. For the adjustment cost of capital utilization rates ($\bar{\varphi}$), we set a auxiliary variable called utilization parameter ($\zeta$) to be 0.69, following Iacoviello and Neri (2010), and their relationship is $\bar{\varphi} = \zeta/(1-\zeta)$.

Auto-correlation coefficients of all exogenous processes follow from the estimated results by Iacoviello and Neri (2010), with a range between 0.92 and 0.997. In order to match the standard deviation of residential investment of real data, we set the standard deviation of shocks to housing preference and to nonhousing production, respectively, equal to 0.003 and 0.025. To capture the long-term effect of the deviation of inflation rate, the standard deviation of shocks to monetary policy and to the deviation of domestic inflation rate are chosen to be 0.0005 and 0.00001, respectively. To match the variation of trade balance, we set the standard deviation of shock to imported price at 0.03. Other standard deviations of exogenous processes are all uniformly set to be 0.01. As for the policy parameters of Taylor rule, we use the generalized method of moments (GMM) à la Clarida et al. (2000) and Taiwan's data to estimate these parameters. The estimated results are $r_\pi = 1.38$, $r_Y = 0.14$, and $r_R = 0.97$. Note that the reactions to inflation rate and interest rate are significant, but that to output is insignificant. These parameters are summarized in Table 1.

Table 1: Calibrated Parameters

| Description | Values |
|---|---|
| Discount factor | $\beta = 0.99$; $\beta' = 0.97$. |
| Habit formation in consumption | $\varepsilon = 0.32$; $\varepsilon = 0.58$. |
| Labor supply elasticity | $\eta = 0.52$; $\eta' = 0.51$. |
| Disutility of labor across sector | $\xi = 0.66$; $\xi' = 0.97$. |
| Depreciation rate | $\delta_k = \delta_h = 0.03$. |
| Cobb-Douglas coefficient | $\alpha = 0.79$; $\mu_c = 0.35$; $\mu_h = \mu_l = \mu_b = 0.1$. |
| Price elasticity of exports & imports | $\nu_x = \nu = 0.6$. |
| S.S. of inflation rate & relative price | $\pi_d = \pi_m = \pi^* = \gamma_{pdp} = \gamma_{pdpm} = 1$. |
| S.S. of markup | $X_d = X_{wc} = X_{wh} = 1.15$; $X_m = 1$. |
| S.S. preference on house | $j = 0.12$. |
| LTV ratio | $m = 0.85$. |
| Share of imports | $\omega_m = 0.6169$. |
| auxiliary parameter of exports | $\bar{\omega} = 1.4769$. |
| Phillips curve: nominal stickiness | $\theta_d = 0.83$; $\theta_m = 0.50$; $\theta_{wc} = 0.79$; $\theta_{wh} = 0.91$. |
| Phillips curve: indexation | $\iota_d = 0.69$; $\iota_m = 0.50$; $\iota_{wc} = 0.08$; $\iota_{wh} = 0.40$. |
| Adjustment cost | $\Phi_{B^*} = 0.00079$; $\Phi_{kc} = 6.05$; $\Phi_{kh} = 5$; $\zeta = 0.69$. |
| AR(1) coefficient | 0.92–0.997. |
| S.D. of exogenous shocks | $\epsilon_j = 0.003$; $\epsilon_{A_c} = 0.025$; $\epsilon_{A_s} = 0.00001$; $u_R = 0.0005$; |
| | $u_m = 0.03$; $\epsilon_z = \epsilon_\tau = \epsilon_{A_k} = \epsilon_{A_h} = u_l = u_d = 0.01$. |
| Policy parameter (estimated) | $r_R = 0.97$; $r_\pi = 1.38$; $r_Y = 0.14$. |

Source: Iacoviello and Neri (2010), Kollmann (2002), Cheng et al. (2008), and Teo (2009).

## 3.3 Properties of the Model

After calibrating the model, this subsection presents results of moment matching and demonstrates impulse response to housing preference shock, which plays major roles to explain the fluctuation of the economy, for four alternative versions of the model: baseline, flexible price ($\theta_d = \theta_m = 0$), flexible wage ($\theta_{wc} = \theta_{wh} = 0$), and no collateral effect ($\alpha = 1$).

Table 2 shows that this model explains the behavior of business and residential investment well. The theoretical second moment of major macroeconomic variables are also very close to the data. Furthermore, the model also replicates the correlation of these variables with GDP relatively well. Because of the highly volatile attribution of trade balance with

Table 2: Business Cycle Properties of The Model

| | Data | | Model | |
|---|---|---|---|---|
| Variables | Std. | Corr. | Std. | Corr. |
| Consumption ($C$) | 0.60 | 0.71 | 0.57 | 0.46 |
| Business investment ($IK$) | 3.56 | 0.80 | 3.56 | 0.38 |
| Residential investment ($IH$) | 3.33 | 0.70 | 3.33 | 0.63 |
| Housing price ($q$) | 1.53 | 0.67 | 1.14 | 0.87 |
| Trade balance ($TB$) | 25.70 | -0.01 | 24.82 | -0.41 |

Note: Std. and Corr. are the abbreviation of standard deviation and correlation, respectively.
The column of Std. represents Std($X$) / Std($GDP$).
The column of Corr. represents Corr($X$, $GDP$).

Std. of 25.70, it is very hard to pin down the low correlation between trade balance and GDP. Nevertheless, this model still explains the negative relationship between trade balance and GDP.

Figure 2 plots impulse responses to a housing preference shock. The baseline case with collateral effect (the solid line) shows that an increase in housing preference will induce households to hold more houses, thus generating a persistent increase in housing price. Housing price going up will stimulate housing firm to produce more new houses, thus leading to increases in business investment and residential investment. For consumption, on the one hand, all households' expenditure on houses will increase, so their expenditures on consumption may decline. On the other hand, impatient households' borrowing constraint will be relaxed due to the higher collateral value, therefore enhancing their ability to borrow more. Hence, combining these two effects, the total effect on consumption is positive. Finally, trade balance becomes negative due to a significant rise in domestic aggregate demand.

Figure 2 also shows that if there is no collateral effect (the dashed line), the total effect on consumption is negative because consumption is crowded out by higher demand for housing. Business investment also declines due to lack of collateral effect. For the case of flexible wage (the circled line), when housing firms produce more new houses, because of the setting of cobb-douglas production fuction, more productive inputs, especially the demand for labor, are required. If the wage can be flexibly changed, that will raise the wage paid to labor immediately. This partially offsets the negative effect on trade balance and the positive effects on business investment, residential investment, and GDP.

## 4 Monetary and Macro-prudential Policies

In this section, we discuss the optimal monetary and macro-prudential policies. We search for the optimal policy by maximizing social welfare function, rather than by minimizing an ad hoc loss function

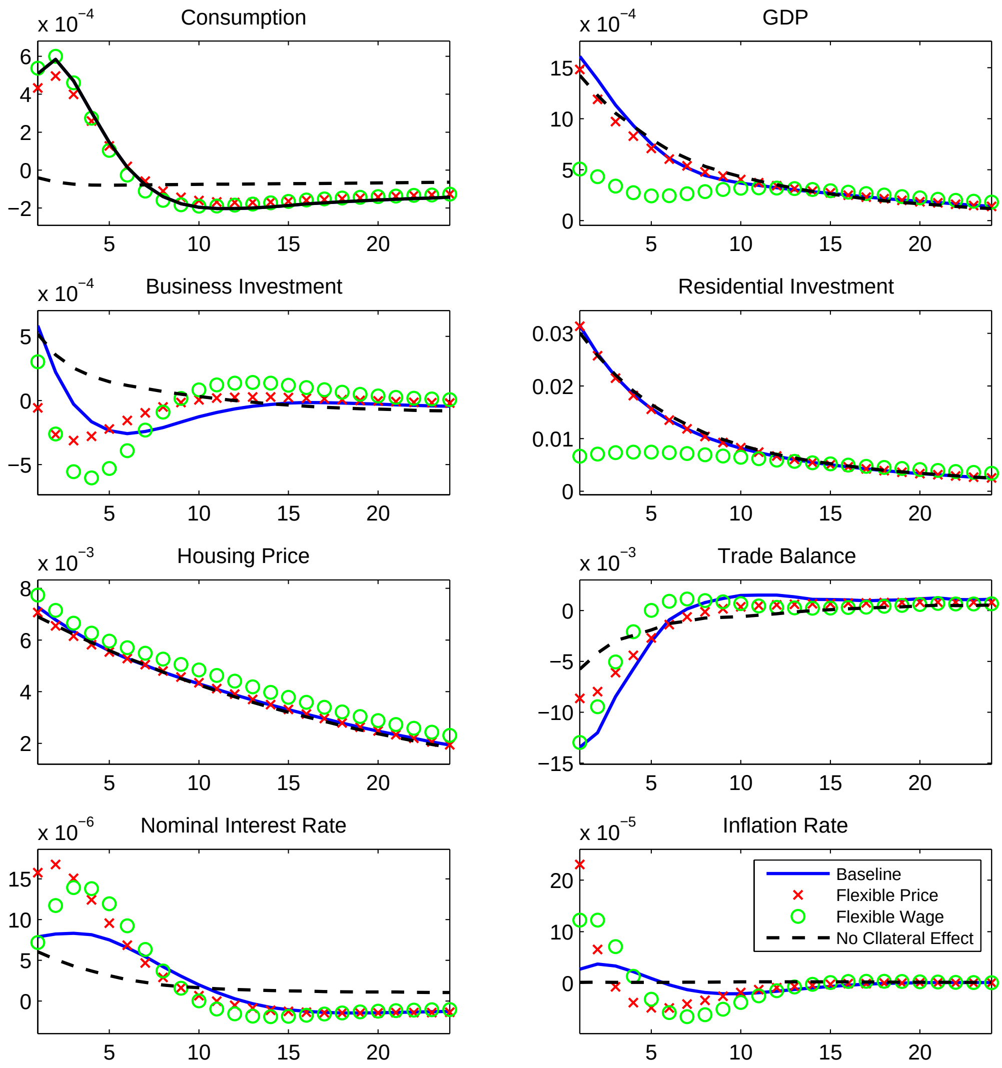


Figure 2: Impulse Responses to a Housing Preference Shock

which typically composed of inflation rate gap and output gap.[5] The advantage of maximizing social welfare over minimizing loss function are as follows. First, the objective of government policies should be set to enhance welfare of the economy as a whole. Thus, we maximize the social welfare function, which combines the expected lifetime utilities of patient and impatient households. Second, instead of minimizing an ad hoc loss function, maximizing social welfare function should provide a more precise and robust result of measuring the transitional dynamics of policy changes.

We will consider different types of interest rate rules given a constant LTV ratio, and counter-cyclical LTV ratio rules given the baseline interest rate rule. The level and stabilization effects of these policies would be discussed as well.

The welfare measure is based on the standard approach commonly used in the literature.[6] The monetary authority maximizes households' welfare function subject to the competitive equilibrium conditions and different policy rules. The welfare function for type-$i$ household at time 0 ($\mathcal{V}_0^i$) is

[5] Minimizing an ad hoc loss function focuses on the stabilization of some endogenous variables that policy maker concerns. That is, policy maker try to minimize the variance of these variables by choosing proper policy parameters.

[6] See, for example, Lambertini et al. (2013) and Schmitt-Grohé and Uribe (2004).

defined as the following conditional expectation of lifetime utility:

$$\mathcal{V}_0^i \equiv \mathrm{E}_0\Big[\sum_{t=0}^{\infty}(\beta^i)^t U^i(C_t^i, C_{t-1}^i, h_t^i, n_{c,t}^i, n_{h,t}^i)\Big] = \frac{U_0^i}{1-\beta},$$

where $U_0^i$ is the per period steady state utility of type-$i$ households. Also following the literature, we compute the welfare function in the initial state being at the deterministic steady state. Because of the existence of heterogeneity, we further define the social welfare function given by:

$$\mathcal{V}_0^s \equiv (1-\beta)\mathcal{V}_0 + (1-\beta')\mathcal{V}_0' = U_0 + U_0',$$

where the weights on households' welfare function, $1-\beta$ and $1-\beta'$, ensure that the social welfare function is the sum of patient and impatient households' utility functions with equal weight.

## 4.1 Optimal Interest Rate Rules

In addition to the baseline policy of (2.7.1), we further consider three alternative interest rate rules leaning against the wind of domestic credit ($B$), housing price ($q$), and exchange rate ($e$), respectively. That is,

$$R_t = R_{t-1}^{r_R}\pi_{d,t}^{(1-r_R)r_\pi}\left(\frac{GDP_t}{GDP_{t-1}}\right)^{r_Y(1-r_R)}\left(\frac{X_t}{X_{t-1}}\right)^{r_X(1-r_R)}R^{(1-r_R)}, \tag{4.1.1}$$

where $X \in \{B, q, e\}$.

We estimate the parameters of the baseline policy of (2.7.1) using Taiwan's data. For the policy rule of (4.1.1), we conduct grid search over a four-parameter space with step size 0.01 to obtain the optimized policy parameters. The search ranges from zero to one for $r_R$, from one to two for $r_\pi$, and from zero to three for $r_Y$ and $r_X$.

Table 3 presents the estimated and the optimized parameters for the baseline policy and the associated optimized interest rate rule. The results indicate that no matter what kinds of variables interest rate rules respond to, optimizing these rules always lead to the smoothing factor equal to zero ($r_R = 0$), i.e., monetary policy involves no interest rate inertia. These four optimized policy rules all perform better than the baseline policy.

Among these four optimized rules, the rule responding to housing price has the best effect on improving social welfare function. The optimized rule takes the form:

$$\ln R_t = 1.23 \ln \pi_{d,t} + 0.32\,(\ln q_t - \ln q_{t-1})\,.$$

This rule displays no inertia effect ($r_R = 0$), has a relatively high coefficient reacting to inflation ($r_\pi = 1.23$), an output gap coefficient close to zero ($r_Y = 0$), and a large coefficient reacting to house price ($r_q = 0.32$). This policy rule improves the social welfare function by 0.0066 relative to the baseline policy.

This result is different from Lambertini et al. (2013), which finds that interest rate rule responding to domestic credit is the best way to improve social welfare function.

The reason why the differences occur may be due to the fact that the volatility of housing price of the US is smaller than the one of Taiwan: the ratio of the standard deviation of housing price to the standard deviation of GDP is 0.86 for the US (Iacoviello and Neri, 2010) and is 1.53 for Taiwan (Table

2). This implies that the optimized policy rule will be more sensitive to change in housing price for the Taiwanese economy than the US, and thus stabilizing housing price can better raise welfare than alternative policy measures.

Table 3 also shows that the rule responding to housing price has the best effect on improving patient households' welfare function. While the rule responding to domestic credit performs the least well among these optimized rules, which raises the social welfare function only by 0.0959; it does, however, raise the impatient households' welfare function.

The columns of level effect in Table 4 reveal that all these four rules lower the stochastic steady state of housing price. Except the case for responding domestic credit, other three cases increase the level of most real variables but slightly decrease the level of residential investment. The rule responding to domestic credit decreases the level of not only residential investment but also business investment and trade balance. The columns of stabilization effect in Table 4 indicate that rules responding to GDP, housing price, and exchange rate can stabilize most macroeconomics variables except residential investment. As for the case of domestic credit, it has the best stabilization effect on borrower's consumption, but at the same time dramatically enlarges the volatility of the other macroeconomic variables, such as business investment, residential investment, and trade balance. This corresponds to the earlier finding that the interest rate rule reacting to domestic credit does not perform well as other optimized rules in maximizing social welfare.

Table 3: Optimized Parameters and Conditional Welfares

| | | Conditional welfares | | |
|---|---|---|---|---|
| Rules | Optimized parameters | Social | Patient | Impatient |
| Baseline policy | $r_R = 0.97$; $r_\pi = 1.38$; $r_Y = 0.14$. | -2.8406 | -17.8202 | -88.7463 |
| Optimal interest rate rule | | | | |
| | $r_R = 0$; $r_\pi = 1.22$; $r_Y = 0.14$. | -2.8343 | -17.6752 | -88.5845 |
| Domestic credit | $r_R = 0$; $r_\pi = 1.61$; $r_Y = 0.72$; $r_b = 0.32$. | -2.8341 | -17.7243 | -88.5616 |
| Housing price | $r_R = 0$; $r_\pi = 1.23$; $r_Y = 0$; $r_q = 0.32$. | -2.8340 | -17.6716 | -88.5757 |
| Exchange rate | $r_R = 0$; $r_\pi = 1.22$; $r_Y = 0.20$; $r_e = 0.26$. | -2.8343 | -17.6732 | -88.5844 |
| Optimal LTV ratio rule | | | | |
| GDP | $v_m = 0.14$; $v_g = 0$. | -2.8406 | -17.8203 | -88.7460 |
| Domestic credit | $v_m = 0.54$; $v_b = -20$. | -2.8377 | -17.8251 | -88.6477 |
| Housing price | $v_m = 0.16$; $v_q = -0.17$. | -2.8406 | -17.8218 | -88.7448 |
| Exchange rate | $v_m = 0.15$; $v_e = -0.83$. | -2.8406 | -17.8199 | -88.7461 |

Table 4 also shows that in contrast to the baseline policy, all of these four rules can effectively improve social welfare function through sacrificing the stability of nominal interest rate, which is consistent with the fact of the optimized value of smoothing factor equal to zero.

Table 4: Level Effects and Stabilization Effects

| | Level effects | | | | | | | | | Stabilization effects | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rules | $GDP$ | $C$ | $C'$ | $IK$ | $IH$ | $q$ | $TB$ | $R$ | $\pi_d$ | $GDP$ | $C$ | $C'$ | $IK$ | $IH$ | $q$ | $TB$ | $R$ | $\pi_d$ |
| Baseline policy | 0.8884 | 0.3531 | -1.3246 | -0.6215 | -1.9786 | -0.3354 | -2.6840 | 0.0101 | 0.0000 | 2.60 | 1.34 | 3.38 | 9.26 | 8.66 | 2.97 | 64.53 | 0.10 | 1.00 |
| Optimal interest rate rule | | | | | | | | | | | | | | | | | | |
| | 0.8885 | 0.3533 | -1.3238 | -0.6208 | -1.9797 | -0.3362 | -2.6239 | 0.0101 | 0.0000 | 2.29 | 1.24 | 1.70 | 8.82 | 9.69 | 2.85 | 59.41 | 1.16 | 1.01 |
| Domestic credit | 0.8885 | 0.3535 | -1.3239 | -0.6219 | -1.9792 | -0.3358 | -2.6881 | 0.0101 | 0.0000 | 2.45 | 1.35 | 1.57 | 10.27 | 10.00 | 3.07 | 67.42 | 2.22 | 0.92 |
| Housing price | 0.8884 | 0.3533 | -1.3239 | -0.6208 | -1.9792 | -0.3359 | -2.6239 | 0.0101 | 0.0000 | 2.39 | 1.26 | 1.63 | 8.63 | 9.17 | 2.88 | 58.54 | 1.04 | 0.97 |
| Exchange rate | 0.8885 | 0.3533 | -1.3237 | -0.6208 | -1.9800 | -0.3364 | -2.6217 | 0.0101 | 0.0000 | 2.27 | 1.23 | 1.66 | 8.86 | 9.92 | 2.84 | 59.25 | 1.34 | 1.02 |
| Optimal LTV ratio rule | | | | | | | | | | | | | | | | | | |
| GDP | 0.8884 | 0.3531 | -1.3246 | -0.6215 | -1.9786 | -0.3354 | -2.6840 | 0.0101 | 0.0000 | 2.60 | 1.34 | 3.38 | 9.26 | 8.66 | 2.97 | 64.53 | 0.10 | 1.00 |
| Domestic credit | 0.8884 | 0.3530 | -1.3243 | -0.6217 | -1.9788 | -0.3355 | -2.6737 | 0.0101 | 0.0000 | 2.58 | 1.34 | 2.57 | 9.33 | 8.50 | 2.93 | 63.18 | 0.10 | 1.01 |
| Housing price | 0.8884 | 0.3531 | -1.3246 | -0.6215 | -1.9786 | -0.3354 | -2.6845 | 0.0101 | 0.0000 | 2.60 | 1.34 | 3.43 | 9.26 | 8.67 | 2.97 | 64.58 | 0.10 | 1.00 |
| Exchange rate | 0.8884 | 0.3531 | -1.3246 | -0.6215 | -1.9786 | -0.3354 | -2.6839 | 0.0101 | 0.0000 | 2.60 | 1.34 | 3.37 | 9.26 | 8.66 | 2.96 | 64.52 | 0.10 | 1.00 |

Note: The column of Level effects represents theoretical stochastic mean of the second-order approximation.
The column of Stabilization effects represents Std(X) in percentage terms.

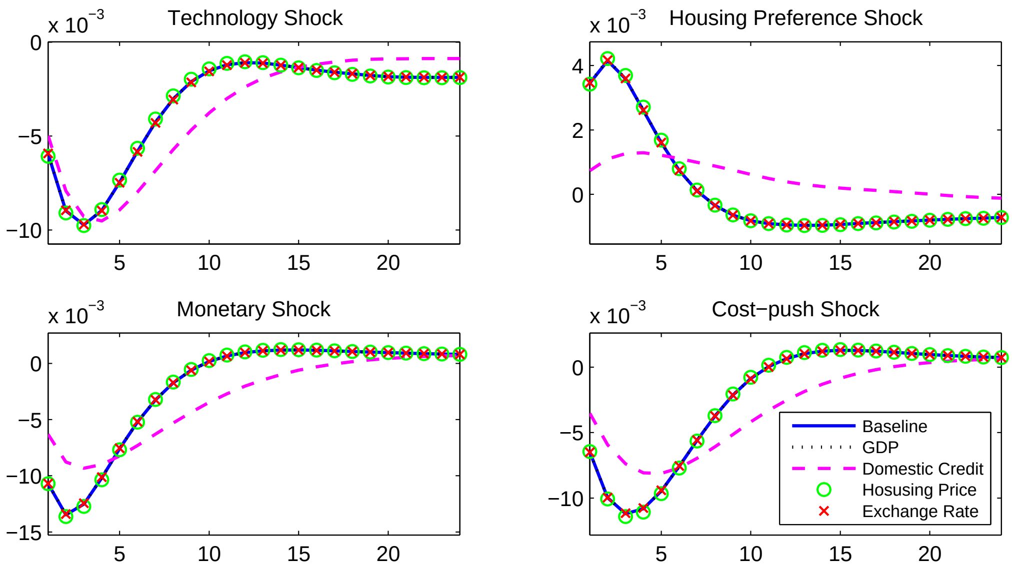


Figure 3: Stabilization Effects of Impatient Households' Consumption

## 4.2 Optimal Counter-cyclical LTV Ratio Rules

In contrast to the maximization of social welfare function by comparing various optimized interest rate rules, this subsection considers four alternative counter-cyclical LTV ratio rules. The LTV can respond to either gross domestic product ($GDP$), domestic credit ($B$), housing price ($q$), or exchange rate ($e$). These rules are assumed to evolve according to the following processes:

$$\ln m_t = v_m \ln m_{t-1} + (1 - v_m) \ln m + (1 - v_m) v_X (\ln X_t - \ln X_{t-1}), \tag{4.2.1}$$

where $X \in \{GDP, B, q, e\}$. For the policy rule of (4.2.1), we conduct grid search over a two-parameter space with step size 0.01 to obtain the optimized policy parameters. The search ranges from zero to one for $v_m$, and from negative twenty to zero for $r_X$.

Table 3 shows that only the case of domestic credit can significantly improve social welfare function and takes the form:

$$\ln m_t = 0.54 \ln m_{t-1} + 0.46 \ln m - 9.2(\ln B_t - \ln B_{t-1}).$$

This rule has a smoothing parameter close to one half ($v_m = 0.54$) and a large domestic credit coefficient of -20 ($v_b = -20$), and improves social welfare by 0.0029 relative to the baseline policy. More specifically, the welfare for impatient households is greatly improved by 0.0986 but that for patient households is slightly decreased by 0.0049. The reason for this phenomenon is that adjusting the LTV ratio rule responding to domestic credit could help stabilize the fluctuations through the channel of collateral constraint, thus mitigating the volatility of impatient households' consumption and increasing the welfare for impatient households.

This observation can be verified by demonstrating impulse responses under four important exogenous shocks for impatient households.[7] Figure 3 clearly indicates that responding to (dashed line)

[7] These shocks are non-housing technology shock ($A_c$), housing preference shock ($j$), monetary shock ($u_R$), and cost-push of domestic goods shock ($u_d$).

domestic credit indeed stabilizes the fluctuation of impatient households' consumption. Table 4 also shows that relative to the baseline policy, the standard deviation of borrowers' consumption is decreased from 3.38 to 2.57, which is consistent with the finding that the rule responding to domestic credit has the best performance of mitigating the volatility of impatient households' consumption. Intuitively, the LTV ratio rules can improve the welfare function for impatient households because LTV ratio only exists in the collateral constraint, which plays an important role in the decision making of impatient households.

Another interesting result from Table 3 is that except the case of exchange rate, all remaining rules increase the welfare function for impatient households but decrease the welfare function for patient households. Apparently, there is a distributional issue here. For this policy rule to be implementable, patient households must be compensated at least up to the welfare level under the baseline policy. A plausible reason why the exchange rate is important to the welfare of patient households is that by taking the exchange rate into account, the central bank could help mitigate the fluctuation of foreign bonds which are only related to patient households so as to enhance patient households' welfare function.

# 5 Conclusion

In this paper, we extend the model developed by Iacoviello and Neri (2010), which is a two-sector and heterogeneous model with collateral constraints, to a small open economy DSGE model by introducing foreign markets à la Kollmann (2002). In order to explain the Taiwanese economy, we calibrate the model to Taiwan's data. With the purpose of finding the optimal policy of the Taiwanese economy, several versions of monetary and macro-prudential policies are discussed. Regarding the interest rate rules, the one that responds to housing price leads to the best effect on mitigating the volatility of macroeconomic variables and improving social welfare function. Regardless of which variable the interest rate rules respond to, these rules always reduce the stochastic mean of housing prices and display no inertia effect. As for LTV ratio rules, the rule responding to domestic credit has the best performance of enhancing the social welfare function because it decreases the volatility of impatient households' consumption. Compared to the LTV ratio rules, the optimal interest rate rule is more effective in improving the social welfare function.

This paper can be improved along several dimensions. First of all, to capture a more elaborate structure of production functions, the model in this paper can be extended to a growth model by assuming that the shocks to non-housing and housing technology follow unit-root processes and the associated trends are evolved according to first-order autoregressive processes. Second, incorporating banking sector into the present model ensures that financial variables, such as the loan-to-value ratio, can be endogenously determined rather than follow exogenous processes controlled by monetary authority. Third, estimating the structural parameters in the model using Bayesian techniques could make the model fit Taiwan's data better so as to not only improve the model's ability to explain the Taiwanese economy but also give a more robust result of simulations.

Fourth, the model can be extended with a more compact structure of foreign markets and emphasizes on the international capital flow, for example, by incorporating a two-country model, where the foreign variables are endogenously decided; or embedding the foreign markets from the demand side, where the variables related to foreign markets follow AR(1) processes. These can improve our understandings on how the foreign markets affect the Taiwanese economy. Fifth, different designs of monetary polices could be considered. For example, money growth rate rules, by which Teo (2009) indicates that Taiwanese economy is suitably explained, and some targeting regime, such as fixed exchange rate or strict inflation rate.

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