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Essays on Open Economy Macroeconomics

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ABSTRACT OF THE DISSERTATION

Essays on Open Economy Macroeconomics

by

Mi Lu

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The world has witnessed that some countries have been benefiting substantially from economic and financial globalization and the expansion of world trade while others have not. At the same time, since economies are more interconnected shocks from one economy spread faster worldwide. With the increasing degree of integration of economies around the world, it seems crucial to study international transmission mechanisms of business cycles and policy designs in open economies. This dissertation addresses three interesting questions from the perspective of open economy macroeconomics: 1) What are the main factors to explain the secular change of the Hong Kong national saving rate? 2) What is the transmission mechanism of the U.S. monetary policy shock and other shocks to the Hong Kong economy under the Currency Board system? 3) What is the role of the banking sector and macroprudential policy in the propagation of national and international business cycles?

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CHAPTER 1

Introduction

This thesis consists of three papers. The first paper (Chapter 2) proposes neoclassical dynamic general equilibrium growth models to examine factors affecting agents' intertemporal decisions in Hong Kong. First, we consider a closed economy one-sector growth model. The results are simulated using shooting algorithm. We find that this closed model with the actual TFP growth and population growth can only explain some of the cyclical behaviors of the Hong Kong saving rate during 1975-2009. In particular, there is a substantial difference between simulated and actual saving rates during 1997-2009. This paper then proposes a small open economy growth model. The simulated results indicate that current account balance, population growth and TFP growth determine the dynamics of the Hong Kong saving rate. Compared to the closed economy model, the open economy model can successfully capture most of the cyclical movements of the Hong Kong saving rate between 1997 and 2009.

The second and the third paper contributes to the literature of New Open Economy Macroeconomics (NOEM) that began in the early 1990s. NOEM models have incorporated general equilibrium frameworks with nominal frictions and imperfect competition in the markets for goods or labor. The NOEM model overcomes the limitations of the Mundell-Fleming model and preserves the empirical wisdom and the close connection to policy debates found in the literature of open economy macroeconomics. In recent years, the research of NOEM has been directed to two main important dimensions: quantitative analysis and the construction of large, multi-country models. Following these two dimensions, the second and the third paper is motivated by numerous efforts to model, evaluate and estimate NOEM models.

The second paper (Chapter 3) explores the international monetary transmission under the Currency Board system by considering a small open economy framework for the Hong Kong economy. It extends the closed economy model with a housing sector and collateral constraint in Iacoviello (2005) into a small open economy (SOE) Dynamic Stochastic General Equilibrium-Vector Autoregressive (DSGE-VAR) model. We assume a hypothetical interest rate channel under the Currency Board system.

The model is estimated with Bayesian techniques. The impulse responses show that the international propagation of the U.S. monetary policy shock as well as other U.S. shocks has a strong spillover on Hong Kong. Asymptotic variance decomposition results suggest that in the long run, domestic shocks account for most of the variability in the main Hong Kong economic series such as output, consumption and house price but shocks from the U.S. are the main driving forces of the fluctuations in Hong Kong interest rate and inflation. These findings provide strong evidence that U.S. disturbances transmit to the Hong Kong economy through the hypothetical interest rate channel under the Currency Board system.

The third paper (Chapter 4) proposes an open economy Dynamic Stochastic General Equilibrium (DSGE) model with financial frictions and bank intermediaries for two large economies: the United States and the Euro area. It investigates the role of the banking sector and macroprudential policies in the propagation of national and international business cycles. In particular, the model allows analysis of the importance of shocks to the banking sector (credit shocks) and to the financial system (financial shocks) in explaining economic fluctuations in the U.S. and in the Euro area. This paper also evaluates the model forecast accuracy of output growth during the Great Recession.

The model is estimated using Bayesian techniques, and several interesting results are unveiled by the proposed framework. First, the amplification effect through collateral constraint is counteracted by a banking attenuator mechanism in the case of a national monetary shock. Second, the banking sector magnifies fluctuations from financial and technology shocks at the national level, and the transmission of shocks across these two regions. Third, we find that credit and financial shocks are important sources of macroeconomic fluctuations in the U.S. and in the Euro area. Fourth, the results indicate that macroprudential measures attenuate the effects of a U.S. fianncial shock and act to stabilize the U.S. and Euro area economies. Fifth, the proposed model provides a better out-of-sample forecasting performance on output growth during the

Great Recession than a model that does not include a banking sector and macroprudential policies. The policy implication is that if macroprudential policies were in place before the Great Recession, the severity of the crisis could have been lessened.

CHAPTER 2

The Dynamics of the Hong Kong Saving Rate

2.1 Introduction

This paper is motivated by the fact that the Hong Kong interest rate follows up the U.S. interest rate under the Currency Board system (see figure 2.1). On October 17, 1983, the Currency Board system[1] was established in Hong Kong to stabilize the exchange rate between the Hong Kong dollar (HKD) and the United States Dollar (USD), at around 7.80 HKD to 1.00 USD. Due to the interest rate linkage, the saving rate in Hong Kong is expected to follow up the saving rate in the United States theoretically. However, historical data shows that there has been a substantial difference between Hong Kong and U.S. saving rates. The net saving rate in the U.S. has declined from an average of 15 percent since the 1960s. The Hong Kong net national saving rate has declined from an average of above 15 percent during 1975-1996 to an average of below 10 percent during the Asian Financial Crisis and started to climb afterwards. This paper attempts to answer the question "What are the main driving factors of the Hong Kong saving rate?" Thus, this paper resorts closed and open economy dynamic general equilibrium models to investigate the dynamics of the Hong Kong saving rate.

This paper contributes to the analysis of the Hong Kong saving rate and small open economy modeling. And also it provides a good example of studying the saving rate in a small open economy.

[1]Unlike a fixed exchange rate system, Hong Kong Monetary Authority (HKMA) cannot influence the exchange rate by actively interfering in the foreign exchange market. Instead, Hong Kong currency is maintained through an automatic interest rate adjustment mechanism. HKMA authorised note-issuing banks are required to deposit the same amount of USD to HKMA. When the market exchange rate is below 7.80, market participants will buy HKD from HKMA. There is an upward pressure on the HKD exchange rate and HKMA sells HKD, which causes monetary base to expand, hence the Hong Kong interest rate falls and the market rate will climb back to 7.80. The same mechanism works when the market rate is above 7.80.

We first apply a closed economy neoclassical dynamic general equilibrium growth model based on Chen, Imrohoroglu and Imrohoroglu (2006, AER). Chen, Imrohoroglu and Imrohoroglu (2006, AER) is one of the papers which are able to quantitatively generate the saving rate. They used the model in Prescott and Hayashi (2002), which featured one sector neoclassical growth model with infinite horizons and variable labor supply, to quantitatively generate the simulated saving rate data for the Japanese economy. Similar to their model, we take actual total factor productivity (TFP) time path to the model as well as other Hong Kong time series data, for example, population growth, worked hours, employment and share of government expenditure in GNP as exogenous variables to simulate the Hong Kong saving rate with the shooting algorithm.

Our quantitative results show that TFP growth and population growth play significant roles in explaining the secular change of the Hong Kong saving rate. However, the model cannot generate the same successful result as Chen, Imrohoroglu and Imrohoroglu (2006, AER). This closed economy model with the actual TFP growth path can only capture the main turning points of the Hong Kong saving rate during 1975-2009. A substantial difference between simulated and actual saving rates is observed after 1997 Asian financial crisis. Since the sovereignty over Hong Kong was transferred from the United Kingdom to China on July 1st, 1997, the interaction between Hong Kong and mainland China has been getting closer and closer. Thanks to bilateral trade, foreign direct investment and tourism with China, the Hong Kong current account balance is rising after 1997, as displayed in figure 2.5. The rising current account suggests that Hong Kong savings exceed investments and Hong Kong is a net lender with respect to the rest of the world. Therefore, we expect that the rising current account is one of the factors to explain the climb of the Hong Kong saving rate after the Asian Financial Crisis.

We then propose a small open economy growth model and take into consideration the Currency Board system. Our model is different from the two-country growth model in Chen, Imrohoroglu and Imrohoroglu (2009, JME). They applied a two-country standard growth model to analyze the decline in the U.S. saving rate and to understand the causes of the current account deficit in the United States. We apply the actual U.S. interest rate and Hong Kong current account balance series as exogenous variables. The simulated results identify that the small open economy model is more successful than the closed economy model in explaining the Hong Kong saving rate. The current account balance as well as TFP growth and population growth are the most important factors generating the time series behavior of the Hong Kong net national saving rate between 1997 and 2009.

The reminder of the paper is organized as follows: in section 2.2, we present the closed economy growth model and simulated result. Section 2.3 describes the small open economy growth model and simulated result. Section 2.4 is concluding remark. Appendix explains how to obtain the value of the calibrated parameters.

2.2 The Closed Economy

Our closed economy model is built on the framework of Chen, Imrohoroglu and Imrohoroglu (2006, AER). The model excludes taxes on capital income because Hong Kong does not impose taxes on capital income. Moreover, the depreciation rate of capital is time invariant. We assume that Hong Kong economy is closed where saving equals investment.

2.2.1 The Model

We consider a perfect foresight closed economy. An infinitely-live representative representative household owns capital and rents it to firms. The household chooses consumption and leisure to maximize the life-time utility:

$$E_t\{\sum_{t=0}^{\infty}\beta^t N_t[logc_t+\alpha log(T-h_t)]\}$$

subject to the budget constraint:

$$C_t + X_t \leq w_t H_t + r_t K_t - \Gamma_t \tag{2.1a}$$

$$X_t = K_{t+1} - (1-\delta)K_t \tag{2.1b}$$

$$\Gamma_t = G_t \tag{2.1c}$$

where β is subjective discount factor; δ is the depreciation rate of capital; α is the share of leisure in the utility function; T is time endowment per household; N_t is the population of working-age households at time t. The population growth rate of working-age households is $n_t - 1$ where $n_t = \frac{N_{t+1}}{N_t}$. $c_t = \frac{C_t}{N_t}$ denotes consumption per household; $h_t = \frac{H_t}{N_t}$ denotes worked hours per household; X_t is aggregate investment; Γ_t is lump-sum tax; r_t is the rental rate of capital at time t; w_t is real wage.

The firm faces a constant returns-to-scale Cobb-Douglas production function:

$$Y_t = A_t K_t^{\theta} H_t^{1-\theta} \tag{2.2}$$

where Y_t is aggregate output, K_t is aggregate capital, A_t is total factor productivity, H_t are aggregate hours at time t. The capital share of output is θ. The growth rate of TFP is defined as $\gamma_t - 1$ where $\gamma_t = (\frac{A_{t+1}}{A_t})^{\frac{1}{(1-\theta)}} = (g_{t+1})^{\frac{1}{(1-\theta)}}$. Y_t denotes GNP.

2.2.2 Data

Table 2.1 reports five time invariant parameters in our analysis: the subjective discount factor β, the depreciation rate of capital δ, the capital share in the production function θ, the share of leisure in the utility function α and total discretionary hours in a week T. Total discretionary hours in a week are taken to be 105. The Hong Kong national account does not have capital stock, therefore we use the time series data from Hong Kong Monetary Authority (HKMA) to construct a series of capital stock and the depreciation rate of capital. The value of the depreciation rate and the sequence of capital stocks are calculated with the commonly used procedure that is referred as the perpetual inventory method. β, δ, α and θ are discussed in the appendix.

We apply the actual time series during 1975-2009 as exogenous variables reported in table 2.2 [2]: TFP growth, $\gamma_t - 1$, population growth, $n_t - 1$, and the share of government purchase in GNP to obtain simulated saving rates. TFP growth is calculated using GNP and population growth. The growth rate of the population is obtained from age 15-64. Employment rate is obtained by $1 -$ unemployment rate. We use the initial capital-output ratio 1.457 in year 1975, to pin down the initial capital stock and set the average of exogenous variables over sample periods as the steady state.

2.2.3 Calibration

The computational methodology is shooting algorithm as discussed in Chen, Imrohoroglu and Imrohoroglu (2006, AER) and Hayashi and Prescott (2002). We obtain the final steady state conditions for the Hong Kong economy. Given the final steady

[2]Data sources: HKMA Statistics Database and LABORSTA Labour Statistics Database.

state conditions and K_0, we compute the equilibrium transition path of C_t, H_t, K_{t+1} and other macroeconomic aggregates towards their steady-state values.

The detrended steady-state saving rate is:

$$\bar{s} = \frac{(\gamma n - 1)\bar{k}}{\bar{y} - \delta \bar{k}}$$

The time varying saving rate is measured by:

$$s_t = \frac{Y_t - G_t - C_t - \delta K_t}{Y_t - \delta K_t} \tag{2.3}$$

We get the simulated saving rate using equation (2.3).

2.2.4 Simulated Result

We compare the net national saving rate generated by our closed economy model with the actual saving rate during the sample 1975-2009 in Figure 2.2. The figure shows the closed economy model is able to capture some of the turning points of the actual Hong Kong saving rate. The simulated saving rate looks more volatile than the actual saving rate. Moreover, figure 2.2 shows a substantial difference between simulated and actual saving rates between 1997 and 2009, which suggests that TFP growth and population growth are not the only factors to explain the cyclical behaviors of the Hong Kong saving rate during 1997-2009. Overall, the result implies that the movements of the Hong Kong saving rate cannot be quantitatively generated by this closed economy model, in contrast to the case of Japan in Chen, Imrohoroglu and Imrohoroglu (2006).

Similar to Chen, Imrohoroglu and Imrohoroglu (2006, AER), we study two experiments on the importance of TFP growth. First, we report the saving rate generated by the model with the actual time series for TFP growth only, labeled “TFP only” in figure 2.3, which shows that changes in TFP growth play a very significant role in explaining the dynamics of the saving rate. Second, interestingly, the model with a constant 1.94-percent TFP growth and the actual time series, labeled “All time series except TFP” does not successfully generate the secular change of the saving rate. These results indicate that TFP growth is one of the main factors to explain the Hong Kong saving rate.

Figure 2.4 illustrates the results of two experiments on the importance of population growth: first, the saving rate generated by the model with the actual time series for population growth only, labeled "POP only"; and, second, the saving rate generated by the model with a constant POP growth (the mean during sample periods) and the actual time series, labeled "All time series except POP". We notice that changes in population growth are less important than the changes in TFP growth in explaining the fluctuations observed in the saving rate throughout the entire period.

The poor performance of this closed economy model on generating the saving rate suggests that it is more appropriate to consider Hong Kong as a small open economy rather than a closed economy given the stylized facts that Hong Kong is one of the world's leading international financial centres because of economic freedom, low taxation and free trade. Figure 2.5 displays the current account balance in Hong Kong since 1997. Particularly, the total value of Hong Kong export and import in goods and services in a year is equivalent to over three times Hong Kong GDP since 1997 [3]. Total export to Mainland China and the U.S. accounts for over 50 percent of total export to all destinations. In 1984, total export to Mainland China and to U.S. account for 17.8 percent and 33.2 percent of total export to all destinations, while in 2009, the percentages are 51.2 and 11.6, respectively. The import from Mainland China and from the U.S. account for 25.0 percent and 10.9 percent of total import from all suppliers in 1984, while the percentages are 46.4 percent and 5.3 percent, respectively, in 2009.

2.3 The Open Economy

We start this section by proposing a small open economy growth model for Hong Kong. We take into account the feature that under the Currency Board system, Hong Kong interest rate follows up the U.S. interest rate. We assume there is no capital adjustment cost so Tobin's q is 1 and both capital and labor are immobile. A risk-free bond is traded internationally each period. We use the U.S. interest rate as the international interest rate.

[3] In 1997, Hong Kong returned to Chinese Sovereignty.

2.3.1 The Model

There is an infinitely-live representative household to choose consumption and leisure to maximize the life-time utility:

$$E_t\{\sum_{t=0}^{\infty}\beta^t N_t[logc_t + \alpha log(T - h_t)]\}$$

subject to the budget constraint:

$$B_{t+1} + C_t + X_t + \leq B_t(1 + r_t^*) + w_t H_t + r_t K_t + TR_t - \Gamma_t \tag{2.4a}$$

$$X_t = K_{t+1} - (1 - \delta)K_t \tag{2.4b}$$

$$\Gamma_t = TR_t + G_t \tag{2.4c}$$

where β is subjective discount factor; δ is the depreciation rate of capital; α is the share of labor leisure in the utility function; T is time endowment per household; N_t is the population of working-age households at time t. The population growth rate of working households is $n_t - 1$ where $n_t = \frac{N_{t+1}}{N_t}$. $c_t = \frac{C_t}{N_t}$ denotes household consumption; $h_t = \frac{H_t}{N_t}$ denotes hours worked per household; X_t is aggregate investment; Γ_t is lump-sum tax; r_t is the rental rate of capital at time t; w_t is real wage. B_t is the beginning of period bond holdings and r_t^* is international interest rate. φ is the investment-capital ratio at the steady state, which is equal to $\gamma n - 1 + \delta$. And Y_t denotes GDP.

The firm faces a constant returns-to-scale Cobb-Douglas production function:

$$Y_t = A_t K_t^{\theta} H_t^{1-\theta}$$

The national accounting identity is given by

$$G_t + I_t + C_t + CA_t = Y_t + B_t r_t^* = GNP_t \tag{2.5}$$

where $CA_t = B_{t+1} - B_t$ is current account and $NX_t = CA_t - B_t r_t^*$ is net export. $I_t = X_t$ is gross investment and

$$I_t = A_t(K_t)^{\theta}(H_t)^{1-\theta} - C_t - G_t - (B_{t+1} - (1 + r_t^*)B_t)$$

First order conditions with respect to C_t, h_t, K_t are

$$\frac{\alpha h_t}{T-h_t} = (1-\tau)(1-\theta)\frac{Y_t}{C_t} \tag{2.6}$$

$$\frac{C_{t+1}}{N_{t+1}} = \beta\frac{C_t}{N_t}[q_{t+1}(1-\delta_{t+1}) + \theta A_{t+1}(K_{t+1})^{\theta-1}(H_{t+1})^{1-\theta}] \tag{2.7}$$

$$\frac{C_{t+1}}{N_{t+1}} = \beta\frac{C_t}{N_t}(1+r^*_{t+1}) \tag{2.8}$$

A competitive equilibrium consists of allocations $\{C_t, I_t, H_t, Y_t, K_{t+1}, B_t, X_t\}$ such that

(1) given policy $\{G_t, TR_t, \Gamma_t\}$ and prices $\{w_t, r_t, r^*_t\}$, the allocation solves the firm's profit maximization problem with factor prices given by $w_t = (1-\theta)A_t K_t^{\theta} H_t^{-\theta}$ and $r_t = \theta A_t K_t^{\theta-1} H_t^{1-\theta}$.

(2) government budget is satisfied.

(3) good market and bond market are clear.

We obtain the following equilibrium conditions by redefining $\tilde{z}_t = \frac{z_t}{A_t^{\frac{1}{1-\theta}} N_t}$ where $\tilde{z}_t$ can be $\{x, k, c, b, i\}$.

$$\tilde{c}_{t+1} = \frac{\tilde{c}_t}{g^{\frac{1}{1-\theta}}}\beta\{q_t(1-\delta_{t+1}) + \theta(\frac{\tilde{k}_t}{\tilde{h}_t})^{\theta-1}\} \tag{2.9a}$$

$$\tilde{c}_{t+1} = \frac{\tilde{c}_t}{g^{\frac{1}{1-\theta}}}\beta(1+r^*_{t+1}) \tag{2.9b}$$

$$\tilde{i}_t = \tilde{x}_t \tag{2.9c}$$

$$\tilde{i}_t = (1-\psi_t)\tilde{k}_t^{\theta}\tilde{h}_t^{1-\theta} - \tilde{c}_t - (\tilde{b}_{t+1}(g_{t+1})^{\frac{1}{1-\theta}} n_{t+1} - (1+r^*_t)\tilde{b}_t) \tag{2.9d}$$

$$CA_t/Y_t = (B_{t+1} - B_t)/Y_t = (\tilde{b}_{t+1}/\tilde{y}_t)(\gamma_t n_t) - \tilde{b}_t/\tilde{y}_t \tag{2.9e}$$

$$\tilde{k}_{t+1} = (1-\delta_t)\tilde{k}_t + \tilde{x}_t \tag{2.9f}$$

Where $\tilde{\varpi}_t$ is the detrended capital labor ratio, defined as $\frac{K_t/H_t}{A_t^{\frac{1}{1-\theta}}}$ and ψ_t is the ratio of government purchase to output, $\frac{G_t}{Y_t}$.

2.3.2 Data

The sample period runs from 1997 to 2009. We break the sample period in 1997 because the data of current account balance (see figure 2.5) is available since 1997. We report the actual time series used in the open economy model in Table 2.3: TFP growth, $\gamma_t - 1$, the ratio of government purchase to GDP, current account balance to GDP ratio and U.S. interest rate. TFP growth is calculated using GDP. Similar to the closed economy, five parameters are time invariant: capital share, the depreciation rate of capital, discounted factor, the share of leisure in utility function and time endowment. We apply actual series such as the U.S. interest rate, current account balance, TFP growth and population growth as exogenous variables to simulate the Hong Kong saving rate.

2.3.3 Calibration

Again, given the steady state of foreign asset distribution, we compute the transition path and the steady state of other variables. The distribution in turn is determined by the transition path and the initial asset distribution b_0. Therefore we need to solve the steady-state and the transition path simultaneously. Starting from the initial asset distributions k_0, b_0, we apply the shooting algorithm to solve the entire path of $\{c_t, k_{t+1}, b_{t+1}, h_t\}$ by using the above equilibrium conditions. We rule out Ponzi schemes by assuming at the steady state agents face a borrowing limit, that is $(1-\psi_T)\tilde{k}_T^{\theta}\tilde{h}_T^{1-\theta} - \tilde{c}_T - \tilde{i}_t = (\tilde{b}_{T+1}(g_{T+1})^{\frac{1}{1-\theta}} n_{T+1} - (1+r_T^*)\tilde{b}_T)$.

Similarly, the detrended steady-state saving rate is given by:

$$\bar{s} = \frac{(\gamma n - 1)\bar{k} + \bar{r}^* \bar{b}}{\bar{y} + \bar{r}^* \bar{b} - \delta \bar{k}}$$

We measure the simulated saving rate using

$$s_t = \frac{Y_t + r_t^* B_t - G_t - C_t - \delta K_t}{Y_t + r_t^* B_t - \delta K_t} \tag{2.10}$$

In the open economy, saving rate is not the same as investment rate.

2.3.4 Simulated Result

Figure 2.6 displays the comparison between simulated saving rate and actual Hong Kong saving rate. We see that our open economy model is able to capture the dynamics of the Hong Kong saving rate after the Asian financial crisis. The result indicates that the current account, population growth and TFP growth are the most important factors to explain the cyclical movements of the Hong Kong saving rate between 1997 and 2009.

2.4 Concluding Remarks

This paper first applies a closed economy neoclassical growth model to explore the factors behind the dynamics of the Hong Kong saving rate. We calibrate the model with the actual time path of TFP growth to Hong Kong data between 1975 and 2009. We find that TFP growth and population growth determine the Hong Kong saving rate during 1975-2009. However, the result indicates that this simple model can only explain some of the cyclical behaviors of the Hong Kong saving rate during 1975-2009.

This paper then proposes a small open economy growth model for Hong Kong. We conduct deterministic simulations using actual series: Hong Kong current account balance, the U.S. interest rate, TFP growth and population growth. The simulation results show that the extended version successfully explains agents's intertemporal decisions. TFP growth, population growth and current account balance are the most important drivers of the Hong Kong saving rate after the Asian financial crisis. Compared to the closed economy model, the small open economy model is able to explain most of the cyclical movements of the Hong Kong saving rate.

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Appendix

In this appendix, we explain how to get the value of the discounted factor β, labor share in production function θ, leisure share in utility function α and TFP.

theta

Following Aiyar and Dalgaard (2005), we estimate the share of the human capital given

$$1-\theta = \frac{(\text{compensation of employees})(1+\frac{\text{self-employed workers}}{\text{paid employees}})}{\text{Y}}$$

According to the constant returns-to-scale, capital share is given by θ.

The data for compensation of employees is collected from UNdata and the data for self-employed workers and paid employees are from the data set in LABORSTA Internet.

delta

We construct the sequence of capital stock according to the perpetual inventory method. The value of δ is chosen to be consistent with the average ratio of depreciation to GDP during the data periods. On the assumption that the depreciation rate and the estimate of the initial capital stock follow $K_t = (1-\delta)K_{t-1} + GFK_t$ where GFK_t is the gross fixed capital formation, we obtain the sequence of capital stocks and the value of δ.

beta

According to Kehoe and Prescott (2007), β is computed with the values of δ and θ as well as the constructed capital stock in every period using

$$\beta = \frac{C_{t+1}}{C_t(1-\delta+\theta Y_{t+1}/K_{t+1})}$$

alpha

In order to calibrate α, we rearrange the first order condition of the consumption intratemporal substitution. We get α by using the series of consumption, hours worked, population, output and θ given the following equation

$$\alpha = \frac{C_t H_t}{Y_t(1-\theta)(\bar{h}N_t - H_t) + C_t H_t}$$

A

Finally, we use the value of θ and the sequence of capital stock to construct the series of TFP following $A_t = \frac{Y_t}{K_t^{\theta} H_t^{1-\theta}}$.

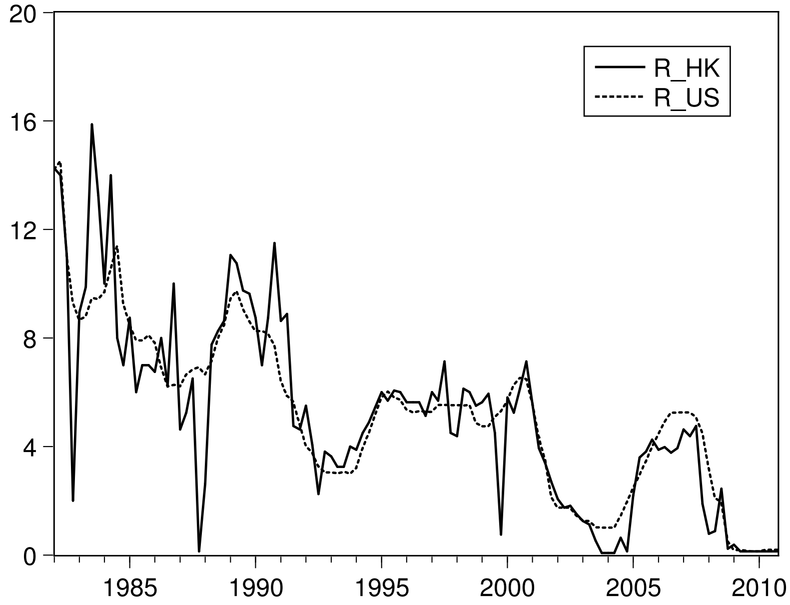

Figure 2.1: Hong Kong vs US Interest Rates

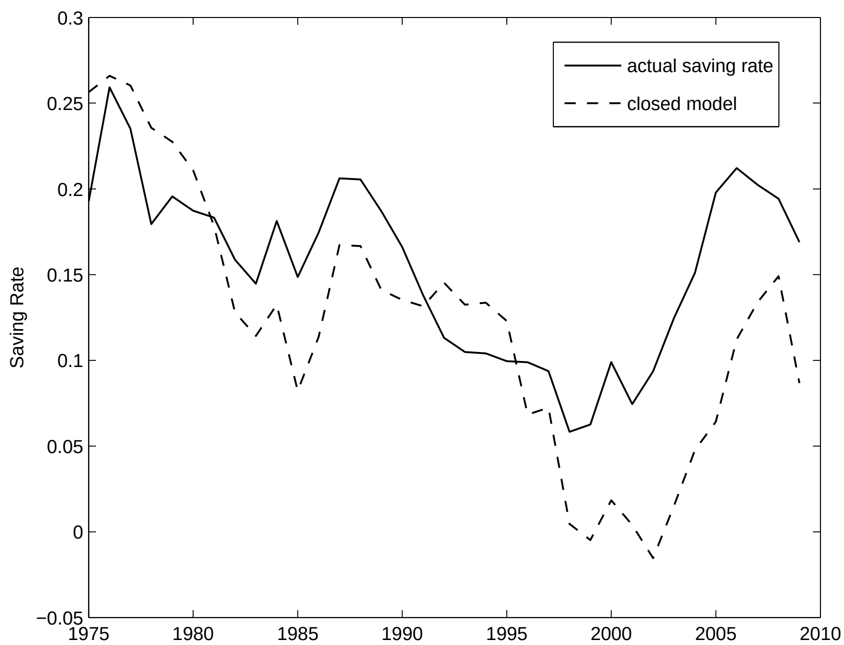

Figure 2.2: Simulated vs Actual Saving Rates (1975-2009, closed economy)

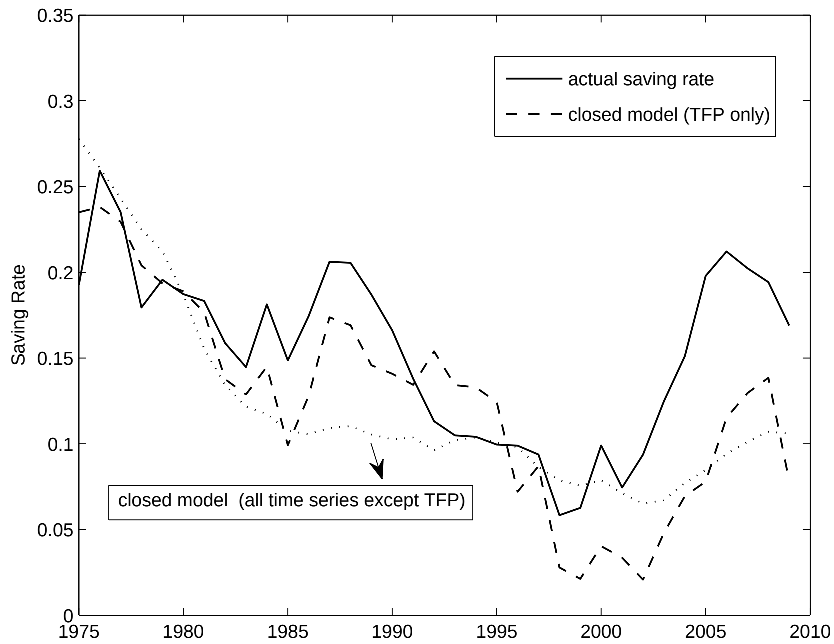

Figure 2.3: Sensitivity Analysis of TFP Growth (1975-2009, closed economy)

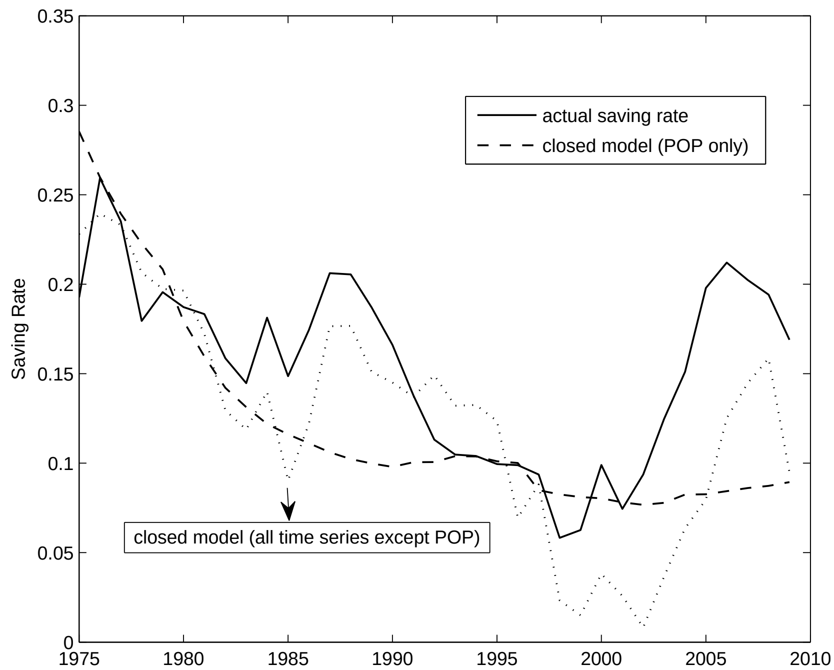

Figure 2.4: Sensitivity Analysis of Population Growth (1975-2009, closed economy)

Figure 2.5: Hong Kong Current Account Balance to GDP Ratios

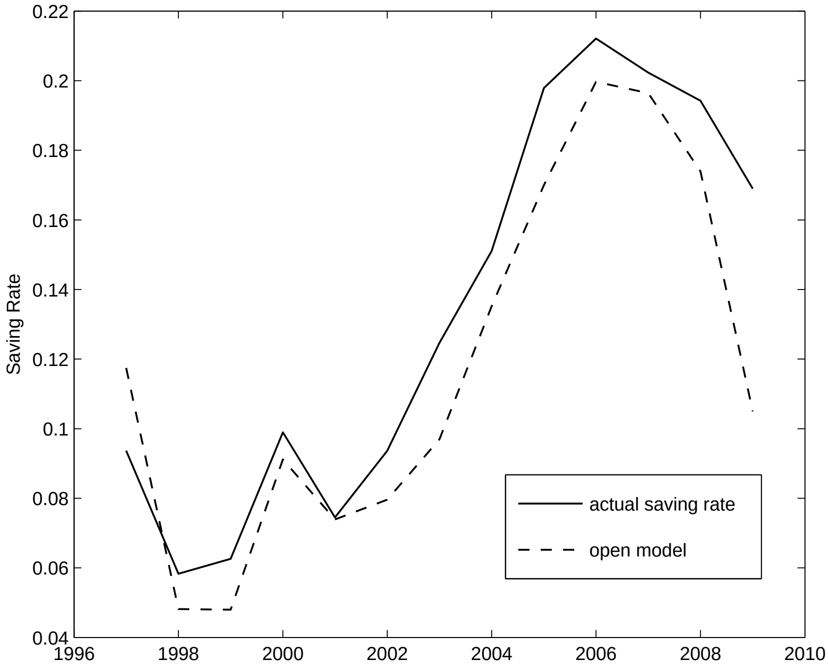

Figure 2.6: Simulated vs Actual Saving Rates (1997-2009, open economy)

Table 2.1: Calibrated Parameters

Parameter	Description	Value
$1-\theta$	Labor share	0.6239
δ	Depreciation rate	0.060736
β	Discount factor	0.915
α	Share of leisure in utility function	1.35
T	Time endowment	105

Table 2.2: Exogenous Variables for Closed Economy

Year	TFP growth	POP growth	G/Y	Hours worked	Employment	Saving rate
1975	1.087194036	1.035364467	0.119690414	48	0.909	0.192671269
1976	1.054434506	1.03011728	0.109980875	48	0.95	0.25924134
1977	1.014681928	1.029511918	0.107509567	48	0.957	0.235082272
1978	1.036422644	1.031138285	0.109061977	48	0.972	0.179485024
1979	1.041953106	1.072319606	0.108060672	48	0.971	0.195578852
1980	1.024183904	1.040912525	0.10521997	48	0.962	0.187211777
1981	0.97786508	1.033934222	0.117276035	48	0.964	0.183276028
1982	1.022226837	1.017406929	0.120109551	48	0.964	0.158631786
1983	1.060657647	1.016833159	0.120254581	48	0.955	0.144717063
1984	0.967081597	1.011018237	0.113694613	48	0.961	0.181291733
1985	1.075977638	1.01237451	0.115976936	48	0.968	0.148590968
1986	1.111218294	1.014689116	0.111200817	48	0.972	0.174448045
1987	1.026821447	1.013666414	0.101885653	46.5	0.983	0.206156506
1988	0.993330691	1.012064343	0.097485912	47.5	0.986	0.205466422
1989	1.018191378	1.012659195	0.100362317	46.3	0.989	0.187000465
1990	1.013485893	1.004955102	0.101887829	45.6	0.987	0.166109532
1991	1.051454799	1.013890975	0.103775744	46.2	0.982	0.137875576
1992	0.989319818	1.008788171	0.110750963	44.5	0.98	0.113142124
1993	1.013042521	1.019552184	0.107692017	45.8	0.98	0.104838314
1994	0.999670189	1.025201613	0.105759514	45.8	0.981	0.10400871
1995	0.939954462	1.020555321	0.105851808	45.1	0.968	0.099482378
1996	1.024849281	1.050123876	0.107236298	46.1	0.972	0.098902189
1997	0.933365641	1.013543919	0.103545825	45.2	0.978	0.09365371
1998	0.994588943	1.011638684	0.108452805	45.2	0.953	0.05832046
1999	1.027035721	1.010333	0.109050742	46	0.938	0.062606057
2000	0.998343239	1.013812155	0.10439839	46.6	0.951	0.09895533
2001	0.992393503	1.011398382	0.108503227	46.5	0.949	0.074481146
2002	1.043649237	1.006272494	0.111044593	46.9	0.927	0.093632852
2003	1.041615676	1.000572246	0.107821431	46.6	0.921	0.124667735
2004	1.027682954	1.012970301	0.100662887	47.1	0.932	0.151063373
2005	1.071385907	1.01014256	0.09250089	46.9	0.944	0.19787592
2006	1.041222815	1.011218461	0.085228268	46.3	0.952	0.212100549
2007	1.032496246	1.013324648	0.081724806	46.6	0.96	0.202326955
2008	0.9349724	1.012175404	0.079687138	45.6	0.964	0.194208345
2009	0.997587275	1.007890989	0.08582055	45	0.977	0.168951551

Note: since there is no data for Hong Kong actual saving rate from HKMA, we calculate the actual saving rate given the equation $s_t = \frac{Y_t - G_t - C_t - \delta K_t}{Y_t - \delta K_t}$ where Y_t is GDP.

Table 2.3: Exogenous Variables for Open Economy

Year	TFP growth	G/Y	CA/Y	U.S. interest rate
1997	0.914467657	0.102850714	-0.036307981	0.0535
1998	0.994385625	0.109950946	0.012346924	0.0497
1999	1.040366535	0.110579747	0.054015564	0.0624
2000	0.983277758	0.104505692	0.036920108	0.0389
2001	1.009659947	0.11027891	0.0534452	0.0167
2002	1.025261713	0.110931787	0.071429175	0.0113
2003	1.047284194	0.109643655	0.104306388	0.0135
2004	1.045034426	0.101810074	0.098731209	0.0321
2005	1.053472475	0.092001697	0.118248638	0.0496
2006	1.031428362	0.086209738	0.12617114	0.0502
2007	1.009877492	0.083450927	0.125200364	0.0193
2008	0.950979094	0.083192713	0.136715797	0.0016
2009	1.007227901	0.088087883	0.08605392	0.0018

CHAPTER 3

International Monetary Transmission in a Small Open Economy

3.1 Introduction

Since the Currency Board System was established in Hong Kong on October 17, 1983, some economists have appreciated the system while others have not. Under the Currency Board System, Hong Kong Monetary Authority does not attempt to manipulate the Hong Kong interest rate and implement its own monetary policy. The peg with the United States Dollar (USD) ties Hong Kong to the U.S. monetary policy very closely. If the Hong Kong business cycle moves with the U.S. business cycle, the U.S. monetary policy benefits the Hong Kong economy. For example, a decrease in the U.S. interest rate to stimulate the recovery from the recession also promotes the economic growth in Hong Kong. However, if there is a misalignment between Hong Kong and the U.S., the peg could impair the Hong Kong economy.

This paper aims to study the role of the Currency Board System in the transmission of the U.S. shocks, especially the U.S. monetary shock to the Hong Kong economy. We apply a small open economy (SOE) dynamic stochastic general equilibrium-Vector autoregressive (DSGE-VAR) model and assume a hypothetical interest rate channel under the Currency Board system.

This paper devotes to the study of the Currency Board System (i.e. Hanke 2002, Kwan and Lui 2005, Hans, He and Leung 2007) and Hong Kong business cycle literature (i.e. Gerlach-Kristen 2006, Han, Liu and Jin 2006, Funke and Paetz 2010). Moreover, it is closely related to the recent empirical work with New Open Economy Macroeconomics (NOEM), especially the research on the influences of foreign-sourced disturbances with the estimated NOEM models (i.e. Lubik and Schorfheide 2005, Adolfson et al. 2007, Adjemian and Darracq Paries 2008, Hodge et al. 2008, Preston and Justiniano 2010). In particular, this paper contributes to the literature of DSGE modeling for the Hong Kong economy (i.e. Cheng and Ho 2009, Funke et al. 2010, Funke and Paetz 2010).

We extend the closed economy model in Iacoviello (2005) to a small open economy framework. The model considers heterogenous households (patient and impatient) who face a house preference shock. Similar to Iacoviello, we introduce a collateral constraint[1] to the limit on the obligations of impatient household and entrepreneur. The framework for the U.S. economy is very simple, no heterogenous agents, no capital accumulation, no housing sector and no collateral constraint.

We consider DSGE-VAR and DSGE frameworks, rather than the VAR framework in the literature of the Hong Kong business cycle. The advantages of DSGE-VAR mainly focus on two respects. First, DSGE-VAR relaxes some of the DSGE restrictions and investigates the effects on the model. The posterior distribution of the hyperparameter λ provides a natural benchmark for comparing the empirical fit of the DSGE model[2]. Second, the DSGE-VAR model improves the DSGE identification and the SVAR identification and provides a better forecasting performance than standard DSGE and VAR model as in Del Negro and Schorfheide (2004) and the subsequent researches (see Nel Negro and Schorfheide 2006, Smets and Wouters 2007, Adjemian and Darracq Paries 2008, Del Negro and Schorfheide 2009 and Park 2010).

Our small open economy model is built on the theoretical framework of Gali and Monacelli (2005) and Lubik and Schorfheide (2005). Gali and Monacelli (2005) laid out a small open economy model with respect to the rest of the world with staggered price setting (Calvo 1983). They analyzed the macroeconomic implications of alternative rule based policy regimes: domestic inflation, CPI based Taylor rules and exchange rate peg. The main contribution of their paper was to model monetary policy as endogenous variable with the short term interest rate as an instrument to rank these three regimes.

[1]There are many examples of dynamic models in which financial frictions may propagate the transmission of shocks to the real economy such as the real models of Kiyotaki and Moore 1997, Carlstrom and Fuerst 1997, the sticky-price model of Bernanke et al. 1999 and monetary business cycle model of Iacoviello 2005.

[2]A large value of λ can be interpreted as evidence in favor of the restrictions imposed by the DSGE model while a small value of λ shows no DSGE restrictions are imposed in the model. If posterior estimate of λ is near zero, it indicates serious misspecification.

Lubik and Schorfheide (2005) extended the framework of Gali and Monacelli (2005) into a two-country large open economy setting and estimated the model with Bayesian technique.

Similar to Gali and Monacelli (2005), we take into account the trade off between the stabilization of exchange rate and terms of trade. We propose a hypothetical interest rate rule to capture the feature under the Currency Board system. Hong Kong currency is stabilized through an automatic interest rate adjustment mechanism. The peg to the U.S. dollar implies that Hong Kong interest rate follows up the U.S. interest rate. We assume that the Hong Kong interest rate is related to its lagged interest rate and the U.S. interest rate and reacts to the deviation of the market exchange rate from its target. We consider a small open economy model for Hong Kong with respect to the United States rather than a two-country model as proposed in Lubik and Schorfheide (2005).

We incorporate many features common in open economy DSGE models as discussed in Adolfson et al. (2007) and Justiniano and Preston (2010). We consider incomplete exchange rate pass-through. Asset markets are incomplete internationally. We introduce a risk premium on external borrowing in the Hong Kong economy. Purchasing power parity does not hold due to a home bias in aggregate domestic demand. We consider a shock to the uncovered interest rate parity condition and two shocks to the distribution sector cost push (affecting the CPI equations). In addition, we introduce a number of nominal, real and financial frictions such as price stickiness, capital adjustment cost and collateral constraint.

The proposed model is estimated with Bayesian methodology. Our findings are listed as follows: first, the comparison of impulse responses between DSGE-BVAR and DSGE suggests a strong economic interaction between Hong Kong and the United States and provides insights into in which directions the DSGE model does not fit well. The impulse response functions in DSGE-BVAR and DSGE are comparable under Hong Kong and the U.S. technology shocks, and the Hong Kong monetary shock. But in the face of other shocks, the impulse responses in DSGE-BVAR are different from the ones in DSGE. Overall, the impulse responses in DSGE lie in the range of 90 percent confidence intervals in DSGE-BVAR. Second, we find that the contribution of the house preference shock to the house price is not significant than expected. Variance decomposition results suggest that in the long run, domestic shocks account for most of the variability in the main Hong Kong economic series such as output, consumption and house price while the U.S. shocks are the main driving forces of Hong Kong interest rate and inflation. These results provide some evidence to evaluate the role of the interest rate channel in the propagation of business cycles, particularly in the face of the shocks from the United States.

The reminders of the structure of the paper are: in section 3.2, we present the model framework for the Hong Kong economy and for the U.S. economy. Section 3.3 introduces market clearing conditions and general equilibrium. Section 3.4 presents DSGE-VAR methodology, priors, estimation result and variance decomposition. Section 3.5 concludes and appendixes.

3.2 Model Framework

We treat the Hong Kong economy (domestic) as a small open economy with respect to the United States (foreign) while the United States is regarded as a relatively closed economy because the trade volume with Hong Kong is negligible.

3.2.1 Hong Kong Economy

There are four agents in the Hong Kong economy: patient household, impatient household, entrepreneur and monetary authority. Financial frictions apply to both entrepreneur and impatient household with the introduction of collateral constraints. We allow variable capital investment for entrepreneur.

Patient Household

An infinitely-lived representative household (indexed by p) chooses consumption C_t^p and labor N_t^p, saves resources D_t and purchases house H_t^p to maximize the following life-time utility

$$E_t\{\sum_{i=0}^{\infty}\beta^i[InC_{t+i}^p + j_t InH_{t+i}^p - \frac{1}{\xi}(N_{t+i}^p)^{\xi}]\}$$

Subject to budget constraint:

$$C_t^p + \frac{e_t B_t^*}{\varrho_t R_t^* P_t} + Q_t(H_t^p - H_{t-1}^p) + D_t = \frac{e_t B_{t-1}^*}{P_t} + R_{t-1}D_{t-1}/\pi_t + W_t N_t^p + F_t^p \qquad (3.1)$$

Let $H_t^p - H_{t-1}^p = \Delta H_t^p$ and we assume there is no depreciation in housing. Q_t is the real price of housing. F_t^p is the lump-sum profit received from retailers. The household's deposit rate R_t is defined as central bank interest rate. Inflation π_t is defined as P_t/P_{t-1}. j_t allows for random disturbances to the marginal utility of housing and it directly affects housing demand. $j_t = \rho_j j_{t-1} + \varepsilon_{j,t}$ where $\varepsilon_{j,t}$ is the house preference shock. The introduction of the house preference shock is to capture the shock that shifts preferences towards housing.

Where R_t^* denotes the U.S. nominal interest rate and ϱ_t is risk premium. e_t is exchange rate. Following Preston and Justiniano (2010), risk premium ϱ_t is defined as

$$\varrho_t = exp[-\chi(\frac{e_t B_t^*}{P_t Y} + \zeta_t)] \tag{3.2}$$

where $J_t = \frac{e_t B_t^*}{P_t Y}$ means the external debt to GDP ratio. χ is risk premium parameter and B_t^* is the average level of foreign debt, P_t is composite price index and Y is the steady state of real output. The endogenous risk premium is an increasing function of the foreign debt in terms of domestic currency to gross domestic product. Risk premium shock ζ_t follows an AR(1) process, $\zeta_t = \rho_\zeta \zeta_{t-1} + \varepsilon_{\zeta,t}$. The introduction of risk premium captures the deviation of uncovered interest parity and ensures that the model has a steady state.

Let λ_t^p be the Lagrange multiplier. First order conditions with respect to consumption, labor supply, owner-occupied housing demand and deposit C_t^P, N_t^P, H_t^P, D_t are

$$\frac{1}{C_t^p} = \lambda_t^p \tag{3.3}$$

$$\lambda_t^p W_t = (N_t^p)^{\xi - 1} \tag{3.4}$$

$$\lambda_t^p Q_t = \frac{j_t}{H_t^p} + \beta E_t(\lambda_{t+1}^p Q_{t+1}) \tag{3.5}$$

$$\frac{1}{R_t} = \beta E_t[\frac{\lambda_{t+1}^p}{\lambda_t^p}(\frac{1}{\pi_{t+1}})] \tag{3.6}$$

Impatient Household

Impatient household (indexed by m) discounts future more heavily than patient household. He/she chooses consumption C_t^m and labor N_t^m, and purchases house H_t^m to maximize the following life-time utility

$$E_t\{\sum_{i=0}^{\infty}(\beta^m)^i[InC_{t+i}^m + j_tInH_{t+i}^m - \frac{1}{\xi}(N_{t+i}^m)^\xi]\}$$

Subject to budget constraint and borrowing constraint (collateral constraint):

$$C_t^m + \frac{e_tB_t^*}{\varrho_tR_t^*P_t} + Q_t(H_t^m - H_{t-1}^m) + R_{t-1}L_{t-1}^m/\pi_t = \frac{e_tB_{t-1}^*}{P_t} + L_t^m + F_t^m + W_tN_t^m \quad (3.7)$$

$$L_t^m \leq m_1E_tQ_{t+1}\frac{\pi_{t+1}}{R_t}H_t^m \quad (3.8)$$

where L_t^m is loan to impatient household and loan rate to impatient household is equal to deposit rate and central bank interest rate R_t. F_t^m is the lump-sum profit received from retailers and m_1 is Loan-to-Value ratio. Here we assume that the disturbances to j_t are common to both patient and impatient households. The collateral constraint implies the obligation of impatient household.

We assume $\beta^m < \beta$, the discount factor of impatient household is less than that of patient household. It suggests that the lower bound of the collateral constraint is binding for small shocks because impatient household decumulates wealth faster than patient household. As the value of m_1 becomes larger, the fluctuations in the value of housing holdings are bigger, thus increasing impatient household's borrowing capacity and consumption and further output and aggregate consumption. Hence, a powerful amplification mechanism to the real economy is created through collateral constraint.

Let λ_t^m be the Lagrange multiplier and Υ_t^m is the multiplier of collateral constraint. First order conditions with respect to consumption, labor supply, owner-occupied housing demand and loan $C_t^m, N_t^m, L_t^m, H_t^m$ are

$$\frac{1}{C_t^m} = \lambda_t^m \quad (3.9)$$

$$\lambda_t^mW_t = (N_t^m)^{\xi-1} \quad (3.10)$$

$$\lambda_t^m = \beta^m E_t(\lambda_{t+1}^m \frac{R_t}{\pi_{t+1}}) + \Upsilon_t^m \tag{3.11}$$

$$\lambda_t^m Q_t = \beta^m E_t \lambda_{t+1}^m (Q_{t+1}) + \Upsilon_t^m m_1 E_t Q_{t+1} \pi_{t+1}/R_t \tag{3.12}$$

Entrepreneur

Entrepreneur (indexed by e) only cares about his/her own consumption and maximizes the following expected utility function:

$$E_t[\sum_{i=0}^{\infty} \gamma^i [InC_{t+i}^e]]$$

where $\gamma < \beta$ is entrepreneur's discount factor and entrepreneur is less patient than households.

Subject to budget constraint and collateral constraint:

$$C_t^e + I_t + \xi_{K,t} + Q_t(H_t^e - H_{t-1}^e) + R_{t-1}L_{t-1}^e/\pi_t = L_t^e + Y_t/X_t - W_t(N_t^p + N_t^m) \tag{3.13}$$

$$L_t^e \leq m_2 E_t Q_{t+1} \frac{\pi_{t+1}}{R_t} H_t^e \tag{3.14}$$

Where L_t^e is loan to entrepreneur and loan rate to entrepreneur is equal to deposit rate and central bank interest rate. Entrepreneur borrows from patient household and finances his/her housing accumulation. Loan and deposit satisfy $L_t^e + L_t^m = -D_t$. X_t denotes the markup of final over intermediate goods charged by retail firms. And $\xi_{K,t} = \psi(I_t/K_{t-1} - \delta)^2 K_{t-1}/(2\delta)$ is the capital adjustment cost. m_2 is Loan-To-Value ratio. Similarly, entrepreneur faces a collateral constraint. The limit on the obligation of entrepreneur is less than or equal to the present value of housing holdings tied to the collateral, $m_2 E_t Q_{t+1} \frac{\pi_{t+1}}{R_t} H_t^e$.

Capital accumulation is

$$K_t = I_t + (1-\delta)K_{t-1} \tag{3.15}$$

Let λ_t^e be the Lagrange multiplier. Υ_t^e is the multiplier of collateral constraint. First order condition with respect to consumption, capital demand, loan and housing demand C_t^e, K_t, L_t^e, H_t^e are:

$$1/C_t^e = \lambda_t^e \tag{3.16}$$

$$v_t = \frac{1}{C_t^e}(\frac{\psi}{\delta}(\frac{I_t}{K_{t-1}}-\delta)\frac{I_t}{K_{t-1}}-\frac{\psi}{2\delta}(\frac{I_t}{K_{t-1}}-\delta)^2)+\gamma E_t(\frac{(1-\alpha-\varepsilon)Y_{t+1}}{C_{t+1}^e X_{t+1} K_t}+v_{t+1}(1-\delta)) \tag{3.17}$$

where $v_t = \frac{1}{C_t^e}(1+\frac{\psi}{\delta}(\frac{I_t}{K_{t-1}}-\delta))$ is capital demand.

$$\lambda_t^e = \gamma E_t(\lambda_{t+1}^e \frac{R_t}{\pi_{t+1}}) + \Upsilon_t^e \tag{3.18}$$

$$\lambda_t^e Q_t = \gamma E_t\{\lambda_{t+1}^e(Q_{t+1} + \frac{\epsilon Y_{t+1}/X_{t+1}}{H_t^e})\} + \Upsilon_t^e m_2 E_t Q_{t+1}\pi_{t+1}/R_t \tag{3.19}$$

Entrepreneur collects capital, labor and housing to produce goods according to the following production function

$$Y_t = A_t(N_t^p)^{\alpha(1-\varpi)}(N_t^m)^{\alpha\varpi}K_{t-1}^{1-\alpha-\epsilon}(H_{t-1}^e)^{\epsilon} \tag{3.20}$$

where A_t is technology shock.

Monetary Authority

The Hong Kong interest rate is adjusted with an aim to stabilize the exchange rate. Three roles of the exchange rate are: 1) the demand of tradable goods is affected by the nominal depreciation rate; 2) under uncovered interest rate parity, the exchange rate is linked to the nominal interest rate; 3) the Hong Kong interest rate reacts directly to the deviation of the market exchange rate from the official value, 7.80 HKD to 1.00 USD.

Our interest rate rule is designed on the basis of the interest rate rules under three exchange rate regimes: fixed, floating and managed exchange rate regimes as discussed in Benigno and Benigno (2008).

First, since the market exchange rate in Hong Kong has a small variation around the official value, the adjustment of the interest rate is to stabilize the exchange rate. Second, Hong Kong Monetary Authority does not implement the independent monetary policy. Hence, the interest rate rule doesn't stabilize domestic inflation, and control output gap, output growth and etc. Third, the Hong Kong interest rate is linked to the U.S. interest rate closely. According to the above characteristics, the Hong Kong interest rate depends on the U.S. interest rate and meanwhile, it reacts to the deviation of market exchange rate from the desired target. Moreover, the Hong Kong interest rate is related to its lagged interest rate. Hence, the Hong Kong interest rate rule is defined as

$$R_t = (R_{t-1})^{\rho_R}[(\frac{e_t}{e^*})^{\phi_0}(R_t^*)]^{(1-\rho_R)}\varepsilon_{\tilde{R},t} \tag{3.21}$$

The log linearization expression of equation (3.21) is $\hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R)(\phi_0 \hat{e}_t + \hat{R}_t^*) + \varepsilon_{R,t}$ where $\hat{e}_t$ denotes the log-deviation of the exchange rate e_t from the target e^*, i.e. $\hat{e}_t = log(\frac{e_t}{e^*})$. $\varepsilon_{R,t}$ is the interest rate shock and $\varepsilon_{R,t} \sim N(0, \sigma_R^2)$.

3.2.2 Open Economy Feature

UIP and Risk Sharing

Composite consumption Γ_t in the domestic country is defined as

$$\Gamma_t = [(1-\kappa)^{\frac{1}{\eta}}(\Gamma_{H,t})^{\frac{\eta-1}{\eta}} + (\kappa)^{\frac{1}{\eta}}(\Gamma_{F,t})^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}} \tag{3.22}$$

where $0 \leq \kappa < 1$ is inversely related to the degree of home bias in preferences or the import share and $\eta > 0$ is the intratemporal substitutability between domestic and foreign goods. $\Gamma_{H,t}$ is the index of consumption goods produced in the domestic country given by the CES function:

$$\Gamma_{H,t} \equiv (\int_0^1 \Gamma_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(j)dj)^{\frac{\varepsilon}{\varepsilon-1}}$$

where $j \in [0,1]$ denotes good variety and $\varepsilon > 1$ denotes the elasticity of substitution between varieties.

Similarly, $\Gamma_{F,t}$ is the index of imported goods given by the CES function:

$$\Gamma_{F,t} \equiv (\int_0^1 \Gamma_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}(j)dj)^{\frac{\varepsilon}{\varepsilon-1}}$$

The demand functions derived from the optimal allocation of any given expenditure are

$$\Gamma_{H,t}(j) = (\frac{P_{H,t}(j)}{P_{H,t}})^{-\varepsilon}\Gamma_{H,t} \tag{3.23a}$$

$$\Gamma_{F,t}(j) = (\frac{P_{F,t}(j)}{P_{F,t}})^{-\varepsilon}\Gamma_{F,t} \tag{3.23b}$$

for all $j \in [0,1]$. where $P_{H,t} \equiv (\int_0^1 P_{H,t}(j)^{1-\varepsilon}dj)^{\frac{1}{1-\varepsilon}}$ is the price index of domestically produced goods and $P_{F,t} \equiv (\int_0^1 P_{F,t}(j)^{1-\varepsilon}dj)^{\frac{1}{1-\varepsilon}}$ is the price index of imported goods.

Composite price index (CPI) in the domestic country is

$$P_t = [(1-\kappa)(P_{H,t})^{1-\eta} + \kappa(P_{F,t})^{1-\eta}]^{\frac{1}{1-\eta}} \tag{3.24}$$

Notice that if κ is equal to zero, there is no trade between domestic country and foreign country, which implies the economy is closed. Equation (3.24) shows that the overall price index comprises of the price index of goods produced in the domestic country and the price index of imported goods.

We derive the optimal allocation of expenditures between domestic and imported goods with demand functions and price indexes:

$$\Gamma_{H,t} = (1-\kappa)(\frac{P_{H,t}}{P_t})^{-\eta}\Gamma_t \tag{3.25a}$$

$$\Gamma_{F,t} = \kappa(\frac{P_{F,t}}{P_t})^{-\eta}\Gamma_t \tag{3.25b}$$

Under uncovered interest rate parity, the expected return from domestic risk-free bonds must be the same as the expected return from foreign bonds measured in domestic currency. We assume that the international asset market is incomplete, which implies risk-sharing between households is imperfect in these two regions. In equilibrium, asset returns should be equalized. Hence, international risk sharing condition satisfies

$$\frac{R_t}{\varrho_t R_t^*} = E_t[\frac{e_{t+1}}{e_t}]$$

We take log linearization around the perfect foresight steady state and get

$$\hat{R}_t - \hat{R}_t^* = E_t(\hat{e}_{t+1} - \hat{e}_t) - \chi(J_t + \zeta_t) \tag{3.26}$$

Equation (3.26) shows the interest rate differential between Hong Kong and the U.S. depends on the difference between the expected and current nominal effective exchange rates and a risk premium.

Terms of trade is defined as $S_t = \frac{P_{F,t}}{P_{H,t}}$, the ratio of the price index of imported goods measured in domestic currency to the price index of goods produced by domestic producers. The log-linearized terms of trade is

$$\hat{S}_t - \hat{S}_{t-1} = \hat{\pi}_{F,t} - \hat{\pi}_{H,t} \tag{3.27}$$

Law of one price is $\psi_{F,t} = \frac{e_t P_t^*}{P_{F,t}}$. If law of one price holds, $\psi_{F,t} = 1$ and $e_t P_t^* = P_{F,t}$.

Real exchange rate is defined as the ratio of CPIs measured in domestic currency, $U_t = \frac{e_t P_t^*}{P_t}$. The log-linearized real exchange rate is

$$\hat{U}_t = \hat{\psi}_{F,t} + (1 - \kappa)\hat{S}_t \tag{3.28}$$

The nominal depreciation rate (or PPP relationship) is

$$E_t\hat{U}_{t+1} - \hat{U}_t = E_t\hat{e}_{t+1} - \hat{e}_t + E_t\pi^*_{t+1} - E_t\pi_{t+1} + \varepsilon_{\vartheta,t} \tag{3.29}$$

Where $\varepsilon_{\vartheta,t}$ is PPP shock. PPP shock is very common in the open economy DSGE model. It is introduced to close the economy and avoid misspecification. The PPP equation shows that the real exchange rate differential is aligned with the movement of the nominal exchange rate if the inflation differential is smoothed.

Domestic Producer

We assume implicit costs of adjusting nominal prices. Domestic producers (indexed by $j \in [0, 1]$) are monopolistically competitive and owned by consumers. Domestic producers adjust prices with staggered setting (Calvo 1983). Each period the firm does not adjust prices with probability θ_H and sets the price optimally $\tilde{P}_{H,t}$ with probability $1 - \theta_H$. Aggregate domestically-produced-good price index is given by the following

Dixit-Stiglitz aggregator:

$$P_{H,t} = [\theta_H P_{H,t-1}^{1-\varepsilon} + (1-\theta_H)(\tilde{P}_{H,t})^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

where $\tilde{P}_{H,t}$ is the average price level chosen by those who have the chance to adjust prices.

Under Calvo price setting, each firm chooses the optimal price $P_{H,t}(j)$ to maximize the expected discounted profit:

$$E_T \sum_{t=T}^{\infty} (\theta_H)^{t-T} Y_{H,t}(j) \Lambda_{T,t} [P_{H,T}(j) - P_{H,t} MC_{H,t}]$$

subject to the demand function

$$Y_{H,t}(j) = [\frac{P_{H,t}(j)}{P_{H,t}}]^{-\varepsilon} Y_{H,t}$$

where $\Lambda_{T,t}$ is stochastic discount factor used for evaluating consumption streams. $Y_{H,t}$ is the output produced by domestic producers and $Y_{H,t} = \Gamma_{H,t} + \Gamma^*_{H,t}$. And $P_{H,t}/MC_{H,t} = P_t/MC_t$.

The forward looking Philips curve is

$$\pi_{H,t} = \beta(E_t \pi_{H,t+1}) + \frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H}(-\hat{X}_t + \kappa \hat{S}_t) + \hat{u}_{h,t} \tag{3.30}$$

Where $\hat{u}_{h,t} = \rho_{U_h} \hat{u}_{h,t-1} + \varepsilon_{H,t}$ is the domestic price cost push shock.

Import Retailer

Similarly, we assume that import retailers that provide foreign differentiated goods for which the law of one price holds in the long run are monopolistically competitive. However, in the short run, small degree of pricing power leads to a violation of the law of one price. Importers face Calvo price setting with probability $1-\theta_F$ that they can adjust price optimally. The aggregate imported-good price index is given by the following Dixit-Stiglitz aggregator:

$$P_{F,t} = [\theta_F P_{F,t-1}^{1-\varepsilon} + (1-\theta_F)(\tilde{P}_{F,t})^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

where $\tilde{P}_{F,t}$ is the average price level chosen by those who have the chance to adjust prices. Importers choose the optimal price $P_{F,t}(j)$ to maximize the expected discounted profit:

$$E_T \sum_{t=T}^{\infty} (\theta_F)^{t-T} \Gamma_{F,t}(j) \Lambda_{T,t}[P_{F,T}(j) - e_t P^*_{F,t}(j)]$$

subject to the demand function

$$\Gamma_{F,t}(j) = [\frac{P_{F,t}(j)}{P_{F,t}}]^{-\varepsilon} \Gamma_{F,t}$$

Because the trade with Hong Kong is trivial, the variation of the price of goods imported from the United States has a negligible effect on the evolution of the price index in the United States. As a result, $P^*_t \cong P^*_{F,t}$.

The forward looking Philips curve is

$$\pi_{F,t} = \beta(E_t \pi_{F,t+1}) + \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F}(\hat{\psi}_{F,t}) + \hat{u}_{f,t} \tag{3.31}$$

Where $\hat{u}_{f,t} = \rho_{U_f} \hat{u}_{f,t-1} + \varepsilon_{F,t}$ is the import price cost push shock.

3.2.3 U.S. Economy

We treat the U.S. economy as a closed economy and assume that all the goods consumed by the agents in the U.S. are from the U.S., that is $C^*_t \cong C^*_{F,t}$ where $C^*_{F,t}$ denotes the goods produced by firms in the U.S. and consumed by the agents in the United States. We assume that there is no capital accumulation in the U.S. economy. The details of the model are discussed as follows.

The household's intertemporal utility function is defined as

$$E_t\{\sum_{i=0}^{\infty} (\beta^*)^i [InC^*_{t+i} - \frac{1}{\sigma}(N^*_{t+i})^{\sigma}]\}$$

Subject to budget constraint:

$$C^*_t + \frac{B_t}{R^*_t} - \frac{B_{t-1}}{\pi^*_t} = W^*_t N^*_t + \Pi^*_t + TR^*_t \tag{3.32}$$

Where B_t is the foreign bond held by the U.S. households and Π^*_t is the profit from firms. Let λ^*_t be the Lagrange multiplier. First order conditions with respect to consumption, labor demand and bond C^*_t, N^*_t, B_t are

$$\frac{1}{C_t^*} = \lambda_t^* \tag{3.33}$$

$$(N_t^*)^{\sigma-1} = \lambda_t^* W_t^* \tag{3.34}$$

$$\frac{\lambda_t^*}{R_t^*} = \beta^* E_{t+1}[\frac{\lambda_{t+1}^*}{\pi_{t+1}^*}] \tag{3.35}$$

Entrepreneur provides final goods to households according to the following production function

$$Y_t^* = A_t^* N_t^* \tag{3.36}$$

Where A_t^* is the U.S. technology shock.

The forward looking Philips curve for the producers in the United States is

$$\pi_t^* = \beta^* E_t \pi_{t+1}^* + \frac{(1-\theta^*)(1-\beta^*\theta^*)}{\theta^*}(\hat{MC}_t^*) + \hat{u}_t \tag{3.37}$$

where $\hat{MC}_t^* = -\hat{\lambda}_t^* - \hat{A}_t^*$ is the log-linearized real marginal cost and inflation shock $\hat{u}_t$ follows an AR(1) process: $\hat{u}_t = \rho_U \hat{u}_{t-1} + \varepsilon_{U,t}$.

The U.S. interest rate rule is

$$R_t^* = (R_{t-1}^*)^{\rho_{R^*}}[(\frac{P_t^*}{P_{t-1}^*})^{\phi_1}(\frac{Y_t^*}{Y_{t-1}^*})^{\phi_2}]^{(1-\rho_{R^*})}\tilde{\varepsilon_{R,t}^*} \tag{3.38}$$

The log linearization of equation (3.38) is $\hat{R}_t^* = \rho_{R^*}\hat{R}_{t-1}^* + (1-\rho_{R^*})(\phi_1^*\pi_t^* + \phi_2^*(\Delta\hat{y}_t^*)) + \varepsilon_{R^*,t}$ where $\varepsilon_{R,t}^*$ is the U.S. monetary policy shock and follows $\varepsilon_{R,t}^* \sim N(0, \sigma_{R^*}^2)$.

3.3 Market Clearing and General Equilibrium

Good market clearing for the Hong Kong economy requires:

$$Y_t = C_t^p + C^m + C_t^e + I_t + NX_t = \Gamma_t + I_t + NX_t \tag{3.39}$$

where $NX_t = \Gamma_{H,t}^* - \Gamma_{F,t}$. $\Gamma_{F,t}$ is the import from the foreign economy (the

United States) to the domestic economy (Hong Kong) and $\Gamma^*_{H,t} = \kappa^*(\frac{P^*_{H,t}}{P^*_t})^{-\zeta}C^*_t$ is the export to the United States where ζ is the intertemporal substitutability across goods in the foreign economy. This demand function is common in the small open economy setting. ζ gives additional flexility in the transmission mechanism of foreign disturbances to the domestic economy. To simplify, we assume $\zeta = \eta$ and $\kappa = \kappa^*$.

House market clearing for the Hong Kong economy requires:

$$H^p_t + H^e_t + H^m_t = \bar{H} \tag{3.40}$$

Good market clearing for the U.S. economy requires:

$$Y^*_t = C^*_t \tag{3.41}$$

Bond market clearing satisfies

$$B_t = B^*_t = 0$$

Under the assumption of the producer currency pricing, the current account balance in the real term is defined as

$$\frac{e_t B^*_t}{\varrho_t R^*_t P_t} + \frac{P_{H,t}}{P_t}\Gamma^*_{H,t} = \frac{e_t B^*_{t-1}}{P_t} + \frac{e_t P^*_{F,t}}{P_t}\Gamma_{F,t} \tag{3.42}$$

The model has a unique stationary equilibrium in which entrepreneur and impatient household hit the borrowing constraint and borrow up to the limit, making interest payments on the debt and rolling over the steady-state stock of debt over forever. The equilibrium is an allocation $\{H^p_t, H^m_t, H^e_t, K_t, N^p_t, N^m_t, C^p_t, C^m_t, C^e_t, D_t, L^m_t, L^e_t, C^*_t, B^*_t, B_t\}$ together with the sequences of values $\{W_t, R_t, P_t, X_t, Q_t, P_{H,t}, P_{F,t}, P^*_t, R^*_t, S_t, U_t, \psi_{F,t}, e_t\}$ and market clearing conditions and ten shocks $\{\varepsilon_{A,t}, \varepsilon^*_{A,t}, \varepsilon_{R,t}, \varepsilon^*_{R,t}, \varepsilon_{H,t}, \varepsilon_{F,t}, \varepsilon_{u,t}, \varepsilon_{\zeta,t}, \varepsilon_{j,t}, \varepsilon_{\vartheta,t}\}$, together with the relevant transversally conditions. Table 3.1 lists the description of all the parameters and Appendix describes the steady state of the model. There are 10 observed variables and 10 shocks. Equation (3.1)-(3.42) consist of the complete model and the log-linearization system can be provided by the author under request.

3.4 Bayesian Estimation

In this section, we describe DSGE-VAR methodology and present the Bayesian estimation on Hong Kong and U.S. dataset of the first order approximation of the model described in the previous section. We are not going to compare the marginal density of DSGE-VAR and DSGE to evaluate DSGEs. We focus on the estimation of DSGE-VAR and the comparison of the impulse responses in DSGE-VAR and DSGE.

3.4.1 Methodology

DSGE-VAR has been fully discussed by Del Negro (2004) and the subsequent works. DSGE-VAR is regarded as the linear DSGE is nested in the VAR model. DSGE-VAR introduces a hyperparameter λ as the weight put on priors. It is interpreted as a factor that scales covariance matrix of the priors that capture deviations from DSGE model restrictions. As explained in Del Negro (2004), if the hyperparameter λ is very large, the model will be fairly close to the DSGE model itself as the prior mass on the VAR coefficients concentrates near the DSGE model restrictions; if the hyperparameter λ is small the resulting model will be fairly close to an unrestricted VAR: the prior on the VAR coefficients is diffuse.

Using Markov Chain Monte Carlo method we can generate draws from the posterior distribution of the parameters and choose the "optimal" value of λ, the weight of the priors. For computation of marginal likelihoods, we use the modified harmonic mean method with the standard weighting function by Geweke (1999).

3.4.2 Data

Our empirical analysis is based on quarterly data[3] for ten macroeconomic variables from 1984Q1 to 2010Q2: real GDP, real consumption, CPI, GDP deflator, real house prices and interbank offer rate from Hong Kong and real GDP, CPI and Federal Fund rate from the U.S. as well as the deviation of nominal exchange rate[4]. Seasonal adjustments have been made to all the series except nominal interest rates. We detrend the converted

[3]Data source: Hong Kong Monetary Authority, Hong Kong Rating and Valuation Department and the Federal Reserve Bank of St. Louis. The monthly series is converted into quarterly frequency by arithmetic averaging.

[4]It is defined as the deviation of the Hong Kong market exchange rate to the official exchange rate, 7.80 HKD to 1.00 USD.

data with a HP filter and the frequency with smoothing parameter is 1600.

Figure 3.1 illustrates the deviation of the market exchange rate from the official exchange rate 7.80 HKD to 1.00 USD. Figure 3.2 describes Hong Kong residential property price index (1999-100). The Hong Kong housing market experienced two major boom-bust cycles over 1984Q1 to 2011Q4. The residential property bubble peaks during the Asian Financial Crisis and it peaks again in the Great Recession. Figure 3.3 depicts that Hong Kong detrended real output is more volatile than U.S. output. Figure 3.4 compares the Hong Kong interest rate with the U.S. interest rate. We see that the Hong Kong interest rate moves closely with the U.S. interest rate but looks more volatile.

3.4.3 Calibrated Parameters and Priors

We calibrate some parameters to capture the salient features of the Hong Kong economy. We describe all the parameters in Table 3.1. Table 3.2 reports the value of calibrated parameters. Labor share in the production function is 0.64. Capital share in the production function is 0.33 and house share is 0.03. As in Iacoviello (2005), the depreciation rate of capital δ is set to 0.03. Income share of the patient household is 0.64. The values of capital and housing adjustment cost are set to be zero. The LTV ratio of entrepreneur and impatient household is 0.89 and 0.55, respectively. The discount factor of the patient household, impatient household and entrepreneur for Hong Kong are 0.99, 0.95 and 0.98, respectively. The discount factor of the U.S. household is 0.99. The risk premium parameter for Hong Kong is 0.054 according to Aswath Damodaran's research[5]. The steady state mark up is 1.15. The steady state value of NX/Y is set to be 0.02, the mean of the data series during sample periods and the steady state value of debt to GDP ratio in Hong Kong is set to be 2.

We assume all the parameters to be a priori independent. The marginal prior distributions for the parameters are listed in Table 3.3. It is very different to find priors because not many papers have researched on the Hong Kong economy. The recent papers in the literature, for example, Cheng and Ho (2009), Funke and Paetz (2010), and McNelis (2009) study price flexibility, housing market and inflation targeting with different sample periods. Openness, $\kappa = 0.3$ is set to be the mean of import share from the United States to Hong Kong. We assume it follows a beta distribution with mean 0.3 and standard error 0.05. The intertemporal substitution elasticity between home

[5] `http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/ctryprem.html`

and foreign consumption goods, $\eta = 1.8$ is obtained by the mean of the import share to GDP. Therefore the prior is set to be a normal distribution with mean 1.8 and standard error 0.1. Concerning the Calvo probabilities of prices, we assume a beta distribution around 0.65 for the Hong Kong economy and 0.75 for the U.S. economy. The initial value of labor disutility is set to be 1.15 in both economies and they follow a normal distribution. Similar to Iacoviello (2005), we assume the house preference shock follows a beta distribution centered on 0.8. Regarding the shocks, we are fitting AR(1) process to some of the shocks to guide the choice of prior means and variances, i.e. two price cost push shocks in the Hong Kong economy and one price cost push shock in the U.S. economy. The prior variance of the PPP shock ε_{ϑ} is based on the nominal depreciation equation. In order to get the prior variance of the monetary policy shocks, $\sigma_{R,t}$ and $\sigma_{R^*,t}$, we run the OLS regression of interest rate equations in both areas. The priors of technology shocks ε_A and ε_{A^*}, as well as the risk premium shock ε_{ζ} refer to the values commonly used in other papers. The standard errors of the innovations are assumed to follow an inverse gamma distribution. Finally, we set a uniform prior for λ and its value to 2.

3.4.4 Estimation Result

Posterior Estimates and Distributions

The results reported in this section have been performed with a DSGE-VAR of order 4. Figure 3.5 and 3.6 shows the marginal posterior distribution for structural parameters. Overall, the posterior distribution of the structural parameters are close to the prior distribution in the DSGE-VAR model. Table 3.3 reports the posterior means and 90 percent posterior probability intervals of parameter estimates. DSGE-VAR estimates in the Hong Kong economy and the U.S. economy are broad in line with the literature. The posterior mode for λ is around 1.29. The value is not too high and not too low. However, price stickiness parameters in the Hong Kong economy are a bit higher than the ones in Cheng and Ho (2009). Moreover, the standard error of Hong Kong technology shock is 5.49, which is reasonable as Hong Kong output dropped dramatically in 1997 (Asian financial crisis) and Great Recession. The posterior mean of the PPP shock is 0.82, lower than the actual mean of the PPP in the nominal depreciation rate equation 1.57. The estimated smoothing value in the Hong Kong interest rate rule is 0.17, which is a bit smaller than the value estimated in the OLS regression (around 0.25). The coefficient and the standard error of Hong Kong house preference shock are 0.93 and 21.34, respectively. The posterior mean of the openness and the elasticity of substitution are 0.4 and 1.7, respectively. The posterior estimates in the U.S. economy are by and large consistent with the literature.

Posterior Impulse Response Analysis

We study the dynamic behavior of the DSGE-VAR model before discussing variance decomposition. First of all, we analyze the propagation mechanism of Hong Kong structural shocks as well as the UIP shock and the risk premium shock to the Hong Kong economy. We also comment on the international spillovers of the U.S. shocks on the Hong Kong economic variables. Figure 3.7 - 3.16 depict the posterior mean of the impulse responses and pointwise 90 percent error bands to ten shocks from Hong Kong and the United States. The size of the shocks is one standard deviation. The dotted lines are DSGE-VAR model and the plain lines and shaded areas are DSGE model. The impulse responses in the DSGE model have been computed with the same draws of the DSGE mode parameters that generate the impulse responses in the DSGE-VAR model. DSGE-VAR is a structurally-identified VAR and as such, provides evidence on domestic and international transmissions of a relatively large set of structural shocks. And it illustrates the potential misspecification of the theoretical model: comparing the propagation of shocks in DSGE-VAR with DSGE sheds some lights on the dimensions of the DSGE model which may not be well-supported by the data.

Domestic Transmission

The effects of contractionary Hong Kong monetary shock is depicted in figure 3.7. There is an anticipated temporary rise in the Hong Kong interest rate but the effect dissipates very quickly. The rise in the interest rate gives an upward pressure on the exchange rate. Thus, the deviation from the target exchange rate first plummets (appreciates) and then increases. The exchange rate vanishes as fast as the Hong Kong interest rate. Output declines in response to contractionary monetary policy in the first few periods and then returns to zero from below. The impacts on overall inflation and domestic inflation (GDP deflator) are very weak. With the sticky price setting, monetary action affects the interest rate, and its rise works by discouraging current consumption and hence output. The effect is reinforced through a drop in housing price, which lowers borrowing and entrepreneurial housing investment. Hence, overall consumption and output decrease more. Hong Kong is a very small open economy and its flexible economic structure enables the Hong Kong economy to adapt quickly to the changing circumstances, thus the effects fade away very fast.

The responses to expansionary Hong Kong technology shock in figure 3.8 are typical. Output and consumption increase, prices decline and Hong Kong dollar depreciates. The interest rate reaction is positive but very small. Housing price climbs.

The responses to domestic and import cost push shocks are described in figure 3.9 and 3.10. The rise in the prices of domestic and imported goods lead to a rise in overall inflation. In figure 3.9, a rise in the price of domestic goods is accompanied by a fall in terms of trade. Terms of trade has a positive influence on the real exchange rate. Thus, the response of the nominal exchange rate depends on inflation and the real exchange rate dynamics according to the PPP relationship. The Hong Kong interest rate not only follows up the U.S. interest rate but also reacts to the deviation of the market exchange rate from its target. If there is an upward pressure on the exchange rate (depreciation), the Hong Kong interest rate drops in order to maintain the exchange rate. While the Hong Kong interest rate falls, Hong Kong firms desire less capital from the rest of the world, which eventually cause a drop in investment, therefore lowering output and consumption. The positive domestic price cost push shock has an insignificant effect on housing price.

In figure 3.10, an increase in the price of imported goods leads to a rise in terms of trade, thereby increasing the exchange rate and lowering the interest rate. Similar to the responses to domestic price cost push shock, investment and output growth decline in the DSGE-VAR model. However, the negative transmission to output is not supported in the DSGE model.

House preference shock is generated from a shock to the marginal rate of substitution j between housing and consumption for all the households. Consumers become more optimistic if there is any disturbance that shifts housing demand, such as temporary tax advantages to housing investment or a sudden increase in demand, thus leading to a rise in house prices. Figure 3.11 displays the impulse responses to a persistent positive house preference shock. Meanwhile, aggregate consumption and output increase and exchange rate decreases slightly. The positive house preference shock has slight effects on Hong Kong overall inflation, domestic inflation (GDP deflator) and interest rate.

The PPP shock is introduced to capture the dynamics of the real exchange rate. The positive PPP shock, as depicted in figure 3.12 gives a downward pressure on nominal exchange rate (appreciation) and a sharp deterioration of the current account. According to the UIP equation, an appreciation of exchange rate can only be achieved by a negative interest rate differential. As seen in figure 3.12, an appreciation in the exchange rate is accompanied by a fall in the Hong Kong interest rate. Hong Kong interest rate follows up the U.S. interest rate and the PPP shock has no effect on the U.S. interest rate. Therefore, the response of the Hong Kong interest rate to the PPP shock is very small. Hong Kong output and consumption rise accordingly.

The positive risk premium shock leads to a big drop in the nominal exchange rate on impact, accompanied by an increase in the Hong Kong interest rate and a decline in output as displayed in figure 3.13. The risk premium does not affect prices very much.

In general, the DSGE-VAR estimation provides impulse responses which are economically interpretable and qualitatively in line with the DSGE estimation. Some impulse responses in DSGE-VAR are even quasi similar to those in DSGE. Take figure 3.7, Hong Kong contractionary monetary shock as an example, the propagation in DSGE-VAR is very close to DSGE. Turning to the household's house preference shock, a marked difference between DSGE-VAR and DSGE concerns the stronger reaction of house price in DSGE-VAR than the one in DSGE-VAR while the rise in GDP and consumption is long-lasting in DSGE-VAR. The transmission of Hong Kong domestic and import price cost push shocks in DSGE-VAR is more pronounced and persistent than DSGE. In addition, in the case of PPP shock and risk premium shock, DSGE-VAR implies a significantly stronger and more persistent response than DSGE.

International Transmission

The comparison of impulse responses between DSGE-BVAR and DSGE gives the interpretation of interdependence between Hong Kong and the United States. Figure 3.14 depicts the effects of the contractionary U.S. monetary shock on Hong Kong. Inflation and output decline. There is a slight appreciation in the exchange rate corresponding with the Hong Kong interest rate hiking. The responses of Hong Kong and U.S. interest rates are in tandem which provide evidence that the main transmission of the shocks across these two regions is through the interest rate channel. Another transmission of the U.S. shocks to the Hong Kong economy is through the relative price movement. It is consistent with the international risk sharing that there is an expenditure switching effect away from domestic goods toward foreign goods. Compared with the Hong Kong monetary shock, Hong Kong output and inflation drop more but exchange rate appreciates less. House price decreases corresponding to a decline in output and consumption.

Figure 3.15 illustrates the effects of the positive U.S. technology shock on the Hong Kong economy. Under the U.S. technology shock, the U.S. output growth increases. Inflation and interest rate decline. Transmission of productivity disturbance, however, is negative, thus lowering Hong Kong output. This can be explained by the assumption of risk-sharing which causes production shifting to the economy with the highest productivity. Exchange rate appreciates and Hong Kong interest rate declines. As a consequence, Hong Kong prices are lower.

The positive U.S. price cost push shock leads to a rise in the U.S. inflation followed by a climb in the U.S. interest rate and a drop in output, as illustrated in figure 3.16. Since the Hong Kong interest rate moves with the U.S. interest rate, there is a downward pressure on the Hong Kong exchange rate (appreciation). In terms of spillover, the transmission of the U.S. cost push shock to the Hong Kong economy is positive. Real variables such as output, consumption and inflation increase.

The comparison of impulse responses between DSGE-VAR and DSGE give a better interpretation of the differences in international spillovers between these two models. Overall, regarding to all the shocks from the U.S., Hong Kong economic variables in DSGE-VAR respond in the same direction as in DSGE. But the magnitude is different. The responses of exchange rate to the U.S. monetary policy, technology and price cost push shocks in DSGE-VAR are very close to those in DSGE. Furthermore, the impulse responses to the U.S. technology shock remain relatively close between DSGE-VAR and DSGE. However, in the cases of U.S. monetary policy shock and price cost push shock, the spillover in DSGE-VAR is much stronger and more persistent on Hong Kong economic variables than in DSGE.

Variance Decomposition

Since October 1983, economists have debated on whether the Currency Board system is good for the Hong Kong economy. Economists argue that U.S. monetary policy interferes with the Hong Kong economy under the Currency Board System regardless that it is well suited to Hong Kong economic conditions. In most times it helps stabilize the Hong Kong economy. However, the peg may harm the Hong Kong economy if there is a misalignment between Hong Kong and U.S. business cycles. This section shows the contribution of domestic and foreign shocks to Hong Kong business cycle fluctuations by calculating variance decomposition. The results of asymptotic variance decomposition based on the mode of the model's posterior distribution are shown in Table 3.4.

Confirming the large identified VAR literature on the role of monetary policy shocks (e.g. Christiano, Eichenbaum, and Evans 1999, Smets and Wouters 2007), domestic and foreign monetary policy shocks contribute to a small fraction of the forecast variance of Hong Kong output in the long run. In line with the literature, Hong Kong output is primarily driven by the supply shock - Hong Kong technology shock, which accounts for around 46 percent of the variation in output. Other domestic shocks can explain about 15 percent of the fluctuation in output. The small contribution of the U.S. shocks to the variability of Hong Kong output provides an interesting comparison with the results found in the SVAR analysis of Han, Liu and Jin (2006). Under the Currency Board system, the impacts of the U.S. monetary shock and other U.S. shocks on the Hong Kong output are counteracted or assimilated by the deviation of the market exchange rate from the official value and the flexible economic structure.

We know that under the Currency Board system, the Hong Kong interest rate is closely tied to the U.S. interest rate. The impulse responses to the U.S. monetary shock in figure 3.14 have provided supportive evidence that the Hong Kong interest rate follows up the U.S. interest rate. What explains the Hong Kong interest rate in the long run? Table 3.4 shows that the U.S. technology and the Hong Kong interest rate (monetary policy) shocks explain most of the long run fluctuation in the Hong Kong interest rate, which is consistent with the fact that Hong Kong monetary authority does not implement monetary policy and the Hong Kong interest rate follows up the U.S. interest rate.

Table 3.4 suggests that Hong Kong technology, domestic price mark-up and the U.S. technology shocks explain a large part of the variability of Hong Kong GDP deflator in the long run; the U.S. technology and import price cost push shocks are the determinant factors to explain the fluctuation in the price index of Hong Kong imported goods. Therefore, Hong Kong overall inflation is mainly driven by the U.S. technology shock. Surprisingly, the fluctuation of the housing price is mainly driven by Hong Kong technology shock, rather than house preference shock. The exchange rate is well explained by Hong Kong risk premium shock, technology shock and monetary policy shock as expected.

3.5 Concluding Remarks

This paper applies a small open economy DSGE-VAR model into Hong Kong economy and estimates the model with Bayesian methodology. The main contribution of this paper covers first the specified interest rate channel to capture the main features of the Currency Board system. We investigate the contribution of the U.S. shocks including U.S. monetary policy shock to the Hong Kong business cycle. We find a stronger spillover of the U.S. shocks on the Hong Kong economy in DSGE-VAR than DSGE suggested by the impulse response functions. Variance decomposition results suggest that in the long run, domestic shocks can explain most of the fluctuations in the main Hong Kong economic series such as output, consumption and house price while the U.S. shocks can contribute to most of the variability of Hong Kong interest rate and inflation. These findings provide some evidence to evaluate the role of the interest rate channel in the propagation of business cycles under the Currency Board system. Moreover, we find that household preference shock is not a crucial factor to explain Hong Kong house price fluctuation.

Our open economy model is an open fully micro-founded model with real and nominal rigidities with ten shocks. Our results are model dependent. As a consequence, we believe that there may be several extensions needed to done. First, we haven't introduced wage stickiness, wage indexation and wage cost push shock. The literature, for example, Smets and Wouters (2007), show that wage cost push shock is as important as technology shock behind business cycles. Second, according to the stylized fact that Hong Kong has an almost open capital account, imported investment or capital inflows and outflows can be introduced to make the model richer and more realistic as discussed by Adolfson (2007). Third, the Hong Kong economy has relied on Mainland China more heavily since 1997. The extension of the two-economy model to a three-economy model is possible to explore the international transmission mechanism and Hong Kong business cycle more accurately.

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Appendix

$$X = \frac{1}{1 - 1/\varepsilon}$$

$$\bar{K}/\bar{Y} = \frac{1}{X}\frac{\gamma(1-\alpha-\epsilon)}{1-(1-\delta)\gamma}$$

$$\bar{I}/\bar{Y} = \frac{\delta}{X}\frac{\gamma(1-\alpha-\epsilon)}{1-(1-\delta)\gamma}$$

$$\bar{Q}\bar{H}^e/\bar{Y} = \frac{\gamma\epsilon}{1-\gamma_e}\frac{1}{X}$$

$$\bar{L^e}/\bar{Y} = \frac{\beta m_2 \gamma\epsilon}{1-\gamma_e}\frac{1}{X}$$

$$\bar{R}\bar{L^e}/\bar{Y} = \frac{m_2\gamma\epsilon}{1-\gamma_e}\frac{1}{X}$$

Let $s^{'} = \frac{\alpha(1-\varpi)+X-1}{X}$ and $s^{''} = \frac{\alpha\varpi+X-1}{X}$ be the income share of patient and impatient households. The real estate for each household is

$$\bar{Q}\bar{H}^p/\bar{Y} = \frac{jm_2\epsilon}{1-\gamma}\frac{1}{X} + \frac{j}{1-\beta}s^{'} + \frac{j}{1-\beta^m - m_1(\beta-\beta^m - j(1-\beta))}m_1 s^{''}$$

$$\bar{Q}\bar{H}^m/\bar{Y} = \frac{j}{1-\beta^m - m_1(\beta-\beta^m - j(1-\beta))}m_1 s^{''}$$

$$\bar{L^m}/\bar{Y} = \frac{j\beta m_2}{1-\beta^m - m_1(\beta-\beta^m) + jm_1(1-\beta)}s^{''}$$

$$\bar{C^m}/\bar{Y} = \frac{1-\beta^m - m_1(\beta-\beta^m)}{1-\beta^m - m_1(\beta-\beta^m) + jm_1(1-\beta)}s^{''}$$

$$\bar{C^e}/\bar{Y} = ((1-\alpha) - \frac{\delta\gamma(1-\alpha-\epsilon)}{1-\gamma(1-\delta)} - \frac{(1-\beta)m_2\gamma\epsilon}{1-\gamma_e})\frac{1}{X} - \frac{\bar{NX}}{\bar{Y}}$$

$$\bar{C^p}/\bar{Y} = s^{'} + (1-\beta)(m_2\frac{\bar{Q}\bar{H}^e}{\bar{Y}} + m_1\frac{\bar{Q}\bar{H}^m}{\bar{Y}})$$

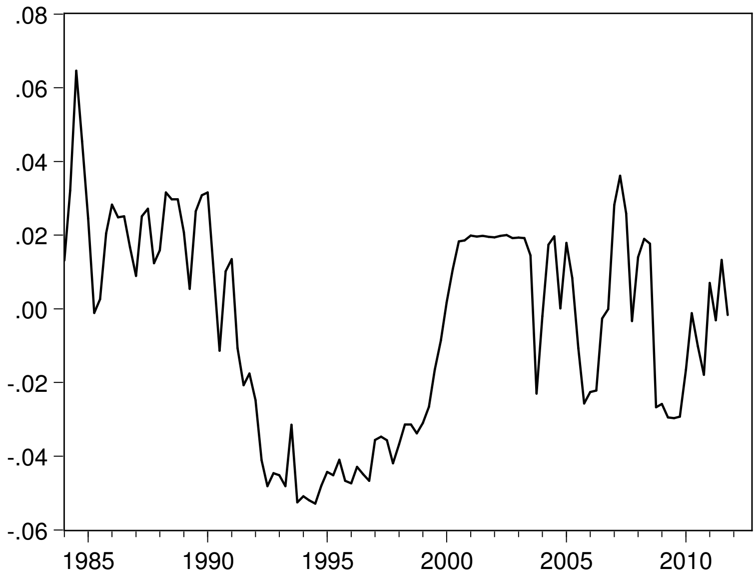


Figure 3.1: Hong Kong Exchange Rate Deviation from Official Rate

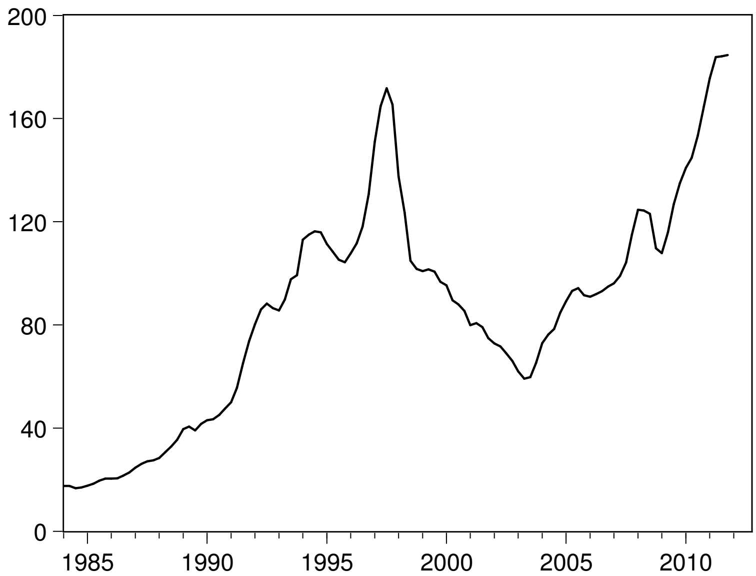


Figure 3.2: Hong Kong Residential Price Index

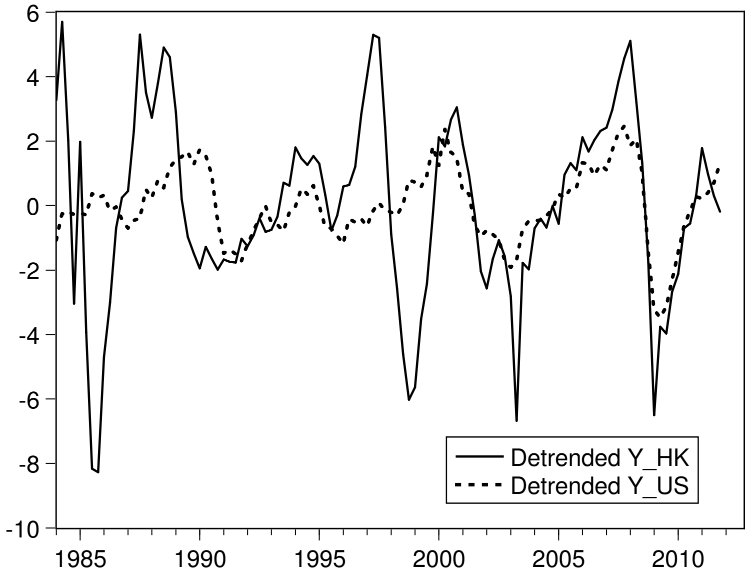


Figure 3.3: Hong Kong vs US Detrended Real GDP

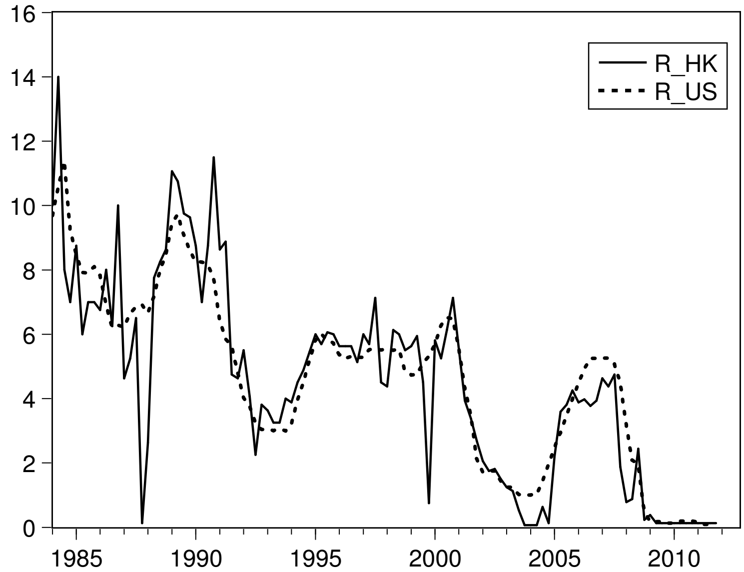
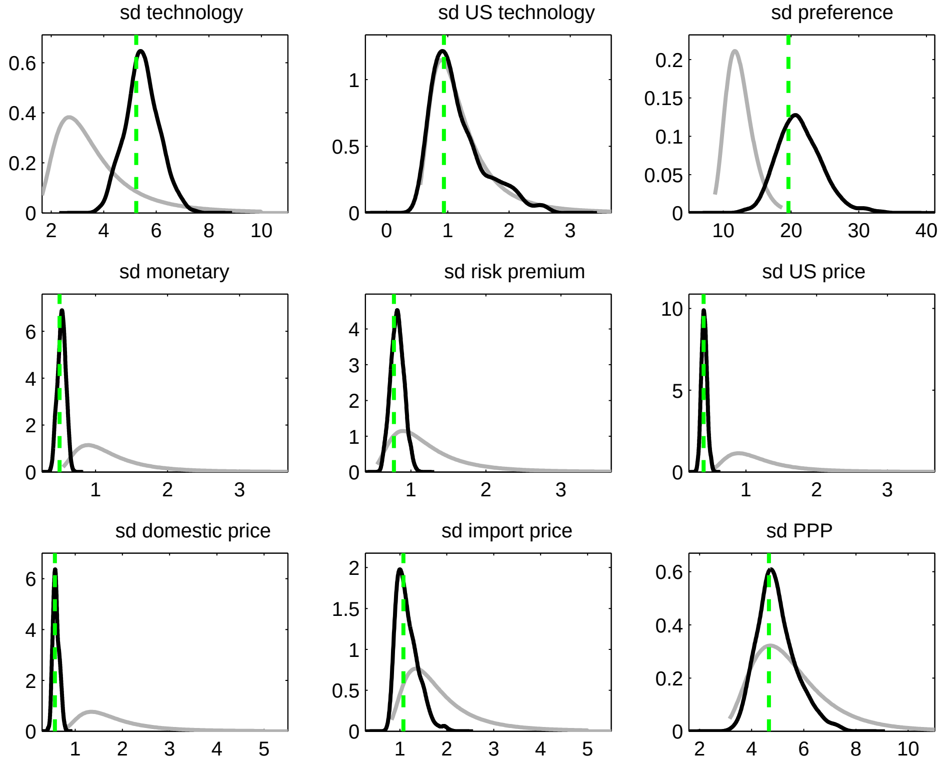
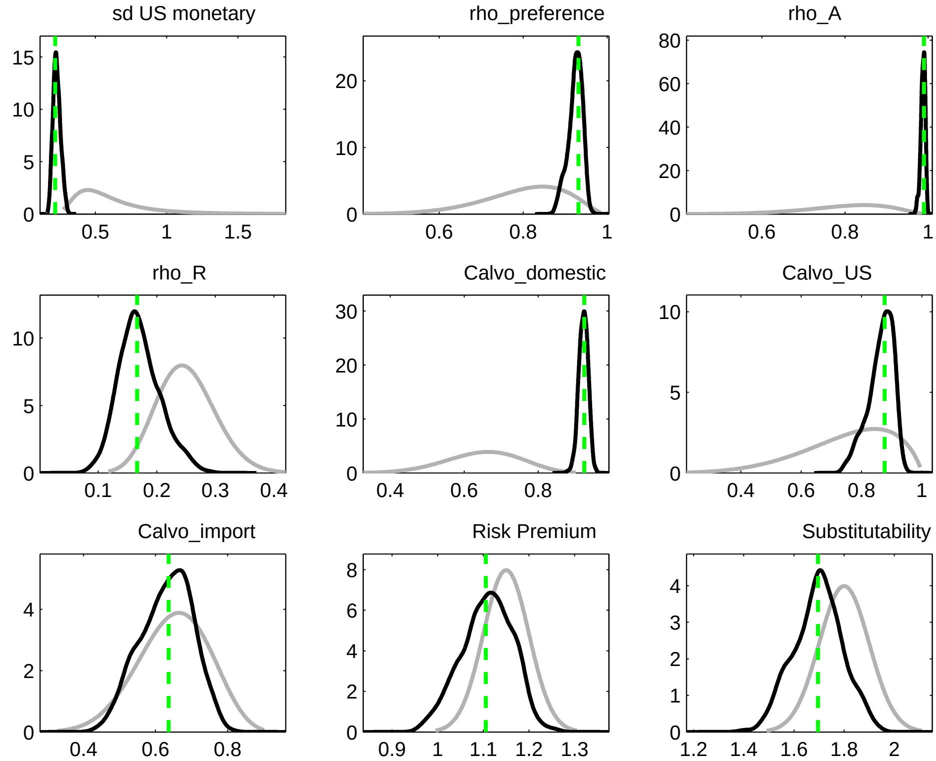


Figure 3.4: Hong Kong vs US Nominal Interest Rates

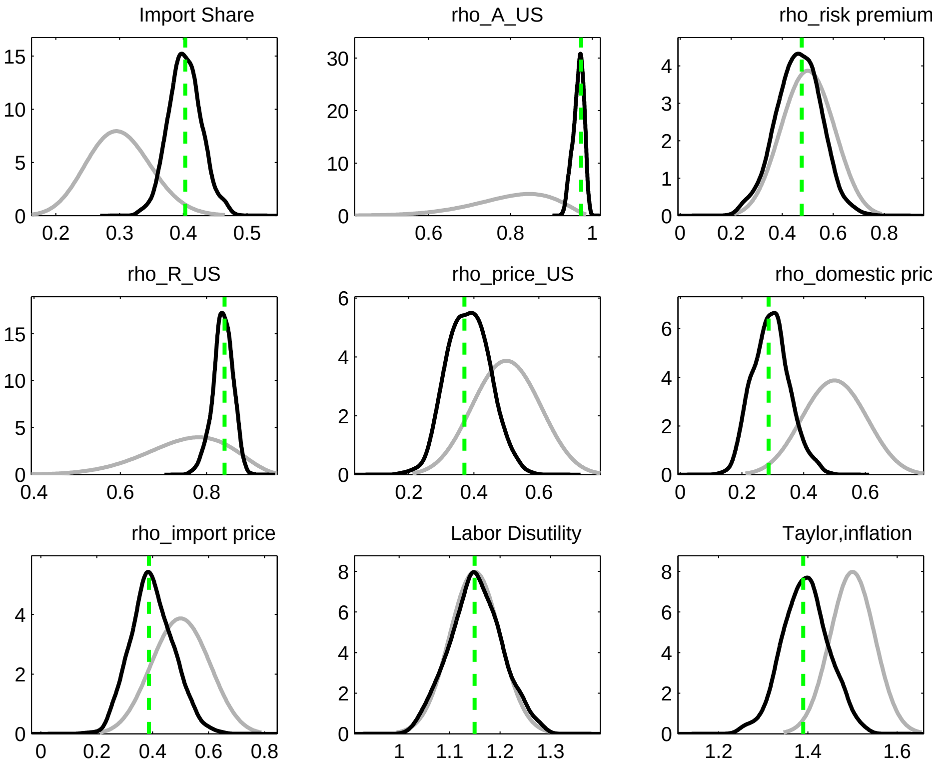


(a)

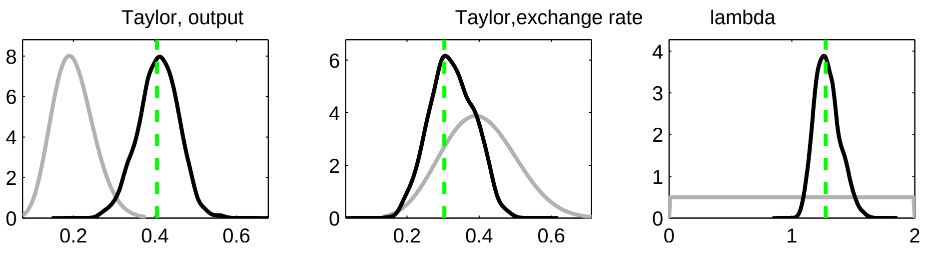


(b)

Figure 3.5: (a) and (b) describe priors and posteriors.



(a)



(b)

Figure 3.6: (a) and (b) describe priors and posteriors.

Figure 3.7: Hong Kong Monetary Policy Shock

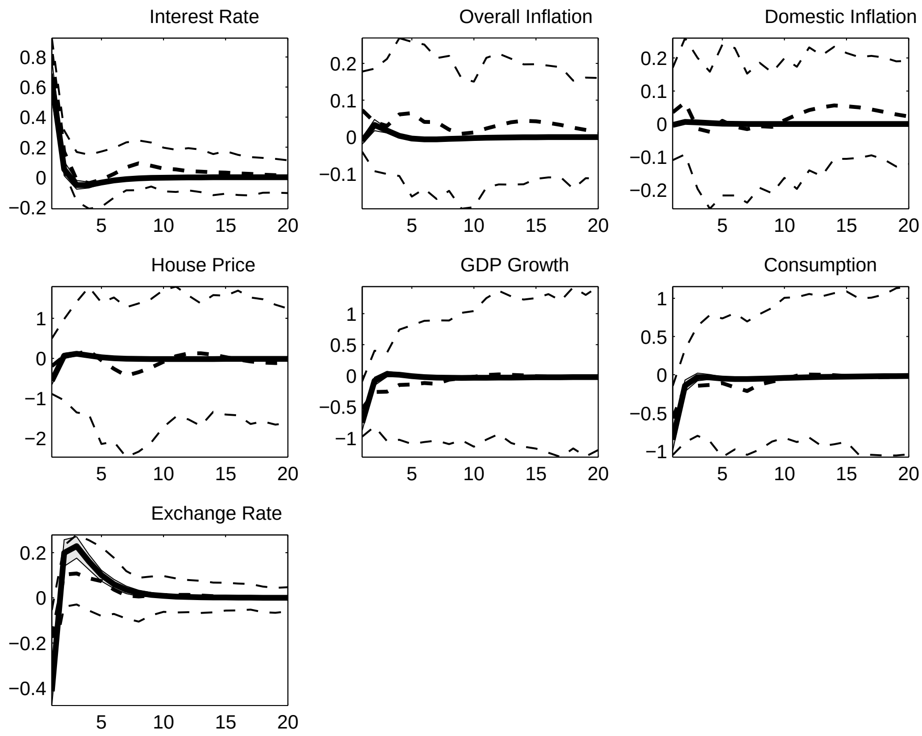


Figure 3.8: Hong Kong Technology Shock

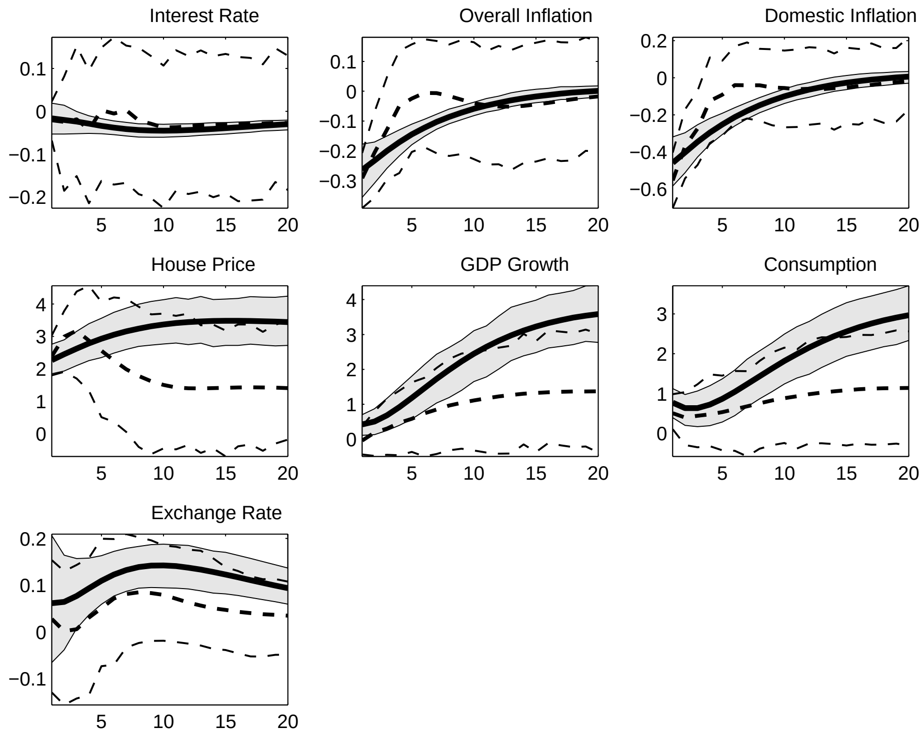


Figure 3.9: Hong Kong Domestic Price Cost Push Shock

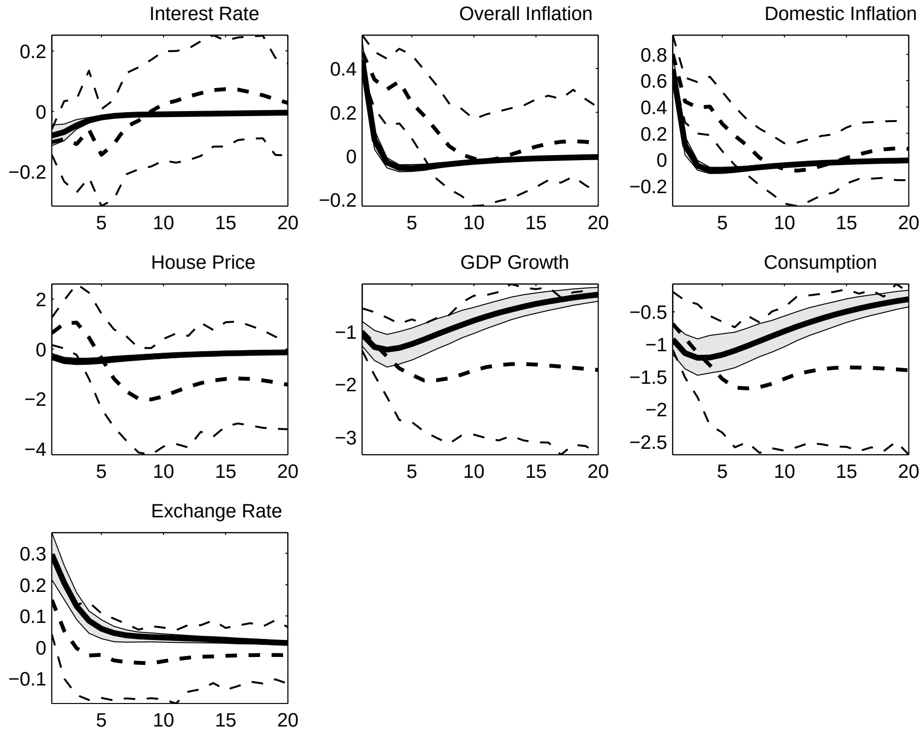


Figure 3.10: Hong Kong Import Price Cost Push Shock

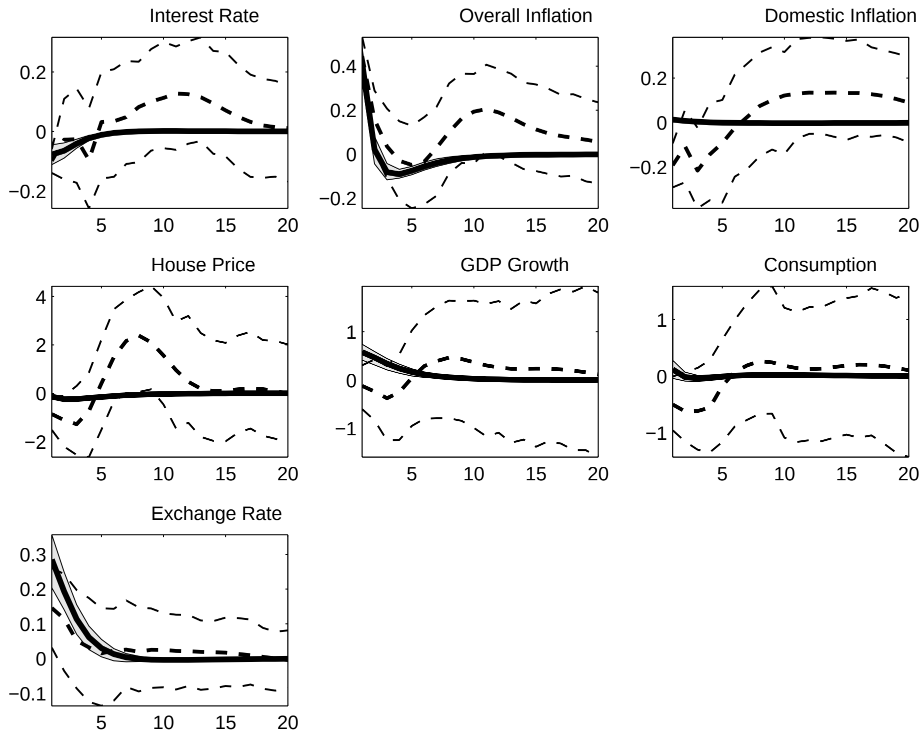


Figure 3.11: Hong Kong Household House Preference Shock

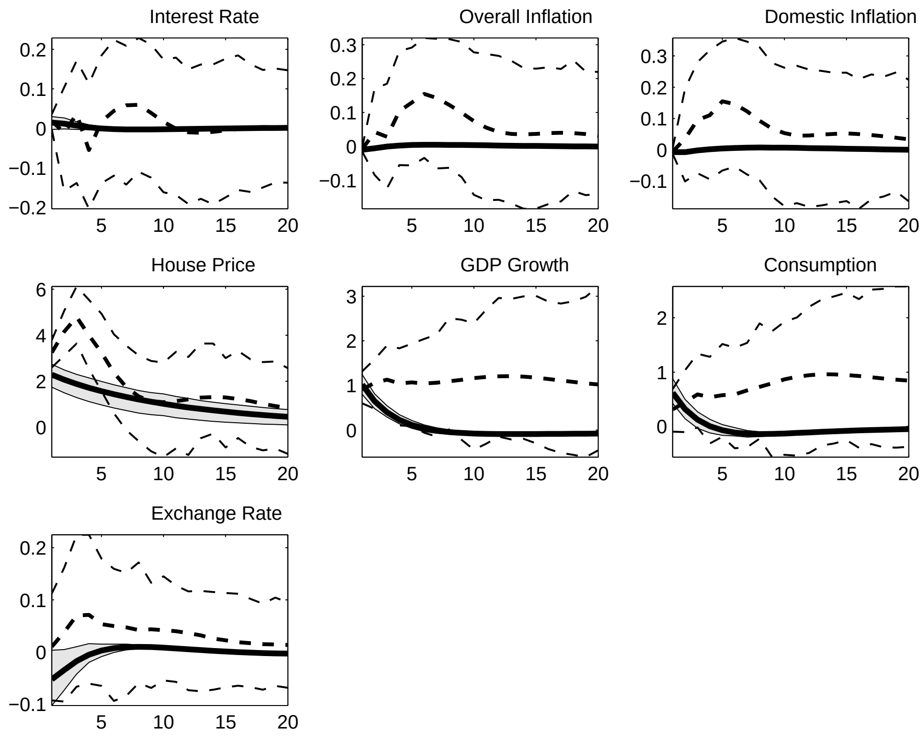


Figure 3.12: PPP Shock

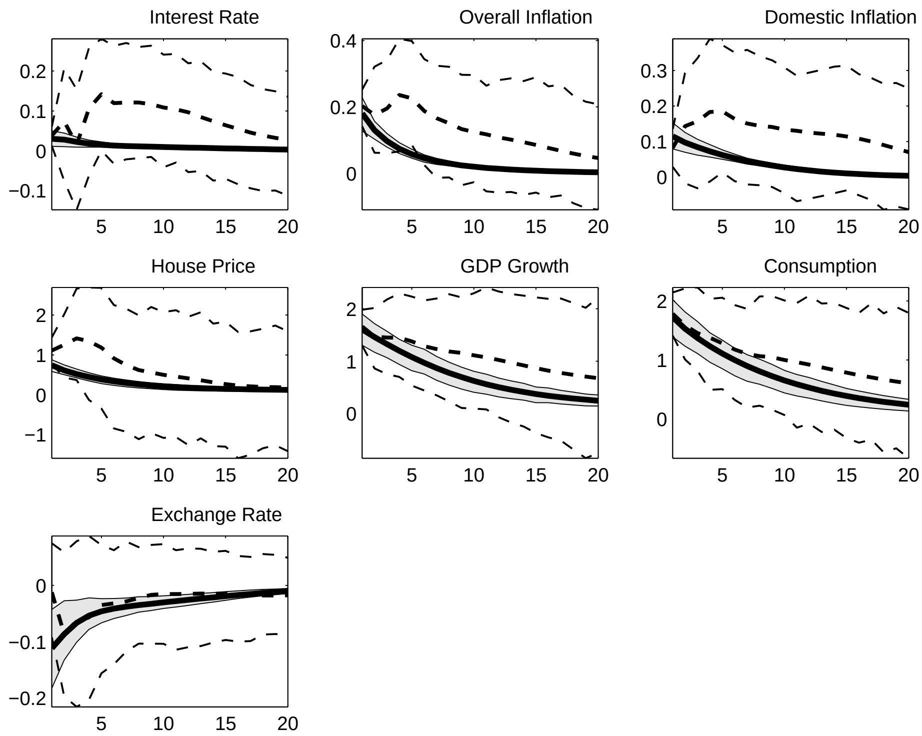


Figure 3.13: Risk Premium Shock

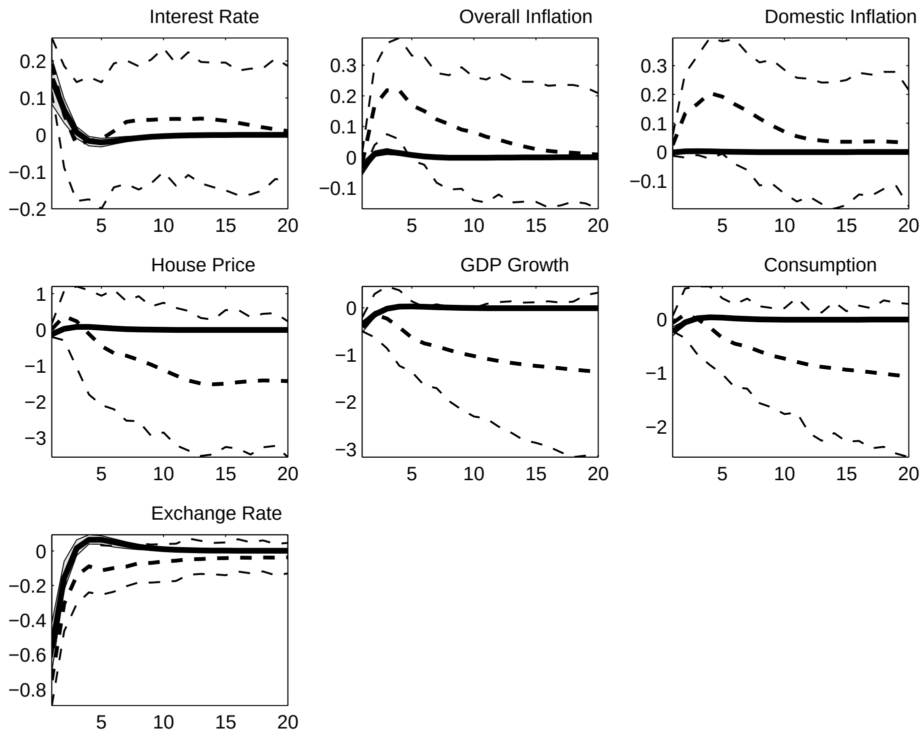


Figure 3.14: US Monetary Policy Shock

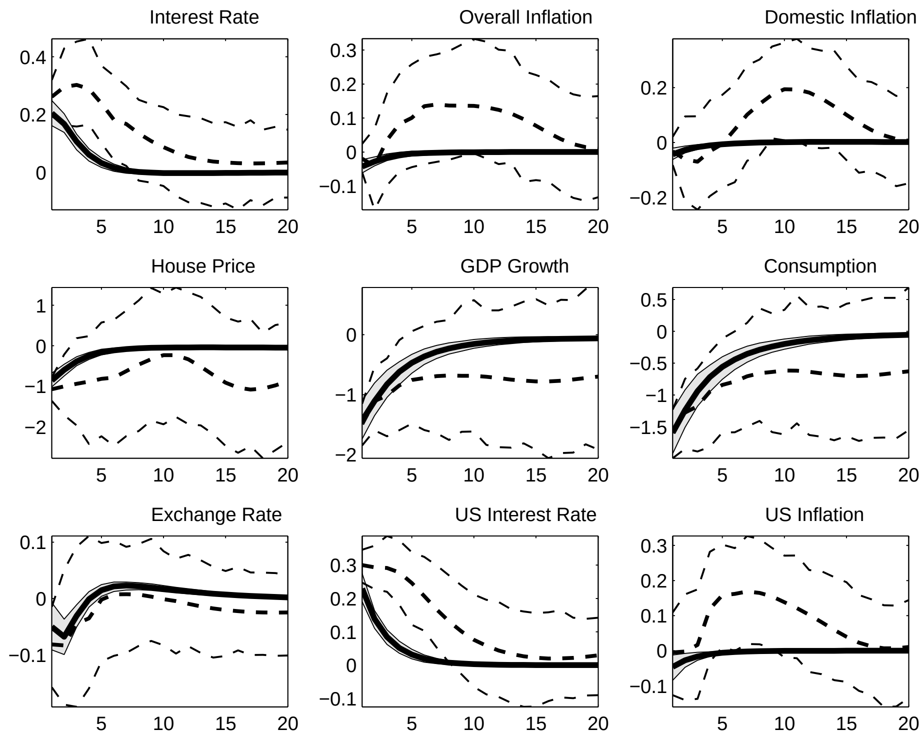


Figure 3.15: US Technology Shock

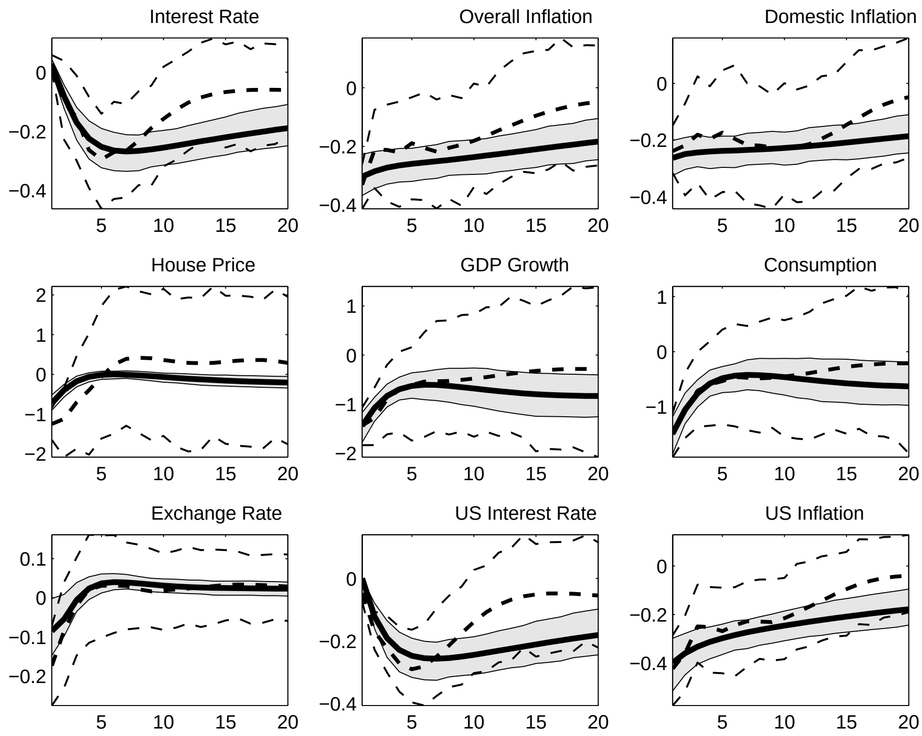


Figure 3.16: US Price Cost Push Shock

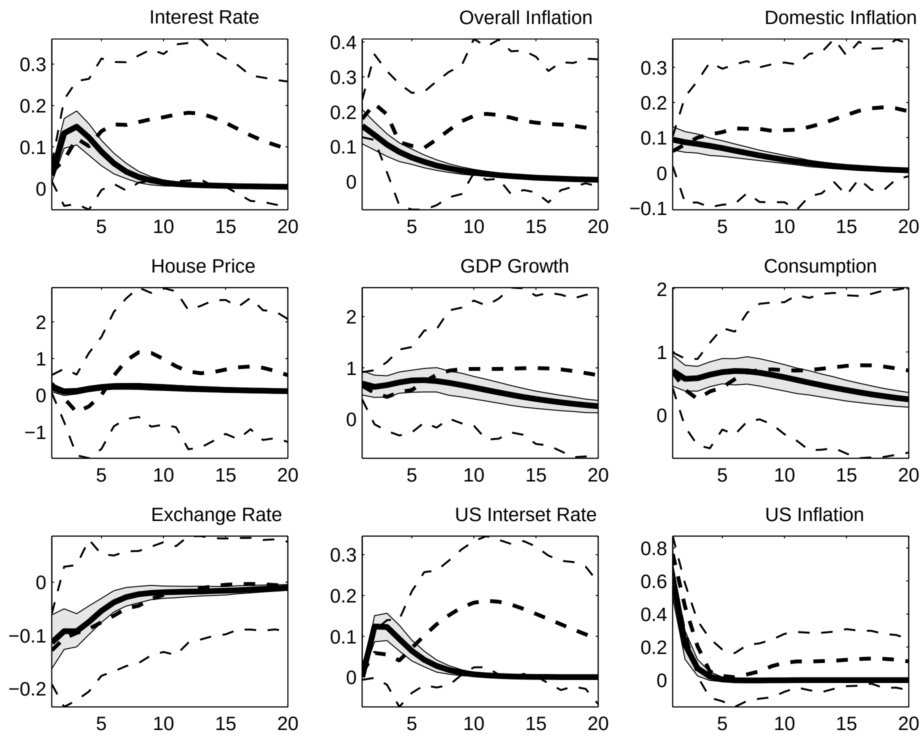


Table 3.1: Description of Parameters

Parameter	Description
α	Labor Share in production function
ϵ	Housing share in production function
$1-\alpha-\epsilon$	Capital share in production function
ϖ	Income share of patient household
j	Housing share in utility function
ψ	Capital adjustment cost parameter
δ	Capital depreciation rate
χ	Risk premium
ξ	Labor disutility of Hong Kong household
σ	Labor disutility of the U.S. household
m_1	LTV ratio of impatient household
m_2	LTV ratio of entrepreneur
β	Discount factor of Hong Kong patient household
β^m	Discount factor of Hong Kong impatient household
γ	Discount factor of Hong Kong entrepreneur
β^*	Discount factor of the U.S. household
κ	Import Share
η	Intratemporal substitutability between domestic and foreign goods
ε	Elasticity of substitution between varieties
θ_H	Sticky price probability of Hong Kong domestic producers
θ_F	Sticky price probability of Hong Kong import retailers
θ^*	Sticky price probability of the U.S. producers
ϕ_0	Taylor rule, exchange rate
ϕ_1	Taylor rule, inflation
ϕ_2	Taylor rule, output growth
λ	DSGE prior weight
$\frac{\bar{NX}}{\bar{Y}}$	Net export ratio to GDP in Hong Kong
$\frac{eB}{PY}$	Debt to GDP ratio in Hong Kong
$(\rho_A, \varepsilon_{A,t})$	Hong Kong technology shock
$(\rho_A^*, \varepsilon_{A,t}^*)$	U.S. technology shock
$(\rho_R, \varepsilon_{R,t})$	Hong Kong Taylor rule, smoothing
$(\rho_R^*, \varepsilon_{R,t}^*)$	U.S. Taylor rule, smoothing
$(\rho_{U_h}, \varepsilon_{H,t})$	Hong Kong domestic price cost push shock
$(\rho_{U_f}, \varepsilon_{F,t})$	Hong Kong import price cost push shock
$\varepsilon_{\vartheta,t}$	UIP shock
$(\rho_U, \varepsilon_{U,t})$	U.S. price cost push shock
$(\rho_j, \varepsilon_{j,t})$	Hong Kong household house preference shock
$(\rho_\zeta, \varepsilon_{\zeta,t})$	Risk premium shock

Table 3.2: Calibrated Parameters

Parameter	Value
α	0.64
ϵ	0.03
ϖ	0.3
j	0.12
ψ	2
δ	0.03
χ	0.054
m_2	0.89
m_1	0.55
X	1.15
β	0.99
β^m	0.95
γ	0.98
β^*	0.99
$\frac{e\bar{B}}{\bar{P}\bar{Y}}$	2
$\frac{N\bar{X}}{\bar{Y}}$	0.02

Table 3.3: Prior Densities and Posterior Estimates

	Prior				Posterior		
Parameter	Domain	Density	Para(1)[1]	Para(2)[2]	Mean	5 percent	95 percent
λ	Uniform	$[0, 2)$	1.000	0.5774	1.2885	1.1241	1.4512
ξ	Normal	$[0, +\infty)$	1.150	0.0500	1.1077	1.0172	1.1953
σ	Normal	$[0, +\infty)$	1.150	0.0500	1.1516	1.0602	1.2342
η	Normal	$[0, +\infty)$	1.800	0.1000	1.6951	1.5280	1.8539
κ	Beta	$[0, 1)$	0.300	0.0500	0.4023	0.3574	0.4403
θ_H	Beta	$[0, 1)$	0.650	0.1000	0.9221	0.9030	0.9435
θ_F	Beta	$[0, 1)$	0.650	0.1000	0.6300	0.5020	0.7375
θ^*	Beta	$[0, 1)$	0.750	0.1500	0.8635	0.7973	0.9301
ρ_A	Beta	$[0, 1)$	0.800	0.1000	0.9875	0.9792	0.9960
ρ_R	Beta	$[0, 1)$	0.250	0.0500	0.1704	0.1125	0.2305
ρ_{A^*}	Beta	$[0, 1)$	0.800	0.1000	0.9663	0.9433	0.9862
ρ_{R^*}	Beta	$[0, 1)$	0.750	0.1000	0.8372	0.8015	0.8773
ρ_ζ	Beta	$[0, 1)$	0.500	0.1000	0.4627	0.3230	0.6061
ρ_U	Beta	$[0, 1)$	0.500	0.1000	0.3829	0.2782	0.4890
ρ_{U_h}	Beta	$[0, 1)$	0.500	0.1000	0.2944	0.1945	0.3873
ρ_{U_f}	Beta	$[0, 1)$	0.500	0.1000	0.3980	0.2796	0.5320
ρ_j	Beta	$[0, 1)$	0.800	0.1000	0.9242	0.8951	0.9513
ϕ_1	Normal	$[0, +\infty)$	1.500	0.0500	1.3945	1.3166	1.4848
ϕ_2	Beta	$[0, 1)$	0.200	0.0500	0.4076	0.3267	0.4869
ϕ_0	Beta	$[0, 1)$	0.400	0.1000	0.3244	0.2314	0.4304
$\varepsilon_{A,t}$	Inv Gamma	$[0, +\infty)$	3.760	1.9654	5.4619	4.3179	6.4691
$\varepsilon^*_{A,t}$	Inv Gamma	$[0, +\infty)$	1.253	0.6551	1.1591	0.5686	1.8952
$\varepsilon_{R,t}$	Inv Gamma	$[0, +\infty)$	1.253	0.6551	0.5306	0.4321	0.6199
$\varepsilon^*_{R,t}$	Inv Gamma	$[0, +\infty)$	0.627	0.3276	0.2305	0.1880	0.2734
$\varepsilon_{H,t}$	Inv Gamma	$[0, +\infty)$	1.880	0.9827	0.5947	0.4933	0.7084
$\varepsilon_{F,t}$	Inv Gamma	$[0, +\infty)$	1.880	0.9827	1.1545	0.8183	1.5032
$\varepsilon_{U,t}$	Inv Gamma	$[0, +\infty)$	1.253	0.6551	0.4092	0.3411	0.4726
$\varepsilon_{\zeta,t}$	Inv Gamma	$[0, +\infty)$	5.539	1.6290	4.9522	3.7605	6.1765
$\varepsilon_{j,t}$	Inv Gamma	$[0, +\infty)$	12.475	2.0931	21.2686	16.0410	26.4573
$\varepsilon_{\vartheta,t}$	Inv Gamma	$[0, +\infty)$	1.253	0.6551	0.8191	0.6667	0.9566

[1] The mean of Uniform, Beta, Gamma, Normal and Inverse Gamma distribution.
[2] The standard deviation of Uniform, Beta, Gamma, Normal and Inverse Gamma distribution.

Table 3.4: Decomposition of Asymptotic Variance of Forecast Error

Variable	$\varepsilon_{j,t}$	$\varepsilon_{\vartheta,t}$	$\varepsilon_{U,t}$	$\varepsilon_{H,t}$	$\varepsilon_{F,t}$	$\varepsilon_{\zeta,t}$	$\varepsilon^*_{A,t}$	$\varepsilon^*_{R,t}$	$\varepsilon_{A,t}$	$\varepsilon_{R,t}$
$\hat{Y}_t$	0.55	8.52	3.95	10.32	0.08	0.03	25.90	3.94	46.25	0.46
$\hat{R}_t$	0.02	0.84	3.19	1.20	1.08	1.67	65.95	2.06	5.96	18.03
$\hat{\Gamma}_t$	0.17	6.03	2.77	7.48	0.09	0.02	17.99	2.87	62.22	0.35
$\hat{e}_t$	0.13	6.38	2.01	9.34	8.79	15.50	1.58	1.68	42.83	11.75
$\hat{Q}_t$	2.90	0.48	0.29	0.78	0.03	0.01	3.67	0.23	91.54	0.07
$\hat{\pi}_{H,t}$	0.01	0.90	1.08	28.69	0.00	0.00	51.83	0.05	17.44	0.00
$\hat{\pi}_{F,t}$	0.00	3.91	5.63	0.31	28.40	0.56	60.54	0.02	0.27	0.35
$\hat{\pi}_t$	0.00	2.51	3.28	10.23	9.70	0.19	69.82	0.03	4.11	0.12
$\hat{R}^*_t$	0.00	0.00	2.91	0.00	0.00	0.00	91.95	5.14	0.00	0.00
$\hat{Y}^*_t$	0.00	0.00	14.12	0.00	0.00	0.00	67.43	18.45	0.00	0.00
$\hat{\pi}^*_t$	0.00	0.00	19.79	0.00	0.00	0.00	80.12	0.09	0.00	0.00

CHAPTER 4

The Role of Credit and Financial Frictions in Economic Fluctuations

4.1 Introduction

The world has witnessed the aftermath of the Great Recession, which involved the collapse of large financial institutions, stock market crashes, and real economic effects, such as high unemployment, severe loss in output, and a slow economic recovery. The financial crisis had its roots in the boom and bust of the U.S. housing market in the 2000s, which led to a wave of foreclosures and a crisis in the subprime mortgage market. Many large U.S. banks suffered huge losses with some major players pushed into insolvency. As asset prices plummeted and risk increased, there were large declines in banking lending and liquidity, and substantial drops in aggregate demand and production, which led to further negative feedback loops in asset prices and in the soundness of financial institutions. The financial crises spread globally as the wave of bank failures and the plummet of assets spread around the world.

In the decades prior to the 2007-2009 financial crises, most macroeconomic models did not consider the role of financial intermediaries (see Christiano, Motto and Rostagno 2007, Lubik and Schorfheide 2005, Smets and Wouters 2005). This is related to the fact that introducing the banking sector into dynamic models can be technically difficult. In addition, the role of financial intermediaries was overlooked by many macroeconomists who considered the banking sector as a quantitatively irrelevant “veil”. The recent lessons from the U.S. financial crisis and from the Euro area sovereign debt crisis led to a surge in the interest in the role of banking and financial frictions. Dynamic models that incorporate financial intermediaries are the frontier of macroeconomic research.

This paper proposes an open economy Dynamic Stochastic General Equilibrium (DSGE) model that considers several financial and banking features in order to investigate the role of negative financial and credit shocks in economic fluctuations and crisis contagion from one region to another. The model also includes the potential effect of macroprudential policies in lessening business fluctuations. This is an important feature to consider as the U.S. Financial Crisis Inquiry Commission (2011) finds that the financial crisis could have been avoided if financial regulations were in place and enforced.

In the literature, an active banking system is incorporated into DSGE models with financial friction mainly according to the external finance premium in Bernanke, Gertler and Gilchrist(BGG, 1999) or the collateral constraint tied to real estate values for entrepreneurs in Iacoviello (2005). The banking sector plays two roles in the transmission of shocks to the real economy. On one hand, the banking accelerator effect works the same way as the amplification effect in the collateral constraint channel. On the other hand, the banking attenuator effect refers to a sluggish and heterogeneous pass-through of the change in the policy rate to the bank interest rate on the assumption of the monopolistic competitive banking sector.

Previous literature that considers the banking sector into DSGE models mainly focuses on the closed economy setting (e.g. Aslam and Santoro 2008, Dib 2010, Gerali et al 2008 and 2010, Iacoviello 2011). Recent papers have been discussed the banking sector in the open economy setting, but they are limited to small open economy settings. For example, Brzorza-Brzezina and Makarski (2011) study the effects of the recent credit crunch in the Euro area on the Poland economy. Beaton et al. (2010) find the important role of financial and real shocks by examining the propagation of U.S. shocks to Canada economic activity under a real-financial linkage.

However, our paper investigates the importance of the banking sector in the transmission of business cycles within and across two large economies: the U.S. and the Euro area. To our knowledge, this is the first attempt to consider several features in one dynamic model that allow the study of international transmission of financial and banking crises across regions.

We assume that the large economies set interest rates independently and there is a deviation from uncovered interest parity. In other words, interest rate differential does not follow a zero mean process. Hence, we assume an incomplete asset market in which the interest rate differential is related to the expected exchange rate depreciation and the difference of interest rate risk premiums between these two economies. Our open economy model also features export and import markets, pricing decisions of domestic producers and import retailers, and incomplete exchange rate pass-through (e.g. Lubik and Schorfheide 2005, and Justiniano and Preston 2010).

Our framework considers heterogeneous agents – patient and impatient households as savers and borrowers, respectively. The economies face various shocks, including financial or repayment shocks (see e.g. Iacoviello 2011) and credit shocks, originating in the banking sector (see e.g. Brzorza-Brzezina and Makarski 2011). The Great Recession has shown that losses suffered by financial institutions that own housing mortgages can lead to severe downturns in the economy. Hence, the introduction of financial shock allows us to understand the effects of credit losses originating in the housing sector on business cycles. Moreover, we incorporate two financial frictions through collateral constraints as proposed in Iacoviello (2005). The first friction is introduced to impatient households and entrepreneurs who are credit-constrained in how much they can borrow from banks. The loan demands for impatient households or entrepreneurs are constrained by the value of housing collateral, or the value of housing and physical capital collateral. The second friction considered is that banks are credit-constrained in how much they can collect from patient households. An amplification of economic fluctuations is created through collateral constraints.

Our proposed banking sector emphasizes the credit channel in the propagation of business cycles. Banks provide credit for the global economic activity through the banking lending channel, which leads to frictions deriving from the balance sheet situation of banks. We assume a monopolistic competitive banking sector that adjusts bank interest rates following staggered price setting (see Calvo 1983)[1]. We not only allow banks to have the power to set the lending rate, but also the power to set the deposit rate. Monopolistic competition introduces a steady-state wedge between bank interest rates and policy rate, which creates time-varying spreads between interest rates. Banks collect deposits from patient households and deposit them into banks through the interbank market. Meanwhile, banks issue loans to impatient households (sub-primers) and

[1]We also consider a version of our model in which bank interest rates are assumed instead to be flexible.

entrepreneurs. Bankers, as the sole owners of banks, receive all profits from intermediation activity and only invest in the bank capital.

In particular, we assume that macroprudential policy is coordinated with monetary policy to examine its effect on the economy, especially under U.S. financial shocks. Macroprudential measures entail higher cost that is passed onto borrowers in the form of higher lending rate as proposed in Kannan, Rabanal and Scott (2009) and Quint and Rabanal (2011).

Using data for the United States and the Euro area, we estimate the model using Bayesian techniques to investigate the role of the banking sector and macroprudential policies in the propagation of business cycles. The model particularly allows analysis of the importance of credit and financial shocks in explaining economic fluctuations in the U.S. and in the Euro area. This paper also evaluates the model forecast accuracy of output growth during the Great Recession.

Several findings stand out. First, the banking channel is an important facet of the dynamics of the economy, as found in recent literature (e.g. Gerali et al. 2010, Goodfriend and McCallum 2007, Andres and Arce 2008, Aslam and Santoro 2008 and Christiano et al. 2007). The banking sector acts to dampen the impact of the amplification effect created by collateral constraint under national monetary policy shock while it magnifies national technology and financial shocks. Additionally, the banking sector propagates the transmission of shocks across the U.S. and the Euro area. Second, we find that credit and financial shocks are important sources of macroeconomic fluctuations in the U.S. and in the Euro area. Third, macroprudential measures attenuate the effects of U.S. financial shocks on the U.S. and Euro area economies.

Finally, this paper revisits the forecasting performance of New Keynesian DSGE model. Smets and Wouters (2007) find that DSGE model has a comparable or slightly superior forecast performance relative to competing frameworks such as vector autoregressive (VAR) and Bayesian VAR models. Numerous papers have since studied the forecasting ability of DSGE models. Recently, Del Negro and Schorfheide (2012) and Chauvet, Lu and Potter (2012), examine the real time forecast ability of DSGE models in the Great Recession. Differently from previous literature, this paper highlights the role of financial shocks, banking and financial frictions in explaining the variability of future output growth. The results suggest that out-of-sample forecasts from our proposed model with banks outperform a model without banks during the Great Recession.

The rest of the paper is organized as follows. Section 4.2 describes the model framework. Section 4.3 covers priors and posteriors of the Bayesian estimation. Section 4.4 explains the results as illustrated by impulse response functions. Section 4.5 reports variance decomposition. Section 4.6 goes on to discuss macroprudential policy tools, and session 4.7 reports out-of-sample forecasting. Session 4.8 concludes.

4.2 Model Framework

Here we present the home economy block (the United States). The foreign economy block (the Euro area) has a similar structure and to save space is not presented. Figure 4.1 depicts the summary of the model structure.

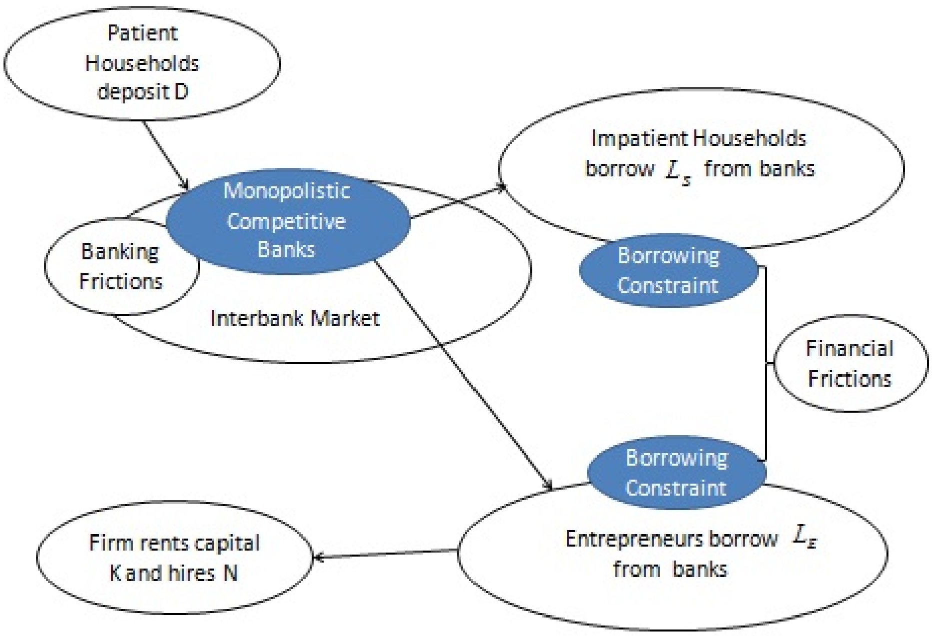


Figure 4.1: The Summary of Model Structure

There are eight agents in each economy: patient households, impatient households, entrepreneurs, banks, firms, capital producers, government and central bank. Patient households work, consume, buy houses and deposit resources into banks. Impatient households (subprimers) also work, consume and buy houses. They do not save but borrow from banks subject to a collateral constraint. Entrepreneurs borrow from banks to accumulate physical capital and housing subject to a collateral constraint and supply intermediate goods to final good firms. Firms produce final goods and provide them to the agents. Capital producers accumulate capital and produce investment. Banks are monopolistic competitive. Central bank sets the policy rate. Government spending is exogenous. We assume capital and labor are immobile across these two economies. International financial intermediaries borrowing and lending are allowed. Therefore, the linkages between these two economies are international trade, relative price movements, international borrowing and lending and exchange rate.

4.2.1 Patient Households

Patient households are characterized by a higher intertemporal discount factor than other agents in the economy and act as savers (indexed by P). They choose consumption C, housing H, deposits D, and time spent working hours N to solve the following intertemporal problem:

$$E_t\{\sum_{i=0}^{\infty}(\beta_P)^i[logC_{P,t+i} + jlogH_{P,t+i} - \frac{(N_{P,t+i})^{\tau}}{\tau}]\}$$

subject to the flow-of-funds constraint:

$$P_tC_{P,t} + D_t + Q_t(H_{P,t} - H_{P,t-1}) = R_{P,t-1}D_{t-1} + W_{P,t}N_{P,t} \tag{4.1}$$

$\Rightarrow$

$$C_{P,t} + d_t + q_t(H_{P,t} - H_{P,t-1}) = R_{P,t-1}d_{t-1}/\pi_t + w_{P,t}N_{P,t} \tag{4.2}$$

where β_P is intertemporal discount factor; $C_{P,t}$ is the composite consumption of patient households, which consists of domestically produced goods and imported goods; D_t denotes deposits with a gross earning return $R_{P,t}$; π_t is composite price index; q_t is real house price; j is the weight on housing in the utility function and τ is labor disutility. $w_{P,t}$ is real wage rate. Housing does not depreciate.

The flow-of-funds constraint suggests that patient households pay for their consumption expenditures in goods and houses with the net return of deposits and the net receipt from the supply for labor to firms. Let λ_t^P be the Lagrange multiplier on the budget constraint. We obtain first order conditions with respect to $C_{P,t}, d_t, N_{P,t}, H_{P,t}$:

$$\frac{1}{C_{P,t}} = \lambda_t^P \tag{4.3a}$$

$$\lambda_t^P = \beta_P R_{P,t} \lambda_{t+1}^P / \pi_{t+1} \tag{4.3b}$$

$$w_{P,t} \lambda_t^P = (N_{P,t})^{\tau-1} \tag{4.3c}$$

$$q_t \lambda_t^P = j/H_{P,t} + \beta_P E_t q_{t+1} \lambda_{t+1}^P \tag{4.3d}$$

Equation (4.3a) and (4.3b) give the Euler equation. (4.3c) and (4.3d) determine the supply for labor and the demand for housing, respectively.

4.2.2 Impatient Households

Impatient households (subprimers) indexed by S consume goods and houses and work. They do not save but borrow money from banks to a fraction of the value of their house holdings. They face the following maximization problem:

$$E_t\{\sum_{i=0}^{\infty}(\beta_S)^i[logC_{S,t+i} + jlogH_{S,t+i} - \frac{(N_{S,t+i})^\tau}{\tau}\}$$

subject to the flow-of-funds constraint:

$$P_t C_{S,t} + Q_t(H_{S,t} - H_{S,t-1}) + R_{S,t-1} L_{S,t-1} - \upsilon_t = L_{S,t} + W_{S,t} N_{S,t} \tag{4.4}$$

$\Rightarrow$

$$C_{S,t} + q_t(H_{S,t} - H_{S,t-1}) + R_{S,t-1} l_{S,t-1}/\pi_t - \upsilon_t = l_{S,t} + w_{S,t} N_{S,t} \tag{4.5}$$

and borrowing constraint:

$$R_{S,t} L_{S,t} \leq E_t(m_S Q_{t+1} H_{S,t}) \tag{4.6}$$

$\Rightarrow$

$$R_{S,t} l_{S,t} \leq E_t(m_S \pi_{t+1} q_{t+1} H_{S,t}) \tag{4.7}$$

where β_S is the discount factor that is strictly lower than β_P; $C_{S,t}$ is the composite consumption of impatient households, which consists of domestically produced goods and imported goods; τ is labor disutility; $L_{S,t}$ denotes (one-period) loans made to subprimers, paying a gross interest rate $R_{S,t}$. m_S denotes the loan-to-value (LTV) ratio in housing. We assume the LTV ratio is constant. The term υ_t is an exogenous financial shock (repayment shock). If the repayment shock is negative (positive), impatient households need to pay less(more) back to banks than they are obligated, suggesting a positive(negative) shock to impatient households' wealth because it allows impatient households to spend more than previously anticipated.

The borrowing constraint ties the limit of borrowing to the present discounted value of housing holdings. The maximum amount $l_{S,t}$ that the creditor (borrower) can borrow is bounded by $E_t(\frac{1}{R_{S,t}} m_S \pi_{t+1} q_{t+1} H_{S,t})$. A binding constraint means the present value of the housing holdings is greater than the interest rate $R_{S,t}$ in the steady state. At the same time, impatient households will not postpone consumption and quickly accumulate wealth. Under this circumstance, they are completely self-financed and the borrowing constraint becomes nonbinding. As discussed in Iacoviello (2005), the collateral constraint channel can potentially act to accelerate the shocks similar to the financial accelerator in BGG (1999). For example, when a looser monetary policy stimulates asset prices, the value of housing holdings increases, which means that borrowers are capable of borrowing more. A powerful amplification mechanism is created through collateral constraint because constrained impatient households value current consumption more than future consumption, and their borrowing capacity and consumption are increasing more than proportionally.

Let $\lambda_{S,t}$ be the Lagrange multiplier on the borrowing constraint and λ_t^S be the Lagrange multiplier on the flow-of-funds constraint. First order conditions with respect to $C_{S,t}, l_{S,t}, N_{S,t}, H_{S,t}$ are derived as follows:

$$\frac{1}{C_{S,t}} = \lambda_t^S \tag{4.8a}$$

$$\lambda_t^S = \beta_S R_{S,t} E_t \lambda_{t+1}^S / \pi_{t+1} + \lambda_{S,t} R_{S,t} \tag{4.8b}$$

$$w_{S,t} \lambda_t^S = (N_{S,t})^{\tau-1} \tag{4.8c}$$

$$q_t \lambda_t^S = j/H_{S,t} + \beta_S E_t q_{t+1} \lambda_{t+1}^S + E_t(\lambda_{S,t} \pi_{t+1} m_S q_{t+1}) \tag{4.8d}$$

Equation (4.8a) and (4.8b) give the Euler equation. (4.8c) and (4.8d) determine the labor supply and the demand for housing, respectively.

4.2.3 Entrepreneurs

Entrepreneurs (indexed by E) only care about their own consumption and maximize the following expected utility function:

$$E_t\{\sum_{i=0}^{\infty}(\beta_E)^i[logC_{E,t+i}]\}$$

subject to the flow-of-funds constraint:

$$\begin{aligned} P_tC_{E,t} + Z_t(K_{E,t} - (1-\delta)K_{E,t-1}) + Q_t(H_{E,t} - H_{E,t-1}) + R_{E,t-1}L_{E,t-1} \\ = L_{E,t} + R_{K,t}K_{E,t-1} + R_{V,t}Q_tH_{E,t-1} \end{aligned} \tag{4.9}$$

$\Rightarrow$

$$\begin{aligned} C_{E,t} + z_t(K_{E,t} - (1-\delta)K_{E,t-1}) + q_t(H_{E,t} - H_{E,t-1}) + R_{E,t-1}l_{E,t-1}/\pi_t \\ = l_{E,t} + r_{K,t}K_{E,t-1} + R_{V,t}q_tH_{E,t-1} \end{aligned} \tag{4.10}$$

and borrowing constraint:

$$L_{E,t}R_{E,t} \leq E_t(m_HQ_{t+1}H_{E,t}) + m_KZ_{t+1}(1-\delta)K_{E,t} \tag{4.11}$$

$\Rightarrow$

$$l_{E,t}R_{E,t} \leq E_t(m_H\pi_{t+1}q_{t+1}H_{E,t}) + m_K\pi_{t+1}z_{t+1}(1-\delta)K_{E,t} \tag{4.12}$$

where β_E is the discount factor that is strictly lower than β_P; $C_{E,t}$ is composite consumption of entrepreneurs, which consists of domestically produced goods and imported goods; $L_{E,t}$ denotes (one-period) loans made to entrepreneurs, paying a gross interest rate $R_{E,t}$. Capital depreciates at rate δ. m_H denotes the loan-to-value (LTV) ratio in housing and m_K denotes the loan-to-value (LTV) ratio to capital. As in Iacoviello (2011), a limit on the obligation of the entrepreneurs is different from the one on impatient households. Entrepreneurs not only accumulate physical capital rented to firms at the rate $R_{K,t}$ but also accumulate housing rented to firms at the rate $R_{V,t}$. Z_t is the price of installed capital. The maximum amount $l_{E,t}$ that entrepreneur can borrow is bound by $\frac{1}{R_{E,t}}[E_t(m_H q_{t+1}\pi_{t+1}H_{E,t}) + m_K z_{t+1}\pi_{t+1}(1-\delta)K_{E,t}]$.

Let $\lambda_{E,t}$ be the Lagrange multiplier on the borrowing constraint and λ_t^E be the Lagrange multiplier on the flow-of-funds constraint. First order conditions with respect to $C_{E,t}, l_{E,t}, K_{E,t}, H_{E,t}$ are

$$\frac{1}{C_{E,t}} = \lambda_t^E \tag{4.13a}$$

$$\lambda_t^E = \beta_E R_{E,t} E_t \lambda_{t+1}^E/\pi_{t+1} + \lambda_{E,t} R_{E,t} \tag{4.13b}$$

$$-m_K(1-\delta)E_t(\lambda_{E,t} z_{t+1}\pi_{t+1}) + \lambda_t^E z_t = \beta_E E_t[r_{K,t+1} + (1-\delta)z_{t+1}]\lambda_{t+1}^E \tag{4.13c}$$

$$q_t\lambda_t^E - E_t(\lambda_{E,t} m_H \pi_{t+1} q_{t+1}) = \beta_E E_t(q_{t+1}(1+R_{V,t+1})\lambda_{t+1}^E) \tag{4.13d}$$

Equation (4.13a) and (4.13b) give the Euler equation. (4.13c) and (4.13d) determine the capital supply and housing demand, respectively.

4.2.4 Financial Intermediation and Banking

In this section, we emphasize the role of the bank lending channel which is essentially the balance sheet channel. One of the transmission mechanisms of business cycles to the real economy is through the bank lending channel that highlights the importance of liabilities on the balance sheet of financial intermediaries.

Three features are introduced into the banking system. First, banks are heterogenous profit-maximizing and intermediate all the transactions among households and entrepreneurs. Second, reserve requirement is incorporated by assuming banks typically fund a fraction of their loans with liabilities (such as deposits). Third, we introduce the sticky interest rate setting, which means that changes in the central bank interest rate may not be fully reflected in the interest rates that banks offer their consumers. The monopolistic competition assumption allows us to study the implication of the market power of banks in conducting their intermediation activity, and thus the imperfect interest rate pass-through that affects the transmission of shocks. In particular, we assume that there are exogenous disturbances to the spreads on deposits and loans which arise independently of monetary policy.

Deposit and Loan Demand

We assume that deposits, loans to households and loans to entrepreneurs are a composite basket of slightly differentiated products, which are supplied by bank j with elasticities of substitution ε_d, ε_{bS} and ε_{bE}, respectively. ε_d, ε_{bS} and ε_{bE} are assumed to be constant.

Banks collect deposits from patient households through the interbank market. Bank j operates in a competitive environment, takes the deposit rate as given and chooses $D_t(j)$ to maximize the following expression

$$\max \int_0^1 D_t(j) R_{P,t}(j) dj$$

subject to the technology for aggregation

$$D_t \leq [\int_0^1 D_t(j)^{\frac{\varepsilon_d - 1}{\varepsilon_d}} dj]^{\frac{\varepsilon_d}{\varepsilon_d - 1}}$$

Banks issue loans to impatient households and entrepreneurs. Impatient households choose $L_{S,t}(j)$ to minimize the total repayment

$$\min \int_0^1 R_{S,t}(j) L_{S,t}(j) dj$$

subject to the technology of aggregation:

$$L_{S,t} \leq [\int_0^1 L_{S,t}(j)^{\frac{\varepsilon_{bS} - 1}{\varepsilon_{bS}}} dj]^{\frac{\varepsilon_{bS}}{\varepsilon_{bS} - 1}}$$

Similarly, entrepreneurs allocate their borrowing $L_{E,t}(j)$ to minimize their total repayment.

The deposit and lending rates are defined as:

$$R_{P,t} = (\int_0^1 R_{P,t}(j)^{1-\varepsilon_d} dj)^{\frac{1}{1-\varepsilon_d}} \tag{4.14a}$$

$$R_{S,t} = (\int_0^1 R_{S,t}(j)^{1-\varepsilon_{bS}} dj)^{\frac{1}{1-\varepsilon_{bS}}} \tag{4.14b}$$

$$R_{E,t} = (\int_0^1 R_{E,t}(j)^{1-\varepsilon_{bE}} dj)^{\frac{1}{1-\varepsilon_{bE}}} \tag{4.14c}$$

We solve the above problem and obtain deposits and loans:

$$D_t(j) = (\frac{R_{P,t}(j)}{R_{P,t}})^{-\varepsilon_d} D_t \tag{4.15a}$$

$$L_{S,t}(j) = (\frac{R_{S,t}(j)}{R_{S,t}})^{-\varepsilon_{bS}} L_{S,t} \tag{4.15b}$$

$$L_{E,t}(j) = (\frac{R_{E,t}(j)}{R_{E,t}})^{-\varepsilon_{bE}} L_{E,t} \tag{4.15c}$$

Banks

We next derive optimal relations for deposit supply and loan supply by profit-maximizing banks. Banks decide interest rates subject to a binding balance sheet constraint. As in Calvo (1983), each bank resets interest rates only with a probability $1-\theta_i$ where $i \in D, E, S$ each period, independently of the time elapsed since the last adjustment. Thus, each period a fraction $1-\theta_i$ of banks reset interest rates, while a fraction θ_i of banks keep their rates unchanged. The deposit and loan rates are given by:

$$R_{P,t} = [\theta_D R_{P,t-1}^{1-\varepsilon_d} + (1-\theta_D)(\tilde{R}_{P,t})^{1-\varepsilon_d}]^{\frac{1}{1-\varepsilon_d}} \tag{4.16a}$$

$$R_{E,t} = [\theta_E R_{E,t-1}^{1-\varepsilon_{bE}} + (1-\theta_E)(\tilde{R}_{E,t})^{1-\varepsilon_{bE}}]^{\frac{1}{1-\varepsilon_{bE}}} \tag{4.16b}$$

$$R_{S,t} = [\theta_S R_{S,t-1}^{1-\varepsilon_{bS}} + (1-\theta_S)(\tilde{R}_{S,t})^{1-\varepsilon_{bS}}]^{\frac{1}{1-\varepsilon_{bS}}} \tag{4.16c}$$

Where $\tilde{R}_{P,t}, \tilde{R}_{E,t}, \tilde{R}_{S,t}$ are deposit rate and loan rates to entrepreneurs and impatient households chosen by banks who are able to adjust.

The profit for the jth bank is calculated by

$$R_{E,t}(j)L_{E,t}(j) + R_{S,t}(j)L_{S,t}(j) + R_{IB,t}B_{IB,t}(j) - R_{P,t}(j)D_t(j)$$

Where $B_{IB,t}(j)$ captures the net position of the jth bank on the interbank market, and $R_{IB,t}$ is the interbank lending rate and equals the policy rate.

Banks can finance their loans using either deposits or bank capital[2]. The bank balance sheet identity is

$$K_{B,t}(j) + (1 - rr)D_t(j) + X_{CB,t}(j) = L_{E,t}(j) + L_{S,t}(j) + B_{IB,t}(j) \tag{4.17}$$

The jth bank obtains funding as follows. First, it receives cash injection $X_{CB,t}(j) = rrD_t(j)$ from the central bank where rr is the reserve requirement; second, it obtains funds from the interbank market; third, the bank receives deposits from patient households; fourth, it raises funds from bankers (shareholders) in the form of equity (bank capital $K_{B,t}$).

Maximization to bank j's profit is subject to the balance sheet identity. Let λ_t^B be the multiplier on the balance sheet constraint. We retrieve the following first order conditions:

$$R_{IB,t} = \lambda_t^B$$

$$R_{P,t} = (1 - rr)\lambda_t^B$$

$$E_t \sum_{k=0}^{\infty} (\theta_D)^k \Lambda_{k,t+k} [\frac{\tilde{R}_{P,t}(j)}{\lambda_{t+k}^B} + \frac{\varepsilon_d}{\varepsilon_d - 1}] D_{t+k}(j) = 0$$

$$E_t \sum_{k=0}^{\infty} (\theta_S)^k \Lambda_{k,t+k} [\frac{\tilde{R}_{S,t}(j)}{\lambda_{t+k}^B} - \frac{\varepsilon_{bS}}{\varepsilon_{bS} - 1}] L_{S,t+k}(j) = 0$$

$$E_t \sum_{k=0}^{\infty} (\theta_E)^k \Lambda_{k,t+k} [\frac{\tilde{R}_{E,t}(j)}{\lambda_{t+k}^B} - \frac{\varepsilon_{bE}}{\varepsilon_{bE} - 1}] L_{E,t+k}(j) = 0$$

Linearizing the first order conditions with respect to $R_{P,t}, R_{S,t}, R_{E,t}$ and combining them with the deposit and loan rates, we obtain the interest rate setting curves

[2]Capital-to-asset ratio is $1 - \gamma$. $\frac{1}{1-\gamma}$ denotes the bank's leverage ratio. As long as γ is less than one, the return of loans is higher than the cost of deposits and loans are less liquid than deposits. Capital requirement constraint implies that banks cannot hold a capital-to-asset ratio greater than or equal to some predetermined ratio. If γ is larger, the liquidity of loans for banks is higher and the compensation required for banks is smaller between lending and borrowing. A lower leverage ratio means the bank is well capitalized and relatively less risky so that they pay less cost when raising capital. The capital-to-asset ratio $K_{B,t}/(L_{E,t} + L_{S,t})$ moves away from an "optimal" value $1 - \gamma$. The "optimal" capital to asset ratio is set equal to 0.09 in our experiments.

for banks:

$$(\hat{R}_{P,t} - \hat{R}_{P,t-1}) = \beta_B(\hat{R}_{P,t+1} - \hat{R}_{P,t}) + \frac{(1-\beta_B\theta_D)(1-\theta_D)}{\theta_D}(-\hat{R}_{P,t} + \hat{R}_t + \hat{Z}_{D,t}) \quad (4.18)$$

$$(\hat{R}_{E,t} - \hat{R}_{E,t-1}) = \beta_B(\hat{R}_{E,t+1} - \hat{R}_{E,t}) + \frac{(1-\beta_B\theta_E)(1-\theta_E)}{\theta_E}(-\hat{R}_{E,t} + \hat{R}_t + \hat{Z}_{E,t}) \quad (4.19)$$

$$(\hat{R}_{S,t} - \hat{R}_{S,t-1}) = \beta_B(\hat{R}_{S,t+1} - \hat{R}_{S,t}) + \frac{(1-\beta_B\theta_S)(1-\theta_S)}{\theta_S}(-\hat{R}_{S,t} + \hat{R}_t + \hat{Z}_{S,t}) \quad (4.20)$$

Where $\hat{Z}_{D,t}$, $\hat{Z}_{E,t}$ and $\hat{Z}_{S,t}$ are the shocks to the spread on deposits and loans (credit shocks), which follow AR(1) process. These shocks respond to the cyclical conditions in the real economy and build up a useful channel to show how the shocks originating in the banking sector affect the real economy.

Using the analytical formula of the steady state of loan and deposit rates, we derive bank spreads as follows

$$\frac{s_E^L}{R_P} = \frac{1-(\varepsilon_{bE}-1)rr}{(\varepsilon_{bE}-1)(1-rr)} \quad (4.21a)$$

$$\frac{s_S^L}{R_P} = \frac{1-(\varepsilon_{bS}-1)rr}{(\varepsilon_{bS}-1)(1-rr)} \quad (4.21b)$$

Where $s_E^L \equiv R_E - R_P$ denote the spread between interest rates faced by patient households and entrepreneurs and $s_S^L \equiv R_S - R_P$ denote the spread between interest rates faced by patient households and impatient households. The bank spreads are affected by the value of ε_{bE}, ε_{bS} and ε_d .We can find $0 \leq rr < (1-(\frac{\varepsilon_{bE}}{\varepsilon_{bE}-1}))$ or $0 \leq rr < (1-(\frac{\varepsilon_{bS}}{\varepsilon_{bS}-1}))$, given the endogenous interest rate spread generated by the banking sector.

Bankers

Bankers, as the sole owners of banks, get all profits from intermediation activity and only invest in the bank capital. Bank capital is accumulated each period according to

$$P_tC_{B,t} + (K_{B,t} - (1-\delta_b)K_{B,t-1}) = \Omega_t^B \tag{4.22}$$

Where δ_b denotes the resources used in managing bank capital and conducting the overall banking intermediation activity. Ω_t^B is the overall profit made by all the banks in nominal term and $C_{B,t}$ is the banker's consumption and equals to $R_{E,t-1}L_{E,t-1} + R_{S,t-1}L_{S,t-1} - R_{P,t-1}D_{t-1} + D_t - L_{E,t} - L_{S,t} - v_t$.

4.2.5 Firms

Entrepreneurs

Entrepreneurs choose the optimal stock of physical capital, the desired amount of labor input and the optimal stock of housing to provide intermediate goods to final-goods producing firms. Entrepreneurs operate a standard constant-returns-to-scale technology according to the following production function:

$$Y_t(j) = A_tA_{W,t}K^{\alpha}_{E,t-1}(j)H^{\upsilon}_{E,t-1}(j)N_{P,t}^{(1-\alpha-\upsilon)(1-\sigma)}(j)N_{S,t}^{(1-\alpha-\upsilon)\sigma}(j)$$

where A_t is the country-specific technology; $A_{W,t}$ is the world-wide technology; we define $\varpi_t = A_{W,t}/A_{W,t-1}$ and ω is the steady state growth rate of $A_{W,t}$; $j \in [0,1]$ denotes good variety.

Entrepreneur j chooses $K_{E,t-1}(j)$, $H_{E,t-1}(j)$, $N_{P,t}(j)$, and $N_{S,t}(j)$ to minimize total cost, given by

$$W_{P,t}N_{P,t}(j)/P_t + W_{S,t}N_{S,t}(j)/P_t + R_{K,t}K_{E,t-1}(j)/P_t + R_{V,t}q_tH_{E,t-1}(j)$$

subject to

$$A_tA_{W,t}K^{\alpha}_{E,t-1}(j)H^{\upsilon}_{E,t-1}(j)N_{P,t}^{(1-\alpha-\upsilon)(1-\sigma)}(j)N_{S,t}^{(1-\alpha-\upsilon)\sigma}(j) - Y_t(j) \geq 0$$

Let MC_t denote the Lagrange multiplier. MC_t is real marginal cost (the inverse of mark-up).

First order conditions with respect to $K_{E,t-1}, H_{E,t-1}, N_{P,t}, N_{S,t}$ are given by

$$\alpha Y_t(j) MC_t = R_{K,t} K_{E,t-1}(j)/P_t \tag{4.23a}$$

$$\upsilon Y_t(j) MC_t = R_{V,t} q_t H_{E,t-1}(j)/P_t \tag{4.23b}$$

$$(1-\alpha-\upsilon)(1-\sigma) Y_t(j) MC_t = W_{P,t} N_{P,t}(j)/P_t \tag{4.23c}$$

$$(1-\alpha-\upsilon)\sigma Y_t(j) MC_t = W_{S,t} N_{S,t}(j)/P_t \tag{4.23d}$$

Final Good Producers

Firms in the final good sector use intermediate goods $Y_t(j)$ from entrepreneurs to produce a homogeneous good, Y_t. The production function that transforms intermediate goods into final goods is

$$Y_t = \{\int_0^1 [Y_t(j)]^{\frac{\varepsilon-1}{\varepsilon}} dj\}^{\frac{\varepsilon}{\varepsilon-1}}$$

where $\varepsilon > 1$.

Aggregate production function is defined as

$$Y_t = A_t A_{W,t} K_{E,t-1}^{\alpha} H_{E,t-1}^{\upsilon} N_{P,t}^{(1-\alpha-\upsilon)(1-\sigma)} N_{S,t}^{(1-\alpha-\upsilon)\sigma} \tag{4.24}$$

where $K_{E,t} = \int_0^1 K_{E,t}(j)dj$, $H_{E,t} = \int_0^1 H_{E,t}(j)dj$ $N_{S,t} = \int_0^1 N_{S,t}(j)dj$ and $N_{P,t} = \int_0^1 N_{P,t}(j)dj$.

4.2.6 Labor Market

We assume a continuum of labor types and one union for each labor type which is representative of the whole household population, i.e. patient and impatient households. Each household sells its labour $N_t(j)$ to firms. Firms transform households' labour into a homogenous input good N_t using the following production function:

$$N_t = [\int_0^1 (N_t(j))^{\frac{\lambda_w-1}{\lambda_w}})dj]^{\frac{\lambda_w}{\lambda_w-1}}$$

where λ_w is wage make up and $1 \leq \lambda_w < \infty$. The labour demand of an individual household is determined by

$$N_t(j) = [\frac{W_t(j)}{W_t}]^{-\lambda_w} N_t$$

where

$$N_t = (N_{P,t})^{(1-\sigma)} (N_{S,t})^{\sigma}$$

$$W_t = [\int_0^1 (W_t(j))^{1-\lambda_w}) dj]^{\frac{1}{1-\lambda_w}}$$

In every period households can change their nominal wage with a random probability $1-\theta_w$. The jth household's reoptimized wage is set to $\tilde{W}_t(j)$. Households who do not reoptimize their wage follow:

$$W_t(j) = [(1-\xi_w)\tilde{\pi} + \xi_w \pi_{t-1}] W_{t-1}(j)$$

where $\tilde{\pi}$ is the steady state inflation rate.

In equilibrium, the labor choice for each single household in the economy is determined by the non-linear wage Phillips curve and the log-linearized wage equation is defined as

$$\begin{aligned} \frac{\theta_w}{1-\theta_w}(\hat{W}_t - \hat{W}_{t-1} + \hat{\pi}_t - \xi_w \hat{\pi}_{t-1}) = & \frac{1-\beta_U \theta_w}{1+(\tau-1)\lambda_w}[(\tau-1)\hat{N}_t - \hat{U}_{C,t} + u_{n,t} - \hat{W}_t] \\ & + \frac{\beta_U \theta_w}{1-\theta_w}(E_t \hat{W}_{t+1} - \hat{W}_t + E_t \hat{\pi}_{t+1} - \xi_w \hat{\pi}_t) \end{aligned} \tag{4.25}$$

Where $\hat{N}_t = \sigma \hat{N}_{S,t} + (1-\sigma)\hat{N}_{P,t}$. The discount factor is $\beta_U = (1-\sigma)\beta_P + \sigma\beta_S$. $\hat{U}_{C,t}$ is the consumption from patient and impatient households and $u_{n,t} = \rho_u u_{n,t-1} + \varepsilon_{n,t}$ where $\varepsilon_{n,t}$ is the wage mark up shock.

4.2.7 Capital Producers

The accumulation of physical capital stock is given by

$$\Theta_t F(I_t, I_{t-1}) = K_t - (1-\delta)K_{t-1} \tag{4.26}$$

Where Θ_t is a stationary investment specific shock, given by an AR(1) process $\hat{\Theta}_t = \rho_I \hat{\Theta}_{t-1} + \varepsilon_{I,t}$. $F(I_t, I_{t-1})$ is the function that turns investment into the physical capital. Similar to Aldofson et al (2007), we assume that

$$F(I_t, I_{t-1}) = (1 - S(\frac{I_t}{I_{t-1}}))I_t$$

where $S^{''}(\Psi_I) > 0$ and $S(\Psi_I) = S^{'}(\Psi_I) = 0$.

The log linearized investment equation is

$$\hat{I}_t = \frac{1}{1+\beta}\hat{I}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{I}_{t+1} + \frac{1/\Psi_I}{1+\beta}\hat{z}_t + \hat{\Theta}_t \tag{4.27}$$

We derive the log-linearized capital accumulation equation as a function of the flow of investment and the relative efficiency of these investment expenditures captured by an investment specific shock Θ_t:

$$\hat{K}_t = (1-\delta)\hat{K}_{t-1} + \delta\hat{I}_{t-1} + \delta\hat{\Theta}_t \tag{4.28}$$

4.2.8 Government and Central Bank

We assume that the central bank interest rate is equal to the interbank interest rate, that is $R_t = R_{IB,t}$. Central bank supplies all the demanded amount of funds in excess of the net liquidity position in the interbank market and sets the interest rate prevailing in the interbank market. The central bank interest rate follows

$$R_t = R^{(1-\rho_R)} R_{t-1}^{\rho_R} (\frac{\pi_t}{\pi})^{\phi_\pi(1-\rho_R)} (\frac{Y_t}{Y_{t-1}})^{\phi_y(1-\rho_R)} (\frac{\Delta E_t}{\Delta E})^{\phi_e(1-\rho_R)} \varepsilon_{R,t} \tag{4.29}$$

where ϕ_y, ϕ_π and ϕ_e are the weights assigned to output gap, inflation stabilization and exchange rate. R is the steady state of nominal interest rate and $\varepsilon_{R,t}$ is an exogenous shock to monetary policy and $\varepsilon_{R,t} \sim N(0, \sigma_R^2)$. Y_t denotes GDP.

Government spending is

$$\hat{G}_t = \rho_G \hat{G}_{t-1} + \varepsilon_{G,t} \tag{4.30}$$

where $\varepsilon_{G,t}$ is an exogenous shock to government spending and $\varepsilon_{G,t} \sim N(0, \sigma_G^2)$.

4.2.9 Open Economy Feature

Export and Import Market

Composite consumption in domestic economy Γ_t is assumed to be a CES index of domestically produced and imported goods according to

$$\Gamma_t = [(1-\kappa)^{\frac{1}{\eta}}(\Gamma_{H,t})^{\frac{\eta-1}{\eta}} + \kappa^{\frac{1}{\eta}}(\Gamma_{F,t})^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}}$$

where $\Gamma_{H,t}$ is the consumption of domestically produced goods and $\Gamma_{F,t}$ is the consumption of imported goods. $0 \leq \kappa < 1$ is inversely related to the degree of home bias in preferences, or import share and $\eta > 0$ is the intratemporal substitutability between domestic and foreign goods. Notice that if κ equals to zero, the economy is closed and there is no international trade.

Composite price index P_t is given by

$$P_t = [(1-\kappa)(P_{H,t})^{1-\eta} + \kappa(P_{F,t})^{1-\eta}]^{\frac{1}{1-\eta}}$$

where $P_{H,t}$ is the price index of domestically produced goods and $P_{F,t}$ is the price index of goods imported from foreign economy.

The optimal allocations of expenditures between domestic and imported goods are

$$\Gamma_{H,t} = (1-\kappa)(\frac{P_{H,t}}{P_t})^{-\eta}\Gamma_t \tag{4.31a}$$

$$\Gamma_{F,t} = \kappa(\frac{P_{F,t}}{P_t})^{-\eta}\Gamma_t \tag{4.31b}$$

Similarly, the aggregate consumption in foreign economy Γ_t^* is defined by a CES function:

$$\Gamma_t^* = [(\kappa^*)^{\frac{1}{\zeta}}(\Gamma_{H,t}^*)^{\frac{\zeta-1}{\zeta}} + (1-\kappa^*)^{\frac{1}{\zeta}}(\Gamma_{F,t}^*)^{\frac{\zeta-1}{\zeta}}]^{\frac{\zeta}{\zeta-1}}$$

Where $\Gamma_{F,t}^*$ is the consumption of domestically produced goods in foreign economy and $\Gamma_{H,t}^*$ is the consumption goods imported from domestic economy.

Composite price index P_t^* in foreign economy is given by

$$P_t^* = [(\kappa^*)(P_{H,t}^*)^{1-\zeta} + (1-\kappa^*)(P_{F,t}^*)^{1-\zeta}]^{\frac{1}{1-\zeta}}$$

where $P_{H,t}^*$ is the price index of imported goods and $P_{F,t}^*$ is the price index of domestically produced goods in foreign economy.

Using composite price index, we obtain the optimal allocations of expenditures between domestic and imported goods in foreign economy

$$\Gamma_{H,t}^* = (\kappa^*)(\frac{P_{H,t}^*}{P_t^*})^{-\zeta}\Gamma_t^* \tag{4.32a}$$

$$\Gamma_{F,t}^* = (1-\kappa^*)(\frac{P_{F,t}^*}{P_t^*})^{-\zeta}\Gamma_t^* \tag{4.32b}$$

Aggregate investment in period t, I_t is composed of domestic and foreign investment goods, where the prices of domestic and imported investment goods are assumed to be the same as the prices of domestic and imported consumption goods, $P_{H,t}$ and $P_{F,t}$ so that the nominal price of a unit of investment equals to composite price level, P_t. I_t is assumed to be a CES index of domestically produced and imported goods given

$$I_t = [(1-\kappa)^{\frac{1}{\eta}}(I_{H,t})^{\frac{\eta-1}{\eta}} + \kappa^{\frac{1}{\eta}}(I_{F,t})^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}} \tag{4.33}$$

where $I_{H,t}$ denotes domestic investment goods and $I_{F,t}$ denotes imported investment goods. The optimal allocations of expenditures between domestic and imported investment goods in home economy are

$$I_{H,t} = (1-\kappa)(\frac{P_{H,t}}{P_t})^{-\eta}I_t \tag{4.34a}$$

$$I_{F,t} = \kappa(\frac{P_{F,t}}{P_t})^{-\eta}I_t \tag{4.34b}$$

Likewise, we get the optimal allocations of expenditures between domestic and imported investment goods in foreign economy

$$I^*_{H,t} = (\kappa^*)(\frac{P^*_{H,t}}{P^*_t})^{-\zeta} I^*_t \tag{4.35a}$$

$$I^*_{F,t} = (1-\kappa^*)(\frac{P^*_{F,t}}{P^*_t})^{-\zeta} I^*_t \tag{4.35b}$$

Nominal Depreciation Rate

Domestic effective terms of trade is defined as $S_t \equiv \frac{P_{F,t}}{P_{H,t}}$ and foreign effective terms of trade is defined as $S^*_t \equiv \frac{P^*_{H,t}}{P^*_{F,t}}$. Domestic consumers purchase goods from foreign economy at the price $P_{F,t}$ and foreign consumers purchase goods from domestic economy at the price $P^*_{H,t}$. Here we assume pass-through from exchange rate movements to the price of imported goods is imperfect as importers adjust their pricing behaviors to extract optimal revenue from consumers, that is, importers sell goods to domestic consumers and charge a mark-up over their cost. Imperfect exchange rate pass-through is defined as the law of one price (LOP) gap in the domestic country as: $\psi_{F,t} = \frac{e_t P^*_{F,t}}{P_{F,t}}$ where e_t is nominal exchange rate. There are endogenous deviations from purchasing power parity (PPP) in the short run, but PPP holds in the long run. If purchasing power parity (PPP) holds, then $\psi_{F,t} = 1$, that is $P_{F,t} = e_t P^*_{F,t}$. The law of one price gap in the foreign economy is defined as $\psi^*_{H,t} = \frac{P_{H,t}}{e_t P^*_{H,t}}$.

We define the domestic real exchange rate as the ratio of the two economies' CPIs, expressed in domestic currency, $Q_t \equiv \frac{e_t P^*_t}{P_t}$. The foreign real exchange rate Q^*_t is equal to Q^{-1}_t. We derive nominal depreciation rate (PPP relationship) from real exchange rate:

$$E_t\hat{Q}_{t+1} - \hat{Q}_t = E_t[\hat{e}_{t+1} + \hat{p}^*_{t+1} - \hat{p}_{t+1}] - [\hat{e}_t + \hat{p}^*_t - \hat{p}_t] = E_t\hat{e}_{t+1} - \hat{e}_t + E_t\hat{\pi}^*_{t+1} - E_t\hat{\pi}_{t+1} \tag{4.36}$$

This PPP equation shows that the real exchange rate differential is aligned with the movement of the nominal exchange rate if the inflation differential is smoothed. In order to reproduce the observed volatility of real exchange rate, we introduce a shock to the PPP equation to capture the model misspecification similar to Lubik and Schorfheide (2005) and Chari, Kehoe and McGrattan (2002):

$$E_t\hat{e}_{t+1} - \hat{e}_t = E_t\hat{Q}_{t+1} - \hat{Q}_t + E_t\hat{\pi}_{t+1} - E_t\hat{\pi}^*_{t+1} + \varepsilon_{E,t} \tag{4.37}$$

where $\varepsilon_{E,t}$ is the PPP shock and $\varepsilon_{E,t} \sim N(0, \sigma^2_E)$.

International Risk Sharing

Financial intermediaries collect deposits from savers and extend loans to borrowers within each economy. In addition, they can issue bonds to international financial intermediaries. We define $R^e_t = R_t/\varepsilon_{rp,t}$ and $R^{e^*}_t = R^*_t/\varepsilon^*_{rp,t}$ as the returns on bonds where R_t denotes the nominal interest rate in home economy and R^*_t denotes the nominal interest rate in foreign economy. $\varepsilon_{rp,t}$ and $\varepsilon^*_{rp,t}$ represent country risk premium shocks on bond holdings represented. If domestic financial intermediaries have excess funds B_t that wish to lend to foreign financial intermediaries, then $B_t > 0$ and foreign intermediaries will pay a higher interest rate $R^*_t/\varepsilon^*_{rp,t}$. In this case, international financial intermediaries make a profit equal to $B_t(R^*_t/\varepsilon^*_{rp,t} - R_t/\varepsilon_{rp,t}) > 0$. Conversely, if the foreign economy becomes a net debtor, then profit is equal to $B_t(R^*_t/\varepsilon^*_{rp,t} - R_t/\varepsilon_{rp,t}) > 0$ because $B_t < 0$ and $(R^*_t/\varepsilon^*_{rp,t} - R_t/\varepsilon_{rp,t}) < 0$.

In addition, we assume that international intermediaries apply a debt elastic risk premium to the spread they charge between bonds in the home economy R^e_t and the foreign economy $R^{e^*}_t$. According to Schmitt-Grohe and Uribe (2003), we consider a time varying shock ϱ_t which plays the role of an uncovered interest parity shock to capture the deviation of uncovered interest parity and ensures that the model has a steady state. ϱ_t is a function of net foreign assets to GDP ratio, $\frac{e_t B^*_t}{P_t Y}$ according to

$$\varrho_t = exp[-\chi(\frac{e_t B^*_t}{P_t Y} + \varepsilon_{\zeta,t})] \tag{4.38}$$

Where χ is the risk premium parameter and B^*_t denotes net foreign assets, and Y is the steady state of GDP. $\varepsilon_{\zeta,t}$ is the risk premium shock and $\varepsilon_{\zeta,t} \sim N(0, \sigma^2_\zeta)$. let $J_t \equiv \frac{e_t B^*_t}{P_t}$.

Under uncovered interest parity, the expected nominal return from domestic bonds in domestic currency terms, must be the same as the expected nominal return from foreign bonds in domestic currency terms, that is $E_t(\frac{1}{R^e_t}) = E_t\{\frac{1}{\varrho_t R^{e^*}_t}\frac{e_t}{e_{t+1}}\}$. We take log linearization around the perfect foresight steady state as follows

$$\hat{R}_t - \hat{R}^*_t = E_t(\hat{e}_{t+1} - \hat{e}_t) + \hat{\varrho}_t + \varepsilon_{rp,t} - \varepsilon^*_{rp,t} \tag{4.39}$$

Equation (4.39) suggests that asset returns should be equalized in the incomplete international asset market.

Domestic Producers

We assume a continuum of monopolistically competitive domestic firms which produce differentiated goods. Domestic firms can adjust prices following Calvo pricing. Each period the firm does not adjust its price with probability θ_H and sets the price optimally $\tilde{P}_{H,t}$ with probability $1 - \theta_H$. The price index of domestically produced goods is given by the Dixit Stiglitz aggregator:

$$P_{H,t} = [\theta_H P^{1-\varepsilon}_{H,t-1} + (1 - \theta_H)(\tilde{P}_{H,t})^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

where $P_{H,t-1}$ is the lagged price level and $\tilde{P}_{H,t}$ is the average price level chosen by those who have the chance to change prices according to the following rule:

$$\hat{\pi}_{H,t} - \xi_p \hat{\pi}_{H,t-1} = \beta(E_t\hat{\pi}_{H,t+1} - \xi_p\hat{\pi}_{H,t}) + \frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H}(\hat{MC}_t + \kappa\hat{S}_t) + u_{H,t} \tag{4.40}$$

where β is the discount factor related to the policy rate and ξ_p is the price indexation. $u_{H,t} = \rho_h u_{H,t-1} + \varepsilon_{H,t}$ where $\varepsilon_{H,t}$ denotes the price mark up shock. Equation (4.40) is the forward looking Philips curve, which shows the relationship between domestic inflation and marginal cost after aggregation over individual firms.

Importing Retailers

Similarly, we assume that retail firms import foreign differentiated goods $\Gamma_{F,t}$. In the short run, the small degree of pricing power leads to a violation of the law of one price. Retailers face the Calvo pricing. The aggregate price index of imported goods is given by the Dixit Stiglitz aggregator:

$$P_{F,t} = [\theta_F P^{1-\varepsilon}_{F,t-1} + (1 - \theta_F)(\tilde{P}_{F,t})^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

where $\tilde{P}_{F,t}$ is the average price level chosen by those who have the chance to change prices according to the following rule:

$$\hat{\pi}_{F,t} - \xi_p \hat{\pi}_{F,t-1} = \beta(E_t \hat{\pi}_{F,t+1} - \xi_p \hat{\pi}_{F,t}) + \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F}(\hat{\psi}_{F,t}) + u_{F,t} \tag{4.41}$$

where $u_{F,t} = \rho_f u_{F,t-1} + \varepsilon_{F,t}$ and $\varepsilon_{F,t}$ is the price mark up shock. Equation (4.41) is a forward looking Philips curve, which suggests the relationship between import price inflation and the law of one price gap in home economy.

Exporting Retailers

We assume a continuum of exporting retailers that sell domestic differentiated goods abroad at a price $P^*_{H,t}$ in terms of foreign currency.

We assume exporting retailers reoptimise their prices with probability $(1-\theta^*_H)$ according to the forward looking Philips curve between export price inflation and the law of one price in foreign economy:

$$\hat{\pi}^*_{H,t} - \xi^*_p \hat{\pi}^*_{H,t-1} = \beta^*(E_t \hat{\pi}^*_{H,t+1} - \xi^*_p \hat{\pi}^*_{H,t}) + \frac{(1-\theta^*_H)(1-\beta^*\theta^*_H)}{\theta^*_H}(\hat{\psi}^*_{H,t}) + u^*_{H,t} \tag{4.42}$$

where $u^*_{H,t} = \rho^*_h u^*_{H,t-1} + \varepsilon^*_{H,t}$ and $\varepsilon^*_{H,t}$ is the export price mark up shock.

4.2.10 Market Clearing

On the assumption of the producer currency pricing, the home economy current account balance expressed in home currency is

$$e_t B^*_{t+1} = e_t B^*_t R^{e^*}_t \varrho_t + e_t P^*_{H,t}(\Gamma^*_{H,t} + I^*_{H,t}) - P_{F,t}(\Gamma_{F,t} + I_{F,t}) \tag{4.43}$$

where B^*_t is the average level of net foreign assets in home economy.

Likewise, the foreign economy current account balance expressed in foreign currency is given by

$$B_{t+1} = B_t R^e_t + P_{F,t}(\Gamma_{F,t} + I_{F,t}) - e_t P^*_{H,t}(\Gamma^*_{H,t} + I^*_{H,t}) \tag{4.44}$$

where B_t is the average level of net foreign assets in foreign economy. International financial market clearing implies

$$B_t + e_t B_t^* = 0 \tag{4.45}$$

The house market clearing in home economy requires:

$$H_{S,t} + H_{E,t} + H_{P,t} = 1 \tag{4.46}$$

The real GDP identity in home economy is given by

$$Y_t = \Gamma_t + I_t + G_t + e_t P_{H,t}^* (\Gamma_{H,t}^* + I_{H,t}^*)/P_t - P_{F,t}(\Gamma_{F,t} + I_{F,t})/P_t \tag{4.47}$$

where

$$\Gamma_t = C_{P,t} + C_{S,t} + C_{E,t} + \Omega_t^B \tag{4.48}$$

The bank balance sheet identity holds in every period in home economy:

$$K_{B,t} + D_t = L_{E,t} + L_{S,t} \tag{4.49}$$

4.3 Estimation

4.3.1 Methodology and Stylized Facts

We use Bayesian technique to estimate the structural parameters of the model. First, we solve the model by using the first order approximation approach. Then we use Kalman filter to derive likelihood function and find the expression of the log posterior kernel. Second, the mode of posterior distribution is obtained by maximizing the log posterior kernel with respect to the parameters. We have the mode of posterior distribution, but we are more interested in the estimates of the parameters. Posterior distributions are obtained via Monte Carlo simulation, using Metropolis-Hastings algorithm. The posterior means of the parameters are used to draw statistical inference on the parameters.

We estimate the model from 1997Q1 to 2011Q4 and the subperiods from

1997Q1 to 2007Q4 in order to investigate the stability of the estimated parameters and explain some important features in the model. The observed variables applied to estimate the model are explained in Appendix A. All the data are seasonally adjusted except nominal exchange rate and interest rates.

Figure 4.2 depicts the UIP residual ($\Delta e_t - \hat{R}_{t-1} + \hat{R}^*_{t-1}$) and real exchange rate ($\Delta e_t + \hat{\pi}^*_t - \hat{\pi}_t$). As in equation (4.37), a shock to the PPP equation $\varepsilon_{E,t}$ is introduced to capture the misidentification. If the estimated variance of $\varepsilon_{E,t}$ is small, we can conclude that the model is able to explain most of the observed real exchange rate dynamics. Figure 4.2 also illustrates log GDP ratios, and compares central bank interest rates and bank interest rates in both economies.

4.3.2 Calibrated Parameters

We fix some parameters and report them in Table 4.1. We calibrate the parameters which are either notoriously difficult to estimate (i.e. markups) or better identified using other information (i.e. factor shares and discount factors).

The discount factors of households and entrepreneurs are calculated by the steady states of the annualized rate on loans to households and to entrepreneurs during sample periods. In our model, as long as bankers are impatient, that is $\beta_B < \beta_H$, bankers will be credit-constrained. Furthermore, as long as $\beta_E < \frac{1}{\gamma\frac{1}{\beta_P}+(1-\gamma)\frac{1}{\beta_B}}$ and $\beta_S < \frac{1}{\gamma\frac{1}{\beta_P}+(1-\gamma)\frac{1}{\beta_B}}$, entrepreneurs and impatient households are credit-constrained. To find the discount factor of banks, we consider the steady state of the annualized rate on the central bank interest rate.

For the United States, the discount factor of patient households is $\beta_H = 0.993$, in line with a steady state 3 percent annualized return on deposits. The entrepreneurial discount factor is $\beta_E = 0.985$ and the discount factor of impatient households is $\beta_S = 0.984$. The discount factor of banks is $\beta_B = 0.992$. The capital share in the aggregate output production, α and the depreciation rate of capital, δ are set to 0.28 and 0.035, respectively to match the sample mean of investment-output and labour income-output ratios. We set the share of commercial real estate in production $\upsilon = 0.05$ and the weight on housing in utility $j = 0.08$. The income share of impatient households is $\sigma = 0.3$. In the good market, we assume a markup of 15 percent and set $\epsilon = 6$. In the labor market, a value of 5 for λ_w delivers a markup of 25 percent.

For the Euro area, the discount factors of patient households, entrepreneurs, impatient households, and banks are set to be $\beta_H^* = 0.994$, $\beta_E^* = 0.987$, $\beta_S^* = 0.988$ and $\beta_B^* = 0.993$, respectively. The capital share in the aggregate output production α^* and the depreciation rate of capital, δ^* are set to 0.25 and 0.035. We apply the same value of the share of commercial real estate in production, the weight on housing in utility function, the income share of impatient households as the United States. The steady states of the markups in the good market and in the labour market are set to be 6 and 5.

It is very difficult to give the value of LTV ratios without data on the debt of housing and capital of credit-constrained agents (households and entrepreneurs). Using the data over the period, we get an average ratio of loans to GDP. The LTV ratios are set to match the steady state share of loans to households and entrepreneurs. For example, in the U.S., the LTV ratio for household mortgage is $m_S = 0.7$; the LTV ratio for commercial real estate is $m_H = 0.15$ and the LTV ratio for entrepreneurial capital is $m_K = 0.15$. In the Euro area, the LTV ratio for household mortgage is set to be $m_S^* = 0.6$. We fix the LTV ratio for commercial real estate $m_H^* = 0.15$ and the LTV ratio for entrepreneurial capital $m_K^* = 0.15$.

For the banking sector in the United States, we calculate the average monthly spread among bank interest rates in our sample periods to get the steady state of the spread between the deposit rate and the interbank rate $\varepsilon_d = -10.26$. Similarly, we calibrate $\varepsilon_{bE} = 2$ and $\varepsilon_{bS} = 1.97$ by exploiting the steady-state relation between the marginal cost of loan production and loan rates to households and entrepreneurs. For the banking sector in the Euro area, we set $\varepsilon_d^* = -20.23$, $\varepsilon_{bE}^* = 2.23$ and $\varepsilon_{bS}^* = 2.27$, respectively. The parameter δ_b and δ_b^* are set at the value 0.0982 to ensure that the ratio of bank capital to total loan is around 0.09.

The risk premium parameter is set to be 0.05 according to Aswath Damodaran's research[3].

4.3.3 Priors and Posterior Estimates

In table 4.3 and 4.4 we present prior distributions, posterior means and 90 percent intervals of the estimated parameters. We face the problem of a short sample, so, in addition to calibrating some parameters, we set some parameters the same across

[3]http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/ctryprem.html

these two economies. All the open economy parameters are estimated, together with a constant growth trend ω of output, the steady state of inflation rate γ_π (γ_π^*), the steady state of interest rate γ_r (γ_r^*) and a common trend of other variables. The steady state interest rate γ_r is related to the discount factor in the Philips curve β where $\beta = 1/(1+\gamma_r/400)$. We assume the standard deviation of shocks is inverse gamma distribution and the persistence of shocks is beta distribution. We use the mean and standard deviation estimated with the data to guide the choice of prior means. For instance, we obtain the persistence and the standard deviation of the PPP shock $\varepsilon_{E,t}$ by running the OLS regression of the nominal depreciation rate. Following Lubik and Schorfheide (2005), we get the prior of the standard deviation of monetary policy shock by running the OLS regression of Taylor rule: $\hat{R}_t = c_1 + c_2\hat{R}_{t-1} + c_3\hat{\pi}_{t-1} + c_4(\hat{Y}_t - \hat{Y}_{t-1}) + c_5\Delta\hat{E}_t + \varepsilon_{R,t}$.

We report two estimation results in table 4.3 and 4.4, one where the whole sample periods are from 1997q1 to 2011q4 and another where the sample periods are from 1997q1 to 2007q4. We see that most of the estimates are consistent with the literature and they are robust in the whole sample and subsample. In the model with the whole sample, the price indexation is estimated over 0.5 in both regions, a bit higher compared with the literature. The persistence of financial shocks is very high, which suggests that at long horizons, financial shocks play significant roles in explaining the forecast error of real variables. The result implies that the economy recovery from a recession caused by a liquidity crisis could be very slow.

Turning to the parameters in the monetary policy reaction function, the estimate of the long run reaction coefficient to inflation is a bit lower in the United States than the one in the Euro area. The estimates of the degree of interest rate smoothing (the coefficient on the lagged interest rate) is 0.88 for the United States and 0.83 for the Euro area in the whole sample, respectively. Policy does appear to react very strongly to the deviation of output from the stochastic worldwide technology trend. The estimates of the reaction to the exchange rate in the United States and in the Euro area are small and interestingly, the value in the United States is greater than that in the Euro area. We find that the variance of the financial shock in the United States is higher than that in the Euro area. The estimate of the standard deviation of country risk premium shock in the United States is smaller than that in the Euro area. The higher estimate of the deviation of risk premium shock in the Euro area is explained by the higher risk with the occurrence of the Euro area sovereign debt crisis. Furthermore, the estimate of the standard deviation of the PPP shock is large, which indicates that the model performs poorly on generating the fluctuation in real exchange rate.

We apply the same priors in the subsample. Most of the estimates are by and large similar to those in the whole sample except openness and substitution elasticity between home and foreign goods. The posterior estimate of the steady growth of world wide technology shock is less than 0.2 and the persistence of world wide technology shock is 0.9, a bit higher than 0.85 in the whole sample. Moreover, we find that the posterior estimates of the structural shocks in the subsample are smaller than those in the whole sample, which are in line with the fact that economic fluctuations are larger during the Great Recession.

4.4 Impulse Responses

In this section we investigate the propagation of shocks to the domestic and foreign economy in our proposed model. In particular, we compare the dynamics of impulse response functions in the benchmark model (a banking sector with the sticky interest rate setting) with another two scenarios. One scenario is that we relax the assumption that the banking sector adjusts interest rates according to Calvo pricing and assume a banking sector with flexible interest rate setting instead; another scenario is that the banking sector and bank capital degenerate. We consider three shocks: financial shock, monetary policy shock(demand shock), and technology shock(supply shock). Here we only explain the impacts of the shocks from the United States on both areas to save space. The effects of the shocks from the Euro area are similar.

4.4.1 Models with Banks and without Banks

In the absence of banks, there is no difference among interest rates such that the deposit rate equals the loan rates to impatient households and entrepreneurs, $R_{P,t} = R_{E,t} = R_{S,t}$ which are equal to the central bank policy rate R_t. Equilibrium borrowing and lending among patient and impatient households, and entrepreneurs follows $D_t = L_{E,t} + L_{S,t}$. Moreover, bank and bank capital disappear, that is $C_{B,t} = 0$ and $K_{B,t} = 0$.

In the presence of banks with the perfectly flexible interest rate setting, the wedges between deposit and lending rates are

$$R_{P,t} = (\frac{\varepsilon_d}{\varepsilon_d - 1})R_{IB,t} = (\frac{|\varepsilon_d|}{|\varepsilon_d| + 1})R_{IB,t} = R_{IB,t}(1 - rr)$$

$$R_{E,t} = (\frac{\varepsilon_{bE}}{\varepsilon_{bE} - 1})R_{IB,t}$$

$$R_{S,t} = (\frac{\varepsilon_{bS}}{\varepsilon_{bS} - 1})R_{IB,t}$$

where $\varepsilon_d < 0$ and $\varepsilon_{bE} > 1$ and $\varepsilon_{bS} > 1$.

Under flexible interest rate setting, we find that $\hat{R}_{S,t} = \hat{R}_{E,t} = \hat{R}_{P,t} = \hat{R}_{IB,t} = \hat{R}_t$.

In the presence of the banking sector with sticky or flexible interest rate settings, the wedges between interest rates can amplify their movements in response to the policy rate. Furthermore, the impact of credit crunch can be reinforced by the wedges between bank interest rates. For example, an exogenous shock reduces asset prices and thus deteriorates the balance sheet of banks. Lenders have little information about the creditworthiness of borrowers, so they require borrowers to set forth their ability to repay. Banks have to tighten the supply of credit, which harms investment and in turn reduces output. The decreased economic activity causes a feedback cycle, leads to a further drop in asset prices, thus worsening the balance sheet of banks. Banks are more cautious to issue loans and economic activity becomes worse. This is so called "banking accelerator" transmission effect. It works in much the same way as the financial accelerator (BGG 1999) that financial frictions can propagate business cycles.

The impact of a monetary policy shock, which is amplified through collateral constraints, is counteracted by a "banking attenuator" mechanism (see e.g Gerali et al. 2008, 2010 and Aslam and Santoro 2008). For instance, the effect of an increase in the policy rate on the marginal rate of substitution between housing services and consumption is attenuated by the banking sector. As the markup between the loan rate over the deposit rate decreases, the attenuation effect vanishes.

4.4.2 Financial Shock

First we discuss the impacts of the U.S. negative financial shock on the U.S. economy as illustrated in figure 4.3. As Iacoviello (2011), the negative financial shock starts with borrowers who pay back banks less than initially agreed on their obligations in the current period, implying that savers transfer wealth toward borrowers. Impatient households have incentive to consume more and borrow more. Banks are willing to lend more to impatient households if the interest rate premium on impatient households is greater than default risk. The negative shock to wealth causes patient households to consume less. Meanwhile, entrepreneurs consume less, borrow less and accumulate less capital.

Since labor supply is elastic, the labor demand of households also responds to the transferring wealth from patient to impatient households. Impatient households work less. Patient households work more subject to the negative wealth effect. The decline in output comes both from a decline in labor demand and from a decline in labor supply. As the marginal product of labor falls, labor demand declines. Because of reduced savings, aggregate capital and investment reduce correspondingly. Inflation declines with a shrink in output.

As housing prices fall and defaults on subprime mortgages rise, banks that specialize in subprime loans suffer more losses. If there is no further adjustment to either loans or deposits, the banker can restore its capital-to-asset ratio by either reducing its deposit from households or reducing consumption. However, reducing consumption is too costly. Thus, banks choose to tighten credit supply, which cause firms and impatient households harder to borrow from banks. At the same time, banks face increased defaults on loans as more firms and individuals go bankruptcy. The losses grow to the point that they push many others into insolvency. The fears of insolvency show up in the federal funds market and cause bank lending to fall more dramatically.

Less spending by firms and individuals who rely on credit causes aggregate demand and output to drop more. Central bank reacts to the shock by reducing the policy interest rate. Deposit and loan rates fall accordingly. The rise in bank spreads reflects the high utility cost of making a loan for the bank in a period which banker's consumption and equity is low.

In the case of banks with the flexible interest rate setting, changing deposit and loan rates is costless. Therefore, the responses of deposit and loan rates to a decline in the policy rate are more significant. In the absence of banks, all interest rates are equal and there is no wedge between interest rates. The amplification mechanism of the banking sector does not come into effect so the responses are least significant.

The U.S. negative financial shock is transmitted to the Euro area through the real and financial channels. First, the fall in the U.S. output leads to a decline in U.S. demand for tradable goods, therefore decreasing the demand for Euro exports. Second, the Euro area, as a net exporter of commodities, suffers from negative terms of trade and wealth effects as world commodity price declines. These negative effects reduce Euro output. Third, because of the fall in the U.S. interest rate relative to the Euro area, the exchange rate appreciates on impact before depreciating. The fall in commodity prices causes the subsequent depreciation of exchange rate, which reduces the price of Euro area goods and increases the demand for Euro exports (price effect). Fourth, the negative financial shock causes a reduction in the U.S. loan supply, thus reducing the total amount of borrowing and lending by U.S. financial intermediaries to the Euro area financial intermediaries. However, this channel interacts with the response of the exchange rate. The depreciation of the exchange rate leads to a deterioration in the balance sheet conditions of the Euro area financial intermediaries, contributing to the increase in the risk premia.

As a result, all of the real and financial transmission channels reduce the Euro area output in the beginning, as illustrated in figure 4.4. As time passes, output increases afterwards. To offset the negative effects on Euro output and inflation, European Central Bank (ECB) decreases the policy rate. In our model, loan and deposit rates move in the same direction as the policy rate. Patient households would like to deposit less in response to a drop in deposit rate. The negative wealth effect caused by a slight drop in Euro output results in a rise in the labor supply of patient households. A redistribution of wealth between impatient and patient households through banks creates different reactions of the labor supply for these two agents. Later, as output climbs, ECB increases the policy interest rate.

Figure 4.4 shows that banks have acceleration effects on propagating the negative financial shock to the Euro area. Figure 4.4 also suggests that lowering the policy interest rate in the Euro area in response to the credit crunch in the U.S. can dampen the impacts of the U.S. financial shock on Euro output, implying that tightening the policy rate helps offset the effects of the U.S. financial crisis on the Euro area partially.

4.4.3 Monetary Policy Shock

Next we consider a U.S. contractionary monetary policy shock. Figure 4.7 depicts that a U.S. contractionary monetary policy shock leads to a rise in the policy interest rate and declines in output and inflation. As the demand for goods decreases, asset prices (i.e. the price of housing) decrease. The decline in asset prices reduces the borrowing capacity of borrowers. Impatient households and entrepreneurs spend less and invest less. Bank interest rates move in the same direction as the policy rate. The markup among interest rates is determining the strength of the banking attenuation effect. Figure 4.7 shows the reactions of bank interest rates in the model with the flexible interest rate setting are stronger than those in the model with the sticky interest rate setting. Moreover, the changes in bank spreads are much bigger in the model with the flexible interest rate setting. The reason is that the sticky interest setting prevents the change of the policy rate to fully pass to bank rates, which causes an irrespectively sluggish adjustment in bank interest rates. In the absence of banks, the responses of inflation, housing price and output are stronger.

Figure 4.8 illustrates the effects of the U.S. contractionary monetary policy shock on the Euro area. The shock leads to an increase in the U.S. central bank interest rate and sharply appreciates the currency but the effect dissipates within a few periods. On one hand, the fall in U.S. demand for tradable goods decreases the demand for Euro area exports. On the other hand, the appreciation of the U.S. dollar implies that the goods produced in the U.S. are relatively more expensive than the goods produced in the Euro area. Hence, such a positive price substitution effect increases Euro exports. U.S. financial intermediaries restrict their lending to Euro financial intermediaries, which contributes to the deterioration of Euro balance sheet conditions and an increase in risk premia. Figure 4.8 shows that the Euro output drops slightly first and later increases significantly. ECB policy rate and bank interest rates increase. Deposits and loans climb correspondingly.

4.4.4 Technology Shock

Figure 4.11 studies the effects of the positive U.S. technology shock on the United States. Because the production is more efficient, the U.S. output rises. The supply of the U.S. goods increases, thus reducing the price of U.S. goods. Technology innovation reduces marginal cost and inflation, which leads to a drop in the central bank policy rate. Meanwhile, exchange rate depreciates in order to sell aboard the additional supply of domestically produced goods. With a positive wealth effect, agents including patient and impatient households and entrepreneurs raise their consumption. At the same time, patient households save more while impatient households and entrepreneurs borrow more. Due to rising savings, the marginal product of labor increases and aggregate capital increases.

In the presence of bank intermediaries, the endogenous propagation mechanism is amplified because credit spreads benefit impatient households and entrepreneurs from the greater availability of credit. The response of investment reflects the bank amplification effect, as illustrated in figure 4.11. We also observe that the change in output is a bit more persistent and it peaks higher than the model without banks.

We look into the impacts of positive U.S. technology shock on the Euro area in figure 4.12. The main international transmission of shocks is relative price movement through the exchange rate channel. As technology innovation boosts the U.S. output, the depreciation of exchange rate implies that the goods produced in the U.S. are relatively cheaper than the goods produced in the Euro area. According to expenditure switching effect and the assumption of international risk-sharing, productivity disturbance from the U.S. lowers Euro output due to the production shifting to the country with the highest productivity, thus decreasing Euro output. Monetary policy accommodates the drop in output. Figure 4.12 shows that the production of goods in the Euro area is less productive and more persistent: the lowest point in output is delayed in the presence of an active banking system.

4.5 Variance Decomposition

To complement our analysis of impulse-response functions, we examine the asymptotic variance decomposition with posterior distribution of parameters. The decomposition helps us understand the variation in a series explained by each of the model's shocks. The results of the decomposition (Benchmark: a banking sector with the sticky interest rate setting) are reported in Table 4.5.

The first observation that follows from the output variance decomposition in the predominant role of domestic shocks for output (around 89.23 percent for the United

States and 82.58 percent for the Euro area). The contribution of the monetary policy shock to the Euro area is a bit stronger than the United States. Worldwide technology shock contributes more to the fluctuation in Euro output compared with the United States. Table 5 indicates that financial shock is more important in explaining the variability of output in the U.S. than the Euro area, 37.41 percent and 14.66 percent, respectively. Together, credit shocks originating in the banking sector can explain about 12.88 of the variability of U.S. output and 9.97 of the variability of Euro output, respectively.

The U.S. country risk premium shock accounts for a trivial fraction of the variability of domestic economic variables while the contribution of Euro risk premium shock is much more significant. Credit shocks are the main driving forces to explain the fluctuations in house price index and bank interest rates in the U.S. and the Euro area.

Table 4.5 suggests that the spillover of the shocks from the Euro economy towards the U.S. economy is too weak to explain a significant proportion of the fluctuation in U.S. output. But the shocks from the United States contribute more to the fluctuations in output, inflation, house price index and interest rates in the Euro area, suggesting that the Euro area is more susceptible to the economic condition of the United States. Consistent with the data, import price markup shocks play insignificant roles in the business cycles of both economies. Exchange rate shock (PPP shock) explains a small fraction of the variability of output as well as other economic variables at business cycle frequencies.

4.6 Policy Experiment

A lot of researches have been conducted on macroprudential measures (see a summary paper of Galati and Moessner 2011). However, few papers have studied macroprudential policy in an open economy framework. Unlike the most recent paper by Unsal (2012) that studies capital controls and macroprudential policy for emerging markets, we analyze how macroprudential policies minimize macroeconomic and financial instability against financial shocks in our proposed open economy model.

Similar to Quint and Rabanal (2011), we assume that macroprudential policy affects bank spreads by allowing banks to lend impatient households and entrepreneurs a fraction $1/\eta_t < 1$ of the value of collateral. $1/\eta_t$ could be interpreted as a liquidity ratio, a reserve requirement, or a capital requirement. Therefore, borrowers are charged over a higher cost of borrowing that rises with nominal credit growth. Macroprudential measures make firms and households harder to borrow during boom times hence make the subsequent bust less dramatic. Macroprudential instruments are introduced into collateral constraints according to

$$L_{E,t} = \frac{1}{\eta_t} \frac{1}{R_{E,t}} [E_t(m_H Q_{t+1} H_{E,t}) + m_K(1-\delta) Z_{t+1} K_{E,t}] \tag{4.50}$$

$$L_{S,t} = \frac{1}{\eta_t R_{S,t}} E_t(m_S Q_{t+1} H_{S,t}) \tag{4.51}$$

Where

$$\eta_t = \gamma_\eta \Upsilon_t \tag{4.52}$$

$\Upsilon_t = CR_t / CR_{t-1}$ is nominal credit growth and $CR_t = L_{E,t} + L_{S,t}$. Macroprudential indicator responds to domestic variables and aims at affecting domestic spreads. The policy reaction function is extended by adding nominal credit growth:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)[\phi_\pi \hat{\pi}_t + \phi_y(\hat{Y}_t - \hat{Y}_{t-1} + \hat{\varpi}_t) + \phi_s \hat{\Upsilon}_t + \phi_e \Delta \hat{E}_t] + \varepsilon_{R,t} \tag{4.53}$$

Equation (4.53) is the mix of Taylor rule and macroprudential policy. Macroprudential policy as a second instrument helps central bank achieve its target in terms of CPI inflation and output gap volatility. In our case, macroprudential regulator does not have her own loss function.

Table 4.6 represents the posterior estimates of the benchmark model with macroprudential policy. The estimated coefficient of nominal credit growth in the Taylor rule in the full sample is 0.356 for the United States, 0.360 for the Euro area respectively. The estimate of macroprudential instrument parameter in the full sample is 2.4999 for the United States, 2.1593 for the Euro area, respectively. Contrary to the benchmark model without macroprudential policy, the coefficient ϕ_y is quite small and the coefficient ϕ_π becomes large.

We study the stabilization performance of macroprudential measures in figure

4.15 and figure 4.16. Figure 4.15 shows the responses to the negative financial shock from the United States. Lending to impatient households becomes more risky, which leads to a drop in loan supply, thus decreasing the supply of capital and hence bringing about a drop in investment, consumption and output in the economy. Overall, the U.S. economy experiences lower demand and inflation drops, together with a bust in credit growth. When macroprudential policy is implemented to the economy, the persistence and the magnitude of interest rates as well as bank spreads are less persistent and behavior smaller. Furthermore, the responses of output, consumption and investment are less significant. These findings are in accord with the literature that macroprudential polices can cushion the financial crisis by indirectly and directly affecting the provision of credit.

When the U.S. financial shock transmits to the Euro area, exchange rate appreciates and macroprudential policy provides a mechanism for promoting macroprudential stability through affecting the interest rate spread countercyclically, as seen in figure 4.16. These results imply that if macroprudential policies were in place before the Great Recession, the severity of the financial crisis could have been lessened.

4.7 Forecasting

We first estimate the model using data from 1997Q1 to 2007Q4. And then we re-estimate the model recursively for each quarter for the period starting in 2008Q1 and ending in 2011Q4 to generate 1 quarter ahead forecasts, using quarter over quarter growth change in GDP per capita data and posterior estimates. The result is evaluated against the Great Recession. Figure 4.17 and figure 4.18 show that actual GDP growth per capita, and out-of-sample predictions from the model with and without a banking sector, together with shading areas for the NBER recession in the U.S. and the ECB recession in the Euro area. The results suggest that the model with a banking sector performs better on predicting the big drop in output growth during the Great Recession than the model without a banking sector.

We consider two loss functions: root mean squared error (RMSE) and Theil inequality coefficient (THEIL).

$$RMSE = \sqrt{\frac{1}{N}\sum_{t=T+1}^{T+N}(\chi_t - \hat{\chi}_t)^2}$$

$$THEIL = \frac{\sqrt{\frac{1}{N}\sum_{t=T+1}^{T+N}(\chi_t - \hat{\chi}_t)^2}}{\sqrt{\frac{1}{N}\sum_{t=T+1}^{T+N}\chi_t^2} + \sqrt{\frac{1}{N}\sum_{t=T+1}^{T+N}\hat{\chi}_t^2}}$$

where χ_t is the observation and $\hat{\chi}_t$ is the forecast. The smaller RMSE, the better the forecasting ability of the proposed model. Theil coefficient ranges between zero and one. Zero indicates a perfect fit. RMSE is scale-dependent while Theil is scale invariant. Theil inequality coefficient can be decomposed into bias, variance, and covariance proportion. Bias and variance proportions show how far the mean and variance of the forecast are from the actual series. The covariance proportion measures the remaining unsystematic forecasting errors. The small value of bias and variance proportions and the concentrated covariance proportion suggest that the forecast is good.

Bias Proportion

$$\frac{(\frac{1}{N}\sum_{t=T+1}^{T+N}\chi_t - \frac{1}{N}\sum_{t=T+1}^{T+N}\hat{\chi}_t)^2}{\frac{1}{N}\sum_{t=T+1}^{T+N}(\chi_t - \hat{\chi}_t)^2}$$

Variance Proportion

$$\frac{[Std(\chi_t) - Std(\hat{\chi}_t)]^2}{\frac{1}{N}\sum_{t=T+1}^{T+N}(\chi_t - \hat{\chi}_t)^2}$$

Covariance Proportion

$$\frac{2[1 - corr(\chi_t, \hat{\chi}_t)]Std(\chi_t)Std(\hat{\chi}_t)}{\frac{1}{N}\sum_{t=T+1}^{T+N}(\chi_t - \hat{\chi}_t)^2}$$

Because the models with and without the banking sector are nested, we apply an encompassing test (ENC-NEW test) as proposed in Clark and McCracken (2001).

$$ENC - NEW = P[\frac{P^{-1}\sum_t(\hat{u}_{1,t+1}^2 - \hat{u}_{1,t+1}\hat{u}_{2,t+1})}{P^{-1}\sum_t \hat{u}_{2,t+1}^2}]$$

Where P denotes the number of 1-step ahead predictions and R denotes in-sample size. In our case, $P = 16$ and $R = 44$. $\hat{u}_{1,t+1}$ is the forecast error from model 1 and $\hat{u}_{2,t+1}$ is the forecast error from model 2. Model 1 is nested in model 2.

Table 4.7 reports RMSE and Theil inequality. The results indicate that the model with a banking sector has a better forecasting performance than the model without a banking sector on both the U.S. and the Euro area real output growth per capita. The ENC-NEW test statistics for the U.S. output growth per capita is 15.8688 and the ENC-NEW test statistics for the Euro area output growth per capita is 11.9509. Hence, the null that the model without banks encompasses the model with banks is strongly rejected.

4.8 Concluding Remarks

This paper proposes an open economy DSGE model with financial frictions and bank intermediaries for the United States and the Euro area. The model is estimated with Bayesian technique. We investigate the role of the banking sector and macroprudential policies in the propagation of national and international business cycles. In particular, the model analyzes the importance of shocks to the banking sector (credit shocks) and to the financial system (financial shocks) in explaining economic fluctuations in the U.S. and in the Euro area. This paper also evaluates the model forecast accuracy of output growth during the Great Recession.

The first important result is that the amplification mechanism through collateral constraints is counteracted by a banking attenuator mechanism in the case of a national monetary policy shock. The second result is that the banking sector magnifies fluctuations from financial and technology shocks at the national level, and the transmission of shocks across these two regions. These results hold even when we relax the assumption that banks adjust interest rates according to Calvo pricing, assuming instead the flexible interest rate setting.

Third, credit and financial shocks can account for a large amount of macroeconomic fluctuations in the U.S. and in the Euro area. In particular, financial shocks are more significant than credit shocks. The results are supported by the high persistence of financial shocks, which is consistent with the fact that the economy recovery from a recession caused by a liquidity crisis is generally more sluggish.

Fourth, we incorporate an additional regulation premium to the cost of borrowing as macroprudential measures into the monetary policy, and find that macroprudential measures attenuate the U.S. financial shocks and act to stabilize the U.S. and Euro area economies. The finding implies that if macroprudential policies were in place before the Great Recession, the severity of the financial crisis could have been lessened. The policy implications derived from our results is in accord with Blanchard (2011, 2012): regulation in the banking sector may prevent future crises or minimize the damage it inflicts on the economy.

Finally, the proposed model provides a better out-of-sample forecasting performance on output growth during the Great Recession than a basic model that does not include the banking sector and macropudential policies.

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Appendix

Appendix A: Data and Sources

For the United States, the data are from Federal Reserve Bank and Census Bureau. Real GDP per capita growth is expressed as $100 * [In(GDP_t/POP_t) - In(GDP_{t-1}/POP_{t-1})]$ where GDP_t is series GDPC96-FRED2 and POP_t is the population of U.S. working-age households (age 16-64). Inflation is defined as $400 * [In(CPI_t/CPI_{t-1})]$ using Consumer Price Index monthly series and converted into quarterly frequency by arithmetic average. Domestic inflation is calculated by Implicit Price Deflator of GDP series, GDPDEF-FRED2. Real house price is House Price Index (new one-family houses sold including value of lot) deflated with implicit price deflator for nonfarm business sector from Census Bureau. Nominal interest rate (quarter-to-quarter, annualized, percent) is Effective Federal Fund Rate FEDFUNDS-FRED2. The monthly series is converted into quarterly frequency by arithmetic averaging. Loan rate to impatient household (quarter-to-quarter, annualized, percent) is contract rate on 30 year, fixed rate conventional home mortgage commitments from Board of Governors of the Federal Reserve System. Loan rate to entrepreneur (quarter-to-quarter, annualized, percent) is Bank Prime Loan Rate series. Deposit rate (quarter-to-quarter, annualized, percent) is 3-Month Treasury Bill, Secondary Market Rate series TB3MS-FRED2. Real wage is expressed as $100 * [In(W_t/W_{t-1})]$ where W_t is Real Compensation Per Hour series from nonfarm business sector. Real investment per capita growth is $100 * [In(INV_t/POP_t) - In(INV_{t-1}/POP_{t-1})]$ where INV_t is Real Gross Private Domestic Investment, series GPDIC96-FRED2. Nominal credit growth is defined as $100 * [In(CR_t/CR_{t-1})]$ where CR_t is bank credit from all commercial banks.

For the Euro area, the data are extracted from the database of Area Wide Model (AWM), European Central Bank and Eurostat. Similar to Lubik and Schorfheide (2005), real GDP up to 2005Q4 is from AWM database. We use the real GDP output growth rate announced in ECB to construct real GDP from 2006Q1 to 2011Q4. Annual population data series is converted to quarterly frequency using quadratic interpolation. Real investment per capita growth is constructed similar to real GDP per capita growth. Inflation (quarter-to-quarter, percent) is Indices of Consumer Prices, HICP overall index from ECB. The monthly series is converted into quarterly frequency by arithmetic averaging. Domestic inflation is calculated by Implicit Price Deflator of GDP series from ECB. Nominal interest rate (quarter-to-quarter, percent) is Money Market Interest Rate, quarterly data [*irt.st.q*] from Eurostat. Real house price (quarter-to-quarter, percent) is Residential Property Price Index deflated with the Harmonized index of consumer prices (HICP) from ECB. Loan rate to impatient household (quarter-to-quarter, percent) is Retail Bank Interest Rate, quarterly data [*irt.h.rtl.q*] from Eurostat up to 2003Q3 and the latest series is from ECB. Loan rate to entrepreneur (quarter-to-quarter, percent) is Retail Bank Interest Rate, loans to entrepreneur over 1 year, quarterly data [*irt.h.rtl.q*] from Eurostat up to 2003Q3 and the latest series is from ECB. Deposit rate (quarter-to-quarter, percent) is Retail Bank Interest Rate, deposits with agreed maturity up to 1 year, quarterly data [*irt.h.rtl.q*] from Eurostat up to 2003Q3 and the latest data is from ECB. Compensation per employee from ECB is divided by GDP price deflator to get real wage variable. Nominal credit growth is calculated by domestic credit from ECB.

Nominal exchange rate (quarter-to-quarter, percent) is nominal exchange rate monthly series EXUSEU-FRED2 (USD per unit of foreign currency) and converted into quarterly frequency by arithmetic averaging.

Appendix B: The Complete Log-linearization Model

Home Economy (the United States)

Patient Households

$$\frac{\bar{C}_P}{\bar{Y}}(\hat{C}_{P,t}) + \bar{q}\frac{\bar{H}_P}{\bar{Y}}(\hat{H}_{P,t} - \hat{H}_{P,t-1}) + \frac{\bar{D}}{\bar{Y}}\hat{d}_t = \bar{R}_P\frac{\bar{D}}{\bar{Y}}(\hat{R}_{P,t-1} + \hat{d}_{P,t-1} - \hat{\pi}_t) + \frac{\bar{W}_P\bar{N}_P}{\bar{Y}}(\hat{w}_{P,t} + \hat{N}_{P,t}) \tag{B-1}$$

$$-\hat{C}_{P,t} = \hat{R}_{P,t} - \hat{\pi}_{t+1} - \hat{C}_{P,t+1} \tag{B-2}$$

$$\hat{w}_{P,t} - \hat{C}_{P,t} = (\tau - 1)\hat{N}_{P,t} \tag{B-3}$$

$$(\hat{q}_t - \hat{C}_{P,t}) + \beta_P(\hat{C}_{P,t+1} - \hat{q}_{t+1}) = (1 - \beta_P)(-\hat{H}_{P,t}) \tag{B-4}$$

Impatient Households

$$\frac{\bar{C}_S}{\bar{Y}}(\hat{C}_{S,t}) + \bar{q}\frac{\bar{H}_S}{\bar{Y}}(\hat{H}_{S,t} - \hat{H}_{S,t-1}) + \bar{R}_S\frac{\bar{L}_S}{\bar{Y}}(\hat{R}_{S,t-1} + \hat{l}_{S,t-1} - \hat{\pi}_t) - \upsilon_t = \frac{\bar{W}_S\bar{N}_S}{\bar{Y}}(\hat{w}_{S,t} + \hat{N}_{S,t}) + \frac{\bar{L}_S}{\bar{Y}}\hat{l}_{S,t} \tag{B-5}$$

$$\hat{l}_{S,t} = \hat{q}_{t+1} + \hat{\pi}_{t+1} + \hat{H}_{S,t} - \hat{R}_{S,t} \tag{B-6}$$

$$(\beta_S\bar{R}_S - 1)\hat{\lambda}_{S,t} = \beta_S\bar{R}_S(-\hat{\pi}_{t+1} - \hat{C}_{S,t+1}) + \hat{C}_{S,t} + \hat{R}_{S,t} \tag{B-7}$$

$$\hat{w}_{S,t} - \hat{C}_{S,t} = (\tau - 1)\hat{N}_{S,t} \tag{B-8}$$

$$\frac{\bar{q}}{\bar{C}_S}(\hat{q}_t - \hat{C}_{S,t}) = \frac{j}{\bar{H}_S}(-\hat{H}_{S,t}) + \frac{\beta_S\bar{q}}{\bar{C}_S}(\hat{q}_{t+1} - \hat{C}_{S,t+1}) + \frac{m_s\bar{q}(1-\beta_S\bar{R}_S)}{\bar{C}_S\bar{R}_S}(\hat{\lambda}_{S,t} + \hat{\pi}_{t+1} + \hat{q}_{t+1}) \tag{B-9}$$

Entrepreneurs

$$\frac{\bar{C}_E}{\bar{Y}}(\hat{C}_{E,t}) + \frac{\bar{K}_E}{\bar{Y}}(\hat{K}_{E,t} - (1-\delta)\hat{K}_{E,t-1}) + \frac{\delta\bar{K}_E}{\bar{Y}}\hat{z}_t + \bar{q}\frac{\bar{H}_E}{\bar{Y}}(\hat{H}_{E,t} - \hat{H}_{E,t-1}) + \bar{R}_E\frac{\bar{L}_E}{\bar{Y}}(\hat{R}_{E,t-1} + \hat{l}_{E,t-1} - \hat{\pi}_t) = \frac{\bar{r}_K\bar{K}_E}{\bar{Y}}(\hat{r}_{K,t} + \hat{K}_{E,t-1}) + \frac{\bar{L}_E}{\bar{Y}}\hat{l}_{E,t} + \frac{\bar{q}\bar{R}_V\bar{H}_E}{\bar{Y}}(\hat{R}_{V,t} + \hat{H}_{E,t-1} + \hat{q}_t) \tag{B-10}$$

$$\frac{\bar{R}_E\bar{L}_E}{\bar{Y}}(\hat{R}_{E,t} + \hat{l}_{E,t}) = \frac{m_H\bar{q}\bar{H}_E}{\bar{Y}}(\hat{q}_{t+1} + \hat{H}_{E,t} + \hat{\pi}_{t+1}) + \frac{m_K(1-\delta)\bar{K}_E}{\bar{Y}}(\hat{K}_{E,t} + \hat{\pi}_{t+1} + \hat{z}_{t+1}) \tag{B-11}$$

$$(\beta_E\bar{R}_E - 1)(\hat{\lambda}_{E,t} + \hat{R}_{E,t}) = \beta_E\bar{R}_E(\hat{R}_{E,t} - \hat{\pi}_{t+1} - \hat{C}_{E,t+1}) + \hat{C}_{E,t} \tag{B-12}$$

$$\beta_E(1-\delta+\bar{r}_K)\hat{C}_{E,t+1} + \hat{z}_t - \hat{C}_{E,t} = \frac{m_K(1-\delta)(1-\beta_E\bar{R}_E)}{\bar{R}_E}(\hat{\lambda}_{E,t} + \hat{\pi}_{t+1} + \hat{z}_{t+1}) + \beta_E\bar{r}_K\hat{r}_{K,t+1} + \beta_E(1-\delta)\hat{z}_{t+1} \tag{B-13}$$

$$(\hat{q}_t - \hat{C}_{E,t}) - (1-\beta_E(1+\bar{R}_V))(\hat{q}_{t+1} + \hat{\lambda}_{E,t} + \hat{\pi}_{t+1}) = \beta_E(1+\bar{R}_V)(-\hat{C}_{E,t+1}) + \beta_E\bar{R}_V\hat{R}_{V,t+1} \tag{B-14}$$

Banks

$$\frac{\bar{D}}{\bar{Y}}\hat{d}_t + \frac{\bar{K}_B}{\bar{Y}}\hat{k}_{B,t} = \frac{\bar{L}_E}{\bar{Y}}\hat{l}_{E,t} + \frac{\bar{L}_S}{\bar{Y}}\hat{l}_{S,t} \tag{B-15}$$

$$\bar{C}_B\hat{C}_{B,t} + \bar{k}_B\hat{k}_{B,t} = (1-\delta_b)(\hat{k}_{B,t-1} - \hat{\pi}_t) + \bar{\Omega}_B\hat{\Omega}_{B,t} \tag{B-16}$$

$$\begin{aligned}\bar{C}_B\hat{C}_{B,t} = \bar{R}_E\bar{L}_E(\hat{R}_{E,t-1} + \hat{l}_{E,t-1} - \hat{\pi}_t) + \bar{R}_S\bar{L}_S(\hat{R}_{S,t-1} + \hat{l}_{S,t-1} - \hat{\pi}_t)\\ -\bar{R}_P\bar{D}(\hat{R}_{P,t-1} + \hat{d}_{t-1} - \hat{\pi}_t) - \bar{L}_E\hat{l}_{E,t} - \bar{L}_S\hat{l}_{S,t} + \bar{D}\hat{d}_t - \upsilon_t\end{aligned} \tag{B-17}$$

$$(\hat{R}_{P,t} - \hat{R}_{P,t-1}) = \beta_B(\hat{R}_{P,t+1} - \hat{R}_{P,t}) + \frac{(1-\beta_B\theta_D)(1-\theta_D)}{\theta_D}(-\hat{R}_{P,t} + \hat{R}_t + \hat{Z}_{D,t}) \tag{B-18}$$

$$(\hat{R}_{E,t} - \hat{R}_{E,t-1}) = \beta_B(\hat{R}_{E,t+1} - \hat{R}_{E,t}) + \frac{(1-\beta_B\theta_E)(1-\theta_E)}{\theta_E}(-\hat{R}_{E,t} + \hat{R}_t + \hat{Z}_{E,t}) \tag{B-19}$$

$$(\hat{R}_{S,t} - \hat{R}_{S,t-1}) = \beta_B(\hat{R}_{S,t+1} - \hat{R}_{S,t}) + \frac{(1-\beta_B\theta_S)(1-\theta_S)}{\theta_S}(-\hat{R}_{S,t} + \hat{R}_t + \hat{Z}_{S,t}) \tag{B-20}$$

Final Good Producers

$$\hat{Y}_t + \hat{MC}_t = \hat{r}_{K,t} + \hat{K}_{E,t-1} \tag{B-21}$$

$$\hat{Y}_t + \hat{MC}_t = \hat{R}_{V,t} + \hat{q}_t + \hat{H}_{E,t-1} \tag{B-22}$$

$$\hat{Y}_t + \hat{MC}_t = \hat{w}_{P,t} + \hat{N}_{P,t} \tag{B-23}$$

$$\hat{Y}_t + \hat{MC}_t = \hat{w}_{S,t} + \hat{N}_{S,t} \tag{B-24}$$

$$\hat{Y}_t = \hat{A}_t + \hat{\varpi}_t + \alpha\hat{K}_{E,t-1} + \upsilon\hat{H}_{E,t-1} + (1-\alpha-\upsilon)(1-\sigma)\hat{N}_{P,t} + (1-\alpha-\upsilon)\sigma\hat{N}_{S,t} \tag{B-25}$$

Capital Producers

$$\hat{I}_t = \frac{1}{1+\beta}\hat{I}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{I}_{t+1} + \frac{1/\Psi_I}{1+\beta}\hat{z}_t + \hat{\Theta}_t \tag{B-26}$$

$$\hat{K}_t = (1-\delta)\hat{K}_{t-1} + \delta\hat{I}_{t-1} + \delta\hat{\Theta}_t \tag{B-27}$$

Price Setting

$$\hat{\pi}_{H,t} - \xi_p\hat{\pi}_{H,t-1} = \beta(E_t\hat{\pi}_{H,t+1} - \xi_p\hat{\pi}_{H,t}) + \frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H}(\hat{MC}_t + \kappa\hat{S}_t) + u_{H,t} \tag{B-28}$$

$$\hat{\pi}_{F,t} - \xi_p\hat{\pi}_{F,t-1} = \beta(E_t\hat{\pi}_{F,t+1} - \xi_p\hat{\pi}_{F,t}) + \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F}(\hat{\psi}_{F,t}) + u_{F,t} \tag{B-29}$$

$$\begin{aligned}\frac{\theta_w}{1-\theta_w}(\hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_t - \xi_w\hat{\pi}_{t-1}) = \frac{1-\beta_U\theta_w}{1+(\tau-1)\lambda_w}&[(\tau-1)\hat{N}_t - \hat{U}_{C,t} + u_{n,t} - \hat{w}_t] \\ +\frac{\beta_U\theta_w}{1-\theta_w}&(E_t\hat{w}_{t+1} - \hat{w}_t + E_t\hat{\pi}_{t+1} - \xi_w\hat{\pi}_t)\end{aligned} \tag{B-30}$$

General Equilibrium

$$\begin{aligned}\hat{Y}_t = \frac{\bar{\Gamma}}{\bar{Y}}\hat{\Gamma}_t + \frac{\bar{I}_{KE}}{\bar{Y}}\hat{I}_{KE,t} + \frac{\bar{G}}{\bar{Y}}\hat{G}_t + \frac{\bar{\Gamma}^*_H}{\bar{Y}}(\hat{e}_t + \hat{P}^*_{H,t} + \hat{\Gamma}^*_{H,t} - \hat{P}_t) \\ +\frac{\bar{I}^*_H}{\bar{Y}}(\hat{e}_t + \hat{P}^*_{H,t} + \hat{I}^*_{H,t} - \hat{P}_t) - \frac{\bar{\Gamma}_F}{\bar{Y}}(\hat{P}_{F,t} + \hat{\Gamma}_{F,t} - \hat{P}_t) - \frac{\bar{I}_F}{\bar{Y}}(\hat{P}_{F,t} + \hat{I}_{F,t} - \hat{P}_t)\end{aligned} \tag{B-31}$$

$$\frac{\bar{C}_P}{\bar{\Gamma}}\hat{C}_{P,t} + \frac{\bar{C}_S}{\bar{\Gamma}}\hat{C}_{S,t} + \frac{\bar{C}_E}{\bar{\Gamma}}\hat{C}_{E,t} + \frac{\bar{\Omega}_B}{\bar{\Gamma}}\hat{\Omega}_{B,t} = \hat{\Gamma}_t \tag{B-32}$$

$$\frac{\bar{H}_S}{\bar{Y}}\hat{H}_{S,t} + \frac{\bar{H}_E}{\bar{Y}}\hat{H}_{E,t} + \frac{\bar{H}_P}{\bar{Y}}\hat{H}_{P,t} = 0 \tag{B-33}$$

$$\hat{R}_t = \rho_R\hat{R}_{t-1} + (1-\rho_R)(\phi_\pi\hat{\pi}_t + \phi_y(\hat{Y}_t - \hat{Y}_{t-1} + \hat{\varpi}_t) + \phi_e\Delta\hat{E}_t) + \varepsilon_{R,t} \tag{B-34}$$

Foreign Economy (the Euro Area)

Patient Households

$$\frac{\bar{C}_P^*}{\bar{Y}^*}(\hat{C}_{P,t}^*)+\bar{q}^*\frac{\bar{H}_P^*}{\bar{Y}^*}(\hat{H}_{P,t}^*-\hat{H}_{P,t-1}^*)+\frac{\bar{D}^*}{\bar{Y}^*}\hat{d}_t^* = \bar{R}_P^*\frac{\bar{D}^*}{\bar{Y}^*}(\hat{R}_{P,t-1}^*+\hat{d}_{P,t-1}^*-\hat{\pi}_t^*)+\frac{\bar{W}_P^*\bar{N}_P^*}{\bar{Y}^*}(\hat{w}_{P,t}^*+\hat{N}_{P,t}^*) \tag{B-35}$$

$$-\hat{C}_{P,t}^* = \hat{R}_{P,t}^* - \hat{\pi}_{t+1}^* - \hat{C}_{P,t+1}^* \tag{B-36}$$

$$\hat{w}_{P,t}^* - \hat{C}_{P,t}^* = (\tau^* - 1)\hat{N}_{P,t}^* \tag{B-37}$$

$$(\hat{q}_t^* - \hat{C}_{P,t}^*) + \beta_P^*(\hat{C}_{P,t+1}^* - \hat{q}_{t+1}^*) = (1-\beta_P^*)(-\hat{H}_{P,t}^*) \tag{B-38}$$

Impatient Households

$$\begin{aligned}\frac{\bar{C}_S^*}{\bar{Y}^*}(\hat{C}_{S,t}^*) + \bar{q}^*\frac{\bar{H}_S^*}{\bar{Y}^*}(\hat{H}_{S,t}^* - \hat{H}_{S,t-1}^*) + \bar{R}_S^*\frac{\bar{L}_S^*}{\bar{Y}^*}(\hat{R}_{S,t-1}^* + \hat{l}_{S,t-1}^* - \hat{\pi}_t^*) - \upsilon_t^* \\ = \frac{\bar{W}_S^*\bar{N}_S^*}{\bar{Y}^*}(\hat{w}_{S,t}^* + \hat{N}_{S,t}^*) + \frac{\bar{L}_S^*}{\bar{Y}^*}\hat{l}_{S,t}^*\end{aligned} \tag{B-39}$$

$$\hat{l}_{S,t}^* = \hat{q}_{t+1}^* + \hat{\pi}_{t+1}^* + \hat{H}_{S,t}^* - \hat{R}_{S,t}^* \tag{B-40}$$

$$(\beta_S^*\bar{R}_S^* - 1)\hat{\lambda}_{S,t}^* = \beta_S^*\bar{R}_S^*(-\hat{\pi}_{t+1}^* - \hat{C}_{S,t+1}^*) + \hat{C}_{S,t}^* + \hat{R}_{S,t}^* \tag{B-41}$$

$$\hat{w}_{S,t}^* - \hat{C}_{S,t}^* = (\tau^* - 1)\hat{N}_{S,t}^* \tag{B-42}$$

$$\frac{\bar{q}^*}{\bar{C}_S^*}(\hat{q}_t^*-\hat{C}_{S,t}^*) = \frac{j^*}{\bar{H}_S^*}(-\hat{H}_{S,t}^*)+\frac{\beta_S^*\bar{q}^*}{\bar{C}_S^*}(\hat{q}_{t+1}^*-\hat{C}_{S,t+1}^*)+\frac{m_s^*\bar{q}^*(1-\beta_S^*\bar{R}_S^*)}{\bar{C}_S^*\bar{R}_S^*}(\hat{\lambda}_{S,t}^*+\hat{\pi}_{t+1}^*+\hat{q}_{t+1}^*) \tag{B-43}$$

Entrepreneurs

$$\begin{aligned}\frac{\bar{C}_E^*}{\bar{Y}^*}(\hat{C}_{E,t}^*) + \frac{\bar{K}_E^*}{\bar{Y}^*}(\hat{K}_{E,t}^* - (1-\delta^*)\hat{K}_{E,t-1}^*) + \frac{\delta^*\bar{K}_E^*}{\bar{Y}^*}\hat{z}_t^* + \bar{q}^*\frac{\bar{H}_E^*}{\bar{Y}^*}(\hat{H}_{E,t}^* - \hat{H}_{E,t-1}^*)+ \\ \bar{R}_E^*\frac{\bar{L}_E^*}{\bar{Y}^*}(\hat{R}_{E,t-1}^* + \hat{l}_{E,t-1}^* - \hat{\pi}_t^*) = \frac{\bar{r}_K^*\bar{K}_E^*}{\bar{Y}^*}(\hat{r}_{K,t}^* + \hat{K}_{E,t-1}^*) + \frac{\bar{L}_E^*}{\bar{Y}^*}\hat{l}_{E,t}^* + \frac{\bar{q}^*\bar{R}_V^*\bar{H}_E^*}{\bar{Y}^*}(\hat{R}_{V,t}^* + \hat{H}_{E,t-1}^* + \hat{q}_t^*)\end{aligned} \tag{B-44}$$

$$\frac{\bar{R}_E^*\bar{L}_E^*}{\bar{Y}^*}(\hat{R}_{E,t}^*+\hat{l}_{E,t}^*) = \frac{m_H^*\bar{q}^*\bar{H}_E^*}{\bar{Y}^*}(\hat{q}_{t+1}^*+\hat{H}_{E,t}^*+\hat{\pi}_{t+1}^*)+\frac{m_K^*(1-\delta^*)\bar{K}_E^*}{\bar{Y}^*}(\hat{K}_{E,t}^*+\hat{\pi}_{t+1}^*+\hat{z}_{t+1}^*) \quad \text{(B-45)}$$

$$(\beta_E^*\bar{R}_E^*-1)(\hat{\lambda}_{E,t}^*+\hat{R}_{E,t}^*) = \beta_E^*\bar{R}_E^*(\hat{R}_{E,t}^*-\hat{\pi}_{t+1}^*-\hat{C}_{E,t+1}^*)+\hat{C}_{E,t}^* \quad \text{(B-46)}$$

$$\begin{aligned} \beta_E^*(1-\delta^*+\bar{r}_K^*)\hat{C}_{E,t+1}^*+\hat{z}_t^*-\hat{C}_{E,t}^* &= \\ \frac{m_K^*(1-\delta^*)(1-\beta_E^*\bar{R}_E^*)}{\bar{R}_E^*}(\hat{\lambda}_{E,t}^*+\hat{\pi}_{t+1}^*+\hat{z}_{t+1}^*)+\beta_E^*\bar{r}_K^*\hat{r}_{K,t+1}^*+\beta_E^*(1-\delta^*)\hat{z}_{t+1}^* \end{aligned} \quad \text{(B-47)}$$

$$(\hat{q}_t^*-\hat{C}_{E,t}^*)-(1-\beta_E^*(1+\bar{R}_V^*))(\hat{q}_{t+1}^*+\hat{\lambda}_{E,t}^*+\hat{\pi}_{t+1}^*) = \beta_E^*(1+\bar{R}_V^*)(-\hat{C}_{E,t+1}^*)+\beta_E^*\bar{R}_V^*\hat{R}_{V,t+1}^* \quad \text{(B-48)}$$

Banks

$$\frac{\bar{D}^*}{\bar{Y}^*}\hat{d}_t^*+\frac{\bar{K}_B^*}{\bar{Y}^*}\hat{k}_{B,t}^* = \frac{\bar{L}_E^*}{\bar{Y}^*}\hat{l}_{E,t}^*+\frac{\bar{L}_S^*}{\bar{Y}^*}\hat{l}_{S,t}^* \quad \text{(B-49)}$$

$$\bar{C}_B^*\hat{C}_{B,t}^*+\bar{k}_B^*\hat{k}_{B,t}^* = (1-\delta_{b^*})(\hat{k}_{B,t-1}^*-\hat{\pi}_t^*)+\bar{\Omega}_B^*\hat{\Omega}_{B,t}^* \quad \text{(B-50)}$$

$$\begin{aligned} \bar{C}_B^*\hat{C}_{B,t}^* &= \bar{R}_E^*\bar{L}_E^*(\hat{R}_{E,t-1}^*+\hat{l}_{E,t-1}^*-\hat{\pi}_t^*) \\ +\bar{R}_S^*\bar{L}_S^*(\hat{R}_{S,t-1}^*+\hat{l}_{S,t-1}^*-\hat{\pi}_t^*)-\bar{R}_P^*\bar{D}^*(\hat{R}_{P,t-1}^*+\hat{d}_{t-1}^*-\hat{\pi}_t^*) &- \bar{L}_E^*\hat{l}_{E,t}^*-\bar{L}_S^*\hat{l}_{S,t}^*+\bar{D}^*\hat{d}_t^*-\upsilon_t^* \end{aligned} \quad \text{(B-51)}$$

$$(\hat{R}_{P,t}^*-\hat{R}_{P,t-1}^*) = \beta_B^*(\hat{R}_{P,t+1}^*-\hat{R}_{P,t}^*)+\frac{(1-\beta_B^*\theta_D^*)(1-\theta_D^*)}{\theta_D^*}(-\hat{R}_{P,t}^*+\hat{R}_t^*+\hat{Z}_{D,t}^*) \quad \text{(B-52)}$$

$$(\hat{R}_{E,t}^*-\hat{R}_{E,t-1}^*) = \beta_B^*(\hat{R}_{E,t+1}^*-\hat{R}_{E,t}^*)+\frac{(1-\beta_B^*\theta_E^*)(1-\theta_E^*)}{\theta_E^*}(-\hat{R}_{E,t}^*+\hat{R}_t^*+\hat{Z}_{E,t}^*) \quad \text{(B-53)}$$

$$(\hat{R}_{S,t}^*-\hat{R}_{S,t-1}^*) = \beta_B^*(\hat{R}_{S,t+1}^*-\hat{R}_{S,t}^*)+\frac{(1-\beta_B^*\theta_S^*)(1-\theta_S^*)}{\theta_S^*}(-\hat{R}_{S,t}^*+\hat{R}_t^*+\hat{Z}_{S,t}^*) \quad \text{(B-54)}$$

Final Good Producers

$$\hat{Y}_t^* + \hat{MC}_t^* = \hat{r}_{K,t}^* + \hat{K}_{E,t-1}^* \tag{B-55}$$

$$\hat{Y}_t^* + \hat{MC}_t^* = \hat{R}_{V,t}^* + \hat{q}_t^* + \hat{H}_{E,t-1}^* \tag{B-56}$$

$$\hat{Y}_t^* + \hat{MC}_t^* = \hat{w}_{P,t}^* + \hat{N}_{P,t}^* \tag{B-57}$$

$$\hat{Y}_t^* + \hat{MC}_t^* = \hat{w}_{S,t}^* + \hat{N}_{S,t}^* \tag{B-58}$$

$$\hat{Y}_t^* = \hat{A}_t^* + \hat{\varpi}_t + \alpha^* \hat{K}_{E,t-1}^* + \upsilon^* \hat{H}_{E,t-1}^* + (1-\alpha^*-\upsilon^*)(1-\sigma^*)\hat{N}_{P,t}^* + (1-\alpha^*-\upsilon^*)\sigma^* \hat{N}_{S,t}^* \tag{B-59}$$

Capital Producers

$$\hat{I}_t^* = \frac{1}{1+\beta^*}\hat{I}_{t-1}^* + \frac{\beta^*}{1+\beta^*}E_t\hat{I}_{t+1}^* + \frac{1/\Psi_I^*}{1+\beta^*}\hat{z}_t^* + \hat{\Theta}_t^* \tag{B-60}$$

$$\hat{K}_t^* = (1-\delta^*)\hat{K}_{t-1}^* + \delta^* \hat{I}_{t-1}^* + \delta^* \hat{\Theta}_t^* \tag{B-61}$$

Price Setting

$$\hat{\pi}_{F,t}^* - \xi_p^* \hat{\pi}_{F,t-1}^* = \beta^*(E_t\hat{\pi}_{F,t+1}^* - \xi_p^* \hat{\pi}_{F,t}^*) + \frac{(1-\theta_F^*)(1-\beta^*\theta_F^*)}{\theta_F^*}(\hat{MC}_t^* + \kappa^* \hat{S}_t^*) + u_{F,t}^* \tag{B-62}$$

$$\hat{\pi}_{H,t}^* - \xi_p^* \hat{\pi}_{H,t-1}^* = \beta^*(E_t\hat{\pi}_{H,t+1}^* - \xi_p^* \hat{\pi}_{H,t}^*) + \frac{(1-\theta_H^*)(1-\beta^*\theta_H^*)}{\theta_H^*}(\hat{\psi}_{H,t}^*) + u_{H,t}^* \tag{B-63}$$

$$\begin{aligned}\frac{\theta_w^*}{1-\theta_w^*}(\hat{w}_t^* - \hat{w}_{t-1}^* + \hat{\pi}_t^* - \xi_w^* \hat{\pi}_{t-1}^*) = {} & \frac{1-\beta_U^*\theta_w^*}{1+(\tau^*-1)\lambda_w^*}[(\tau^*-1)\hat{N}_t^* - \hat{U}_{C,t}^* + u_{n,t}^* - \hat{w}_t^*] \\ & + \frac{\beta_U^*\theta_w^*}{1-\theta_w^*}(E_t\hat{w}_{t+1}^* - \hat{w}_t^* + E_t\hat{\pi}_{t+1}^* - \xi_w^* \hat{\pi}_t^*)\end{aligned} \tag{B-64}$$

General Equilibrium

$$\hat{Y}_t^* = \frac{\bar{\Gamma}^*}{\bar{Y}^*}\hat{\Gamma}_t^* + \frac{\bar{I}_{KE}^*}{\bar{Y}^*}\hat{I}_{KE,t}^* + \frac{\bar{G}^*}{\bar{Y}^*}\hat{G}_t^* - \frac{\bar{\Gamma}_H^*}{\bar{Y}^*}(\hat{P}_{H,t}^* + \hat{\Gamma}_{H,t}^* - \hat{P}_t^*)$$
$$-\frac{\bar{I}_H^*}{\bar{Y}^*}(\hat{P}_{H,t}^* + \hat{I}_{H,t}^* - \hat{P}_t^*) + \frac{\bar{\Gamma_F}}{\bar{Y}^*}(\hat{P}_{F,t} + \hat{\Gamma}_{F,t} - \hat{P}_t^* - \hat{e}_t) + \frac{\bar{I_F}}{\bar{Y}^*}(\hat{P}_{F,t} + \hat{I}_{F,t} - \hat{P}_t^* - \hat{e}_t) \tag{B-65}$$

$$\frac{\bar{C}_P^*}{\bar{\Gamma}^*}\hat{C}_{P,t}^* + \frac{\bar{C}_S^*}{\bar{\Gamma}^*}\hat{C}_{S,t}^* + \frac{\bar{C}_E^*}{\bar{\Gamma}^*}\hat{C}_{E,t}^* + \frac{\bar{\Omega}_B^*}{\bar{\Gamma}^*}\hat{\Omega}_{B,t}^* = \hat{\Gamma}_t^* \tag{B-66}$$

$$\frac{\bar{H}_S^*}{\bar{Y}^*}\hat{H}_{S,t}^* + \frac{\bar{H}_E^*}{\bar{Y}^*}\hat{H}_{E,t}^* + \frac{\bar{H}_P^*}{\bar{Y}^*}\hat{H}_{P,t}^* = 0 \tag{B-67}$$

$$\hat{R}_t^* = \rho_R^*\hat{R}_{t-1}^* + (1-\rho_R^*)(\phi_\pi^*\hat{\pi}_t^* + \phi_y^*(\hat{Y}_t^* - \hat{Y}_{t-1}^* + \hat{\varpi}_t) - \phi_e^*\Delta\hat{E}_t) + \varepsilon_{R,t}^* \tag{B-68}$$

Open Economy Feature

$$\frac{\bar{e}\bar{B}^*}{\bar{P}\bar{Y}}(\hat{e}_t - \hat{e}_{t+1} + \hat{J}_{t+1} - \hat{\pi}_{t+1}) = \frac{\bar{e}\bar{B}^*\bar{R}^*\bar{\varrho}}{\bar{\pi}\bar{Y}}(\hat{\varrho}_t + \hat{R}_t^* + \hat{J}_t) + \frac{\bar{e}\bar{P}_H^*\bar{\Gamma}_H^*}{\bar{P}\bar{Y}}(\hat{e}_t + \hat{P}_{H,t}^* + \hat{\Gamma}_{H,t}^* - \hat{P}_t) +$$
$$\frac{\bar{e}\bar{P}_H^*\bar{I}_H^*}{\bar{P}\bar{Y}}(\hat{e}_t + \hat{P}_{H,t}^* + \hat{I}_{H,t}^* - \hat{P}_t) - \frac{\bar{P}_F\bar{\Gamma}_F}{\bar{P}\bar{Y}}(\hat{P}_{F,t} + \hat{\Gamma}_{F,t} - \hat{P}_t) - \frac{\bar{P}_F\bar{I}_F}{\bar{P}\bar{Y}}(\hat{P}_{F,t} + \hat{I}_{F,t} - \hat{P}_t) \tag{B-69}$$

$$\hat{\varrho}_t = -\chi\frac{\bar{e}\bar{B}^*}{\bar{P}\bar{Y}}(\hat{J}_t) + \varepsilon_{\varrho,t} \tag{B-70}$$

$$\hat{J}_t = \hat{e}_t + \hat{b}_t^* \tag{B-71}$$

$$\hat{b}_t + \hat{e}_t + \hat{b}_t^* = 0 \tag{B-72}$$

$$\hat{\pi}_t = (1-\kappa)\hat{\pi}_{H,t} + \kappa\hat{\pi}_{F,t} \tag{B-73}$$

$$\hat{S}_t = \hat{S}_{t-1} - \hat{\pi}_{H,t} + \hat{\pi}_{F,t} \tag{B-74}$$

$$\hat{Q}_t = \hat{\psi}_{F,t} + (1-\kappa)\hat{S}_t + \kappa^*\hat{S}_t^* \tag{B-75}$$

$$E_t\hat{e}_{t+1} - \hat{e}_t = E_t\hat{Q}_{t+1} - \hat{Q}_t + E_t\hat{\pi}_{t+1} - E_t\hat{\pi}_{t+1}^* + \varepsilon_{E,t} \tag{B-76}$$

$$\hat{R}_t - \hat{R}_t^* = E_t(\hat{e}_{t+1} - \hat{e}_t) + \hat{\varrho}_t + \varepsilon_{rp,t} - \varepsilon_{rp,t}^* \tag{B-77}$$

$$\hat{\pi}_t^* = (1-\kappa^*)\hat{\pi}_{F,t}^* + \kappa^* \hat{\pi}_{H,t}^* \tag{B-78}$$

$$\hat{S}_t^* = \hat{S}_{t-1}^* + \hat{\pi}_{H,t}^* - \hat{\pi}_{F,t}^* \tag{B-79}$$

$$\hat{Q}_t = -\hat{Q}_t^* = -\hat{\psi}_{H,t}^* - (1-\kappa^*)\hat{S}_t^* - \kappa \hat{S}_t \tag{B-80}$$

$$\hat{\Gamma}_{H,t}^* = -\zeta(1-\kappa^*)\hat{S}_t^* + \hat{\Gamma}_t^* \tag{B-81}$$

$$\hat{\Gamma}_{F,t} = -\eta(1-\kappa)\hat{S}_t + \hat{\Gamma}_t \tag{B-82}$$

$$\hat{\Gamma}_{H,t} = -\eta\kappa\hat{S}_t + \hat{\Gamma}_t \tag{B-83}$$

$$\hat{\Gamma}_{F,t}^* = -\zeta\kappa^*\hat{S}_t^* + \hat{\Gamma}_t^* \tag{B-84}$$

$$\hat{I}_{H,t}^* = -\zeta(1-\kappa^*)\hat{S}_t^* + \hat{I}_t^* \tag{B-85}$$

$$\hat{I}_{F,t} = -\eta(1-\kappa)\hat{S}_t + \hat{I}_t \tag{B-86}$$

$$\hat{I}_{H,t} = -\eta\kappa\hat{S}_t + \hat{I}_t \tag{B-87}$$

$$\hat{I}_{F,t}^* = -\zeta\kappa^*\hat{S}_t^* + \hat{I}_t^* \tag{B-88}$$

Appendix C: Steady State

To safe space, we only explain the steady state of the home economy.

$$\bar{MC} = \frac{\varepsilon - 1}{\varepsilon} \tag{C-1}$$

$$\bar{R}_P = 1/\beta_P = \frac{|\varepsilon_d|}{|\varepsilon_d| + 1})\bar{R}_{IB} \tag{C-2}$$

$$\bar{R}_E = (\frac{\varepsilon_{bE}}{\varepsilon_{bE} - 1})\bar{R}_{IB} \tag{C-3}$$

$$\bar{R}_S = (\frac{\varepsilon_{bS}}{\varepsilon_{bS} - 1})\bar{R}_{IB} \tag{C-4}$$

$$\bar{\lambda}_E = (1 - \beta_E \bar{R}_E)/\bar{C}_E/\bar{R}_E \tag{C-5}$$

$$\bar{\lambda}_S = (1 - \beta_S \bar{R}_S)/\bar{C}_S/\bar{R}_E \tag{C-6}$$

$$\bar{R}_K = (1 - m_K(1-\delta)(1 - \beta_E \bar{R}_E)/\bar{R}_E)/\beta_E - (1-\delta) \tag{C-7}$$

$$\bar{R}_V = (1 - (1 - \beta_E \bar{R}_E) m_E/\bar{R}_E)/\beta_E - 1 \tag{C-8}$$

$$\frac{\bar{K}_E}{\bar{Y}} = \frac{\alpha\mu \bar{M}C}{\bar{R}_K} \tag{C-9}$$

$$\bar{q}\bar{R}_V \frac{\bar{H}_E}{\bar{Y}} = \upsilon \bar{M}C \tag{C-10}$$

$$\frac{\bar{L}_E}{\bar{Y}} = (\frac{m_E \bar{q} \bar{H}_E}{\bar{R}_E \bar{Y}} + \frac{m_K \bar{K}_E}{\bar{Y}})/\bar{R}_E \tag{C-11}$$

$$\frac{\bar{C}_E}{\bar{Y}} = \frac{(\bar{R}_K - \delta)\bar{K}_E}{\bar{Y}} + \frac{\bar{L}_E(1 - R_E)}{\bar{Y}} + \bar{q}\bar{R}_V \frac{\bar{H}_E}{\bar{Y}} \tag{C-12}$$

$$\frac{\bar{C}_S}{\bar{Y}} = \frac{(1 - \alpha - \upsilon)\sigma \bar{M}C}{(1 - \frac{m_S}{\bar{R}_S}\frac{j(1-\bar{R}_S)}{(1-\beta_S-(1-\beta_S\bar{R}_S)m_S/\bar{R}_S)})} \tag{C-13}$$

$$\bar{q}\frac{\bar{H}_S}{\bar{Y}} = \frac{j}{(1 - \beta_S - (1 - \beta_S \bar{R}_S) m_S/\bar{R}_S)} \frac{\bar{C}_S}{\bar{Y}} \tag{C-14}$$

$$\frac{\bar{W}_S \bar{N}_S}{\bar{Y}} = (1 - \alpha - \upsilon)\sigma \bar{M}C \tag{C-15}$$

$$\frac{\bar{L}_S}{\bar{Y}} = \frac{m_S \bar{q} \bar{H}_S}{\bar{R}_S \bar{Y}} = \frac{m_S}{\bar{R}_S} \frac{j}{(1-\beta_S-(1-\beta_S\bar{R}_S)m_S/\bar{R}_S)} \frac{\bar{C}_S}{\bar{Y}} \tag{C-16}$$

$$\bar{K}_B + \bar{D} = \bar{L}_E + \bar{L}_S \tag{C-17}$$

$$\frac{\bar{W}_P \bar{N}_P}{\bar{Y}} = (1-\alpha-\upsilon)(1-\sigma)\bar{MC} \tag{C-18}$$

$$\frac{\bar{C}_P}{\bar{Y}} = \frac{\bar{W}_P \bar{N}_P}{\bar{Y}} + \frac{\bar{D}}{\bar{Y}}(R_P - 1) \tag{C-19}$$

$$\bar{q}\frac{\bar{H}_P}{\bar{Y}} = \frac{j}{(1-\beta_P)} \frac{\bar{C}_P}{\bar{Y}} \tag{C-20}$$

$$\bar{C}_B = \bar{R}_S \bar{L}_S + \bar{R}_E \bar{L}_E - \bar{R}_P \bar{D} - \bar{L}_S - \bar{L}_E + \bar{D} \tag{C-21}$$

$$\bar{\Omega}_B = \delta_b \bar{K}_B / \bar{Y} + \bar{C}_B \tag{C-22}$$

$$\bar{\Gamma} = \bar{C}_P + \bar{C}_S + \bar{C}_E + \bar{\Omega}_B \tag{C-23}$$

$$\bar{Y} = \bar{C}_P + \bar{C}_S + \bar{C}_E + \bar{\Omega}_B + \delta \bar{K}_E + \bar{G} + (\kappa^* \bar{\Gamma}^* + \kappa^* \delta^* \bar{K}_E^* - \kappa \bar{\Gamma} - \kappa \delta \bar{K}_E) \tag{C-24}$$

$$\bar{q} = \bar{R}_S \bar{L}_S / \bar{Y} / m_S + \upsilon \bar{MC} / \bar{R}_V + j \bar{C}_P / \bar{Y} / (1-\beta_P) \tag{C-25}$$

Figure 4.2: Stylized Facts

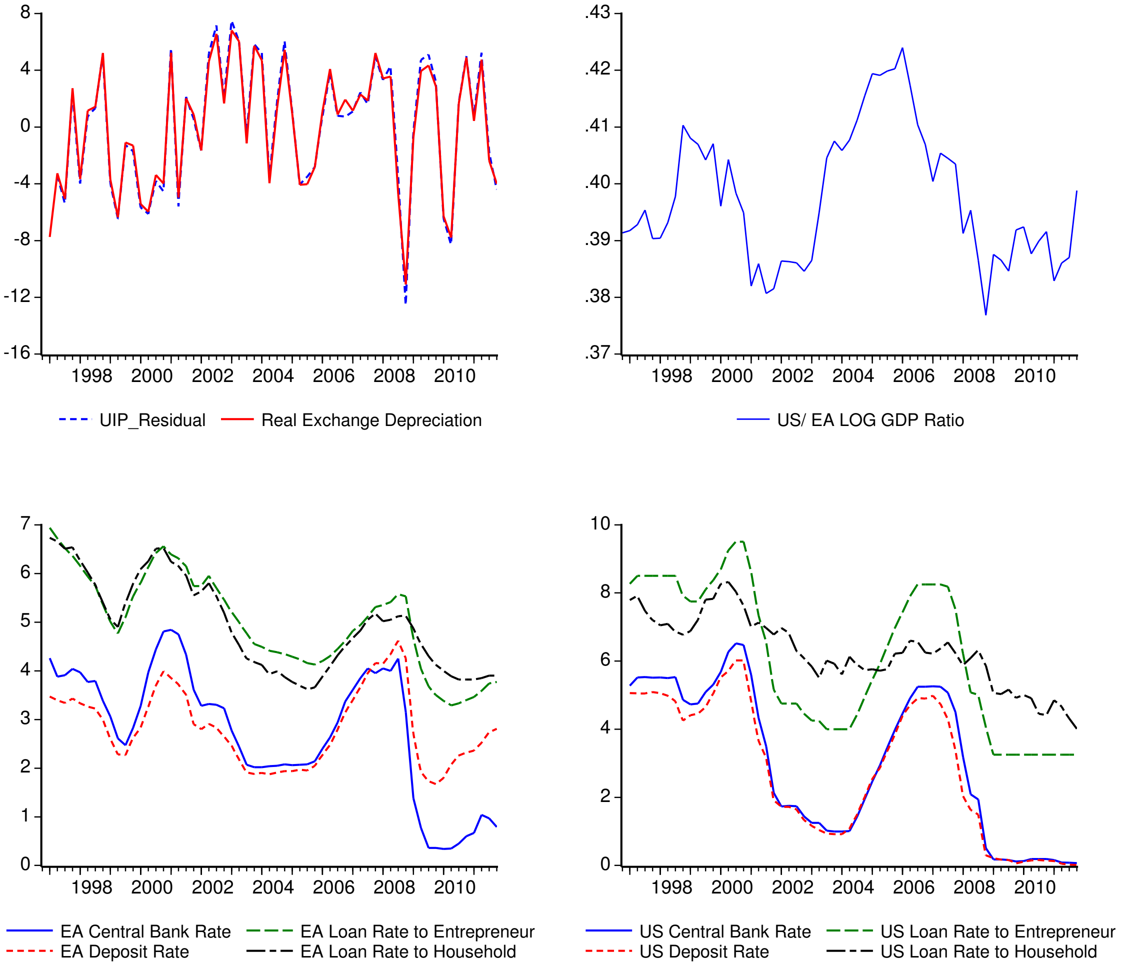

Figure 4.3: US Negative Financial Shock on US

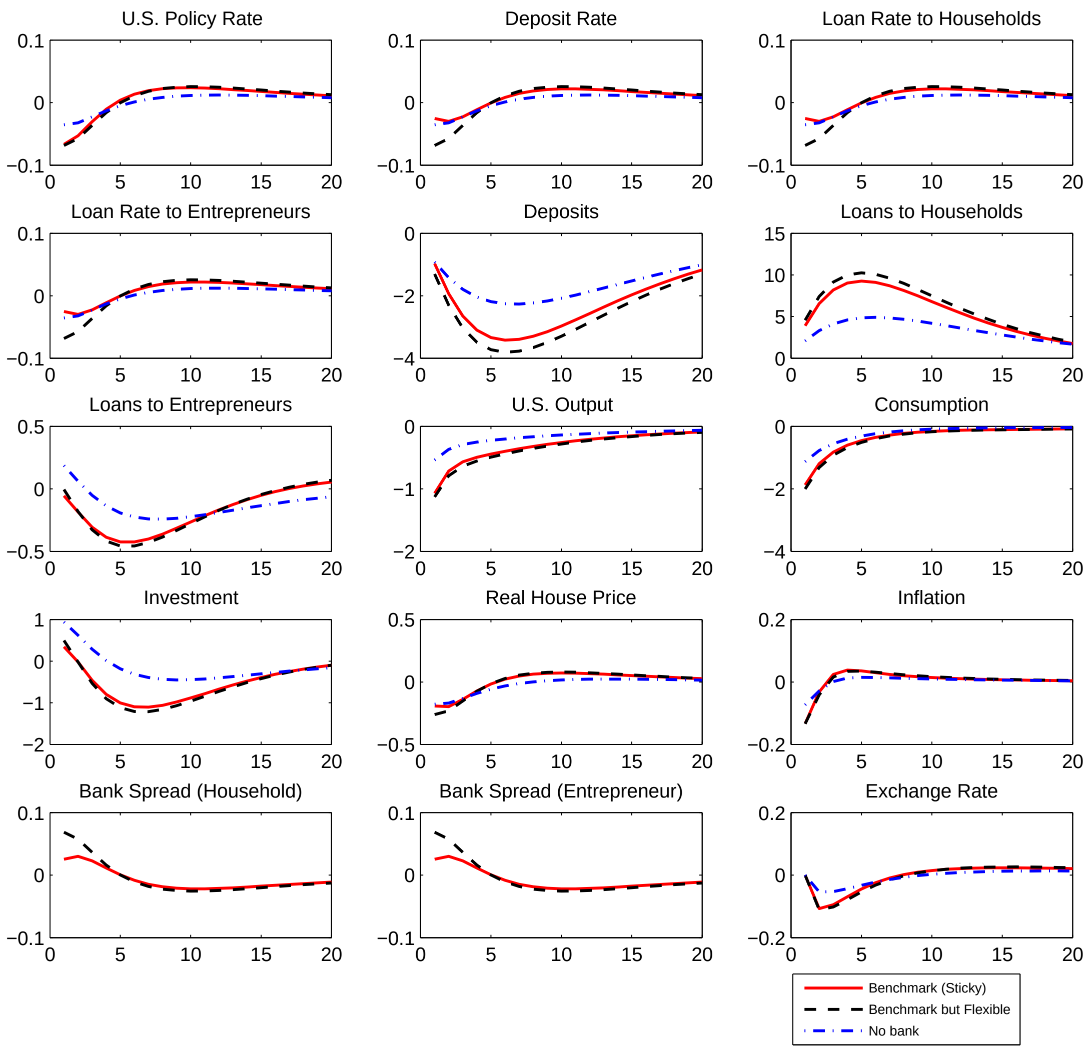

Figure 4.4: US Negative Financial Shock on Euro Area

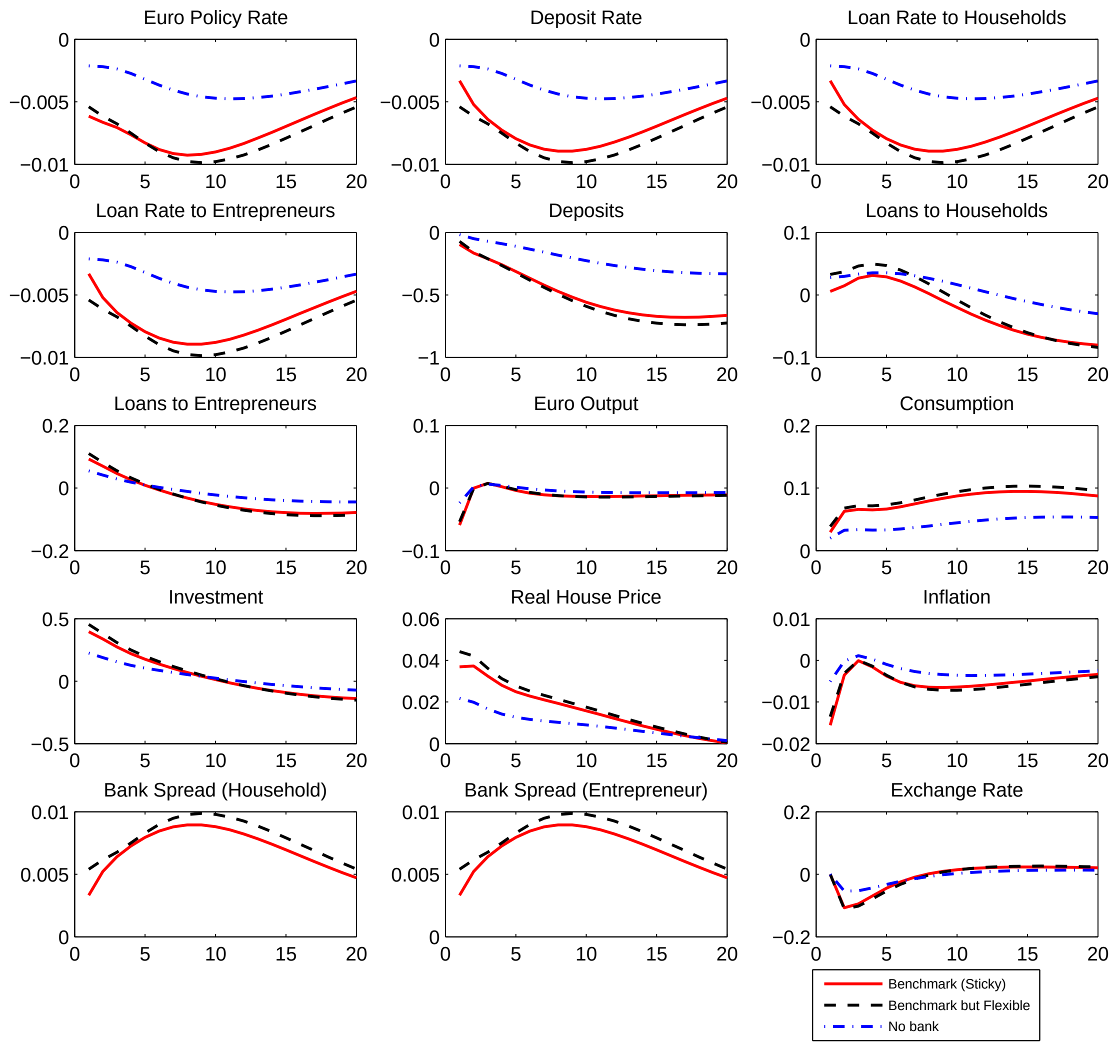

Figure 4.5: Euro Area Negative Financial Shock on Euro Area

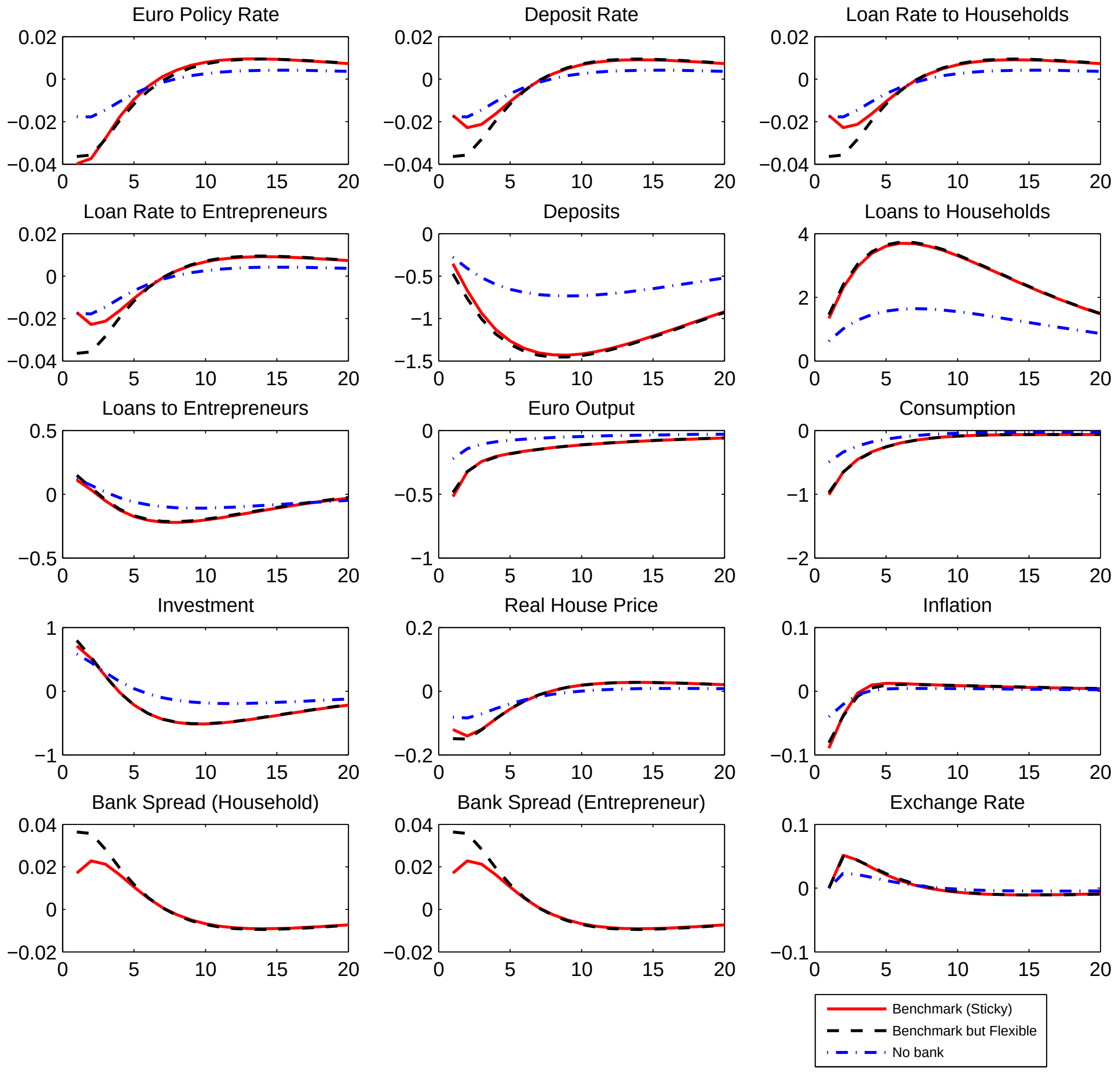

Figure 4.6: Euro Area Negative Financial Shock on US

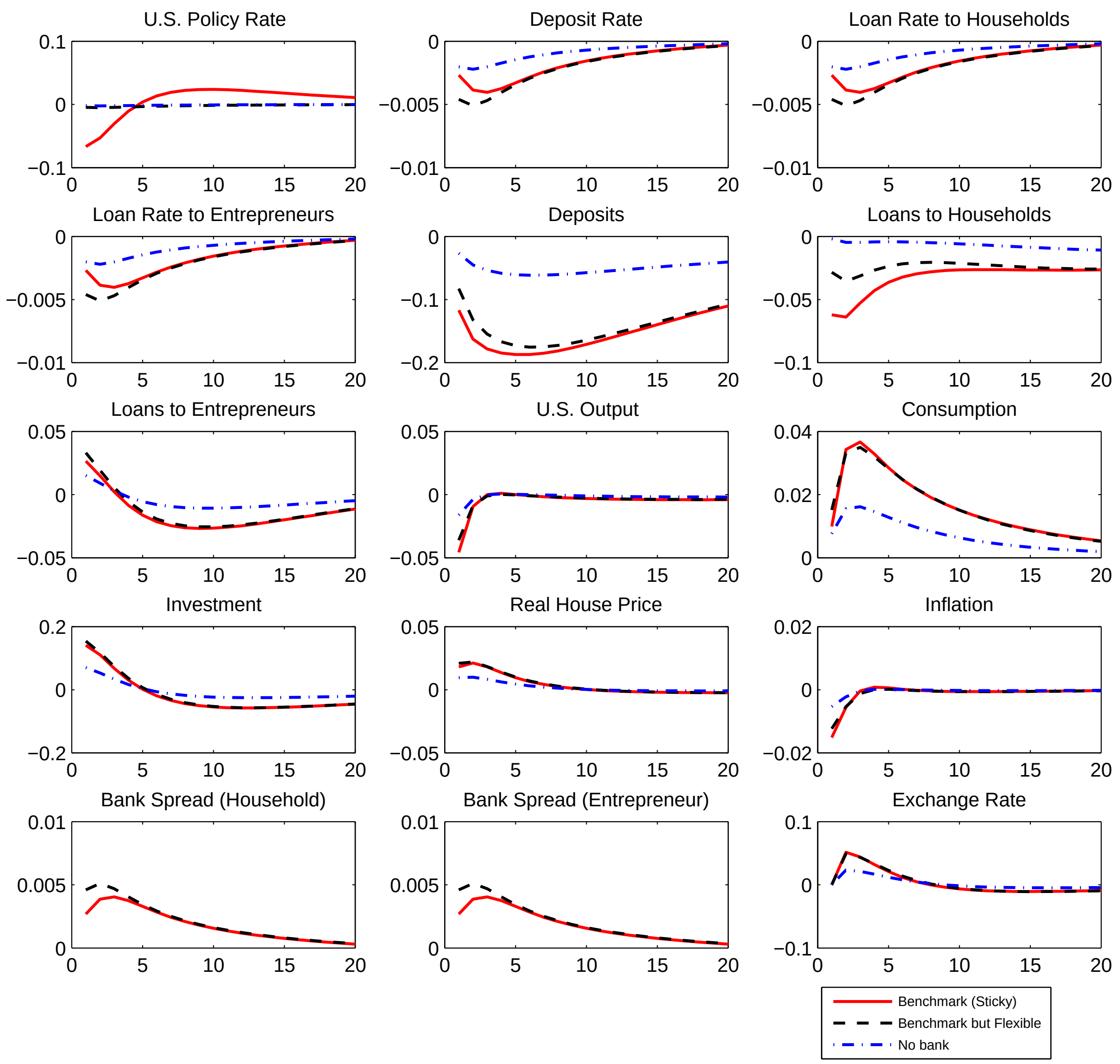

Figure 4.7: US Contractionary Monetary Shock on US

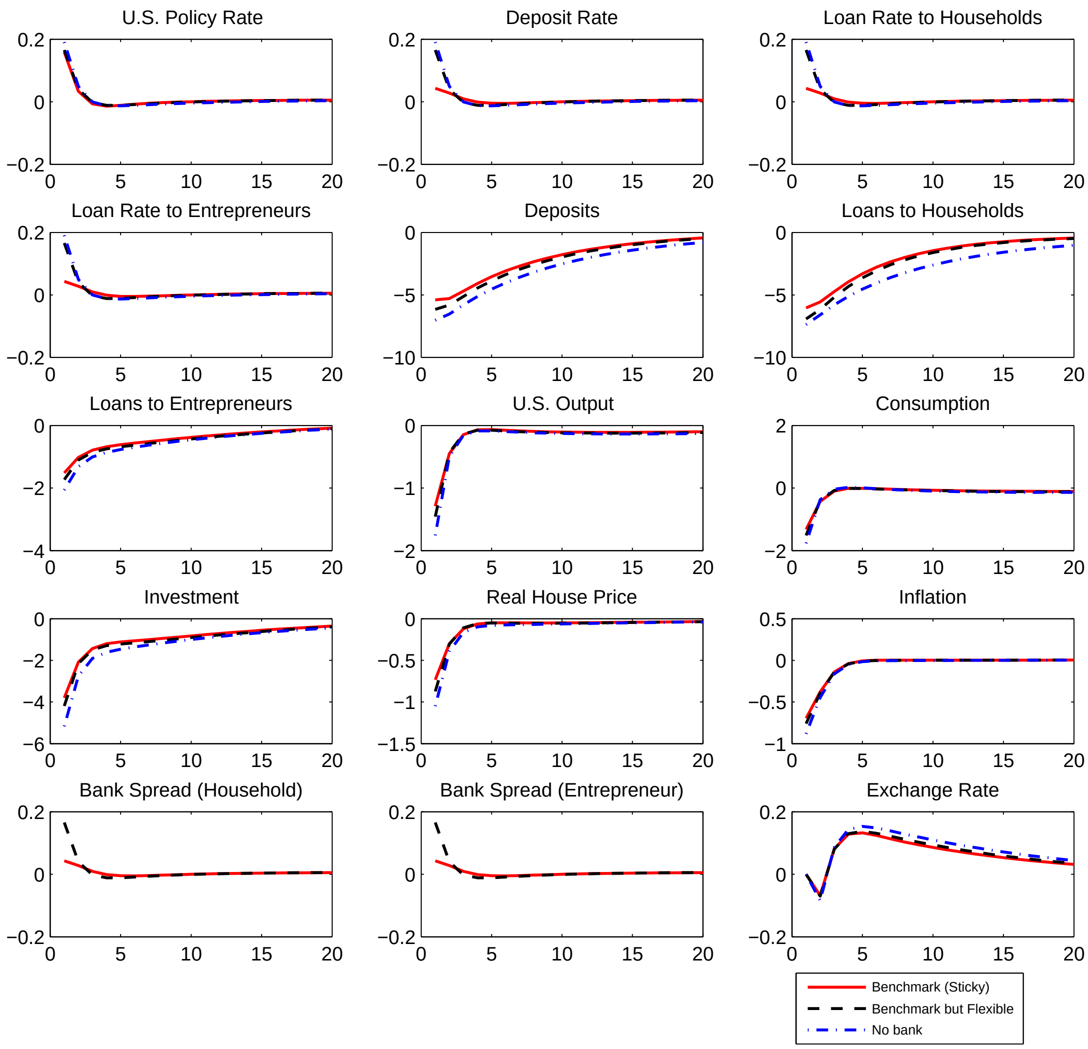

Figure 4.8: US Contractionary Monetary Shock on Euro Area

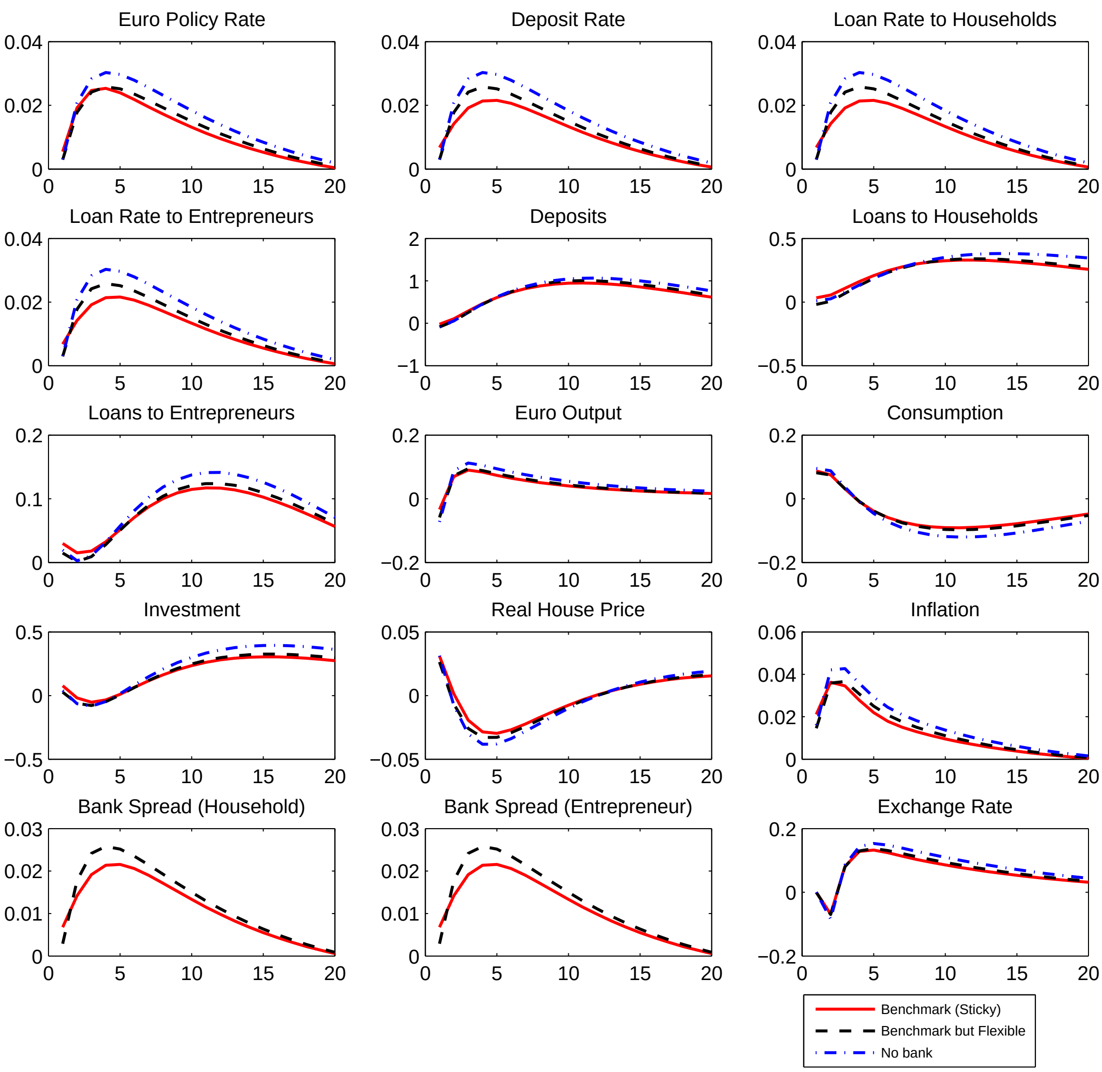

Figure 4.9: Euro Area Contractionary Monetary Shock on Euro Area

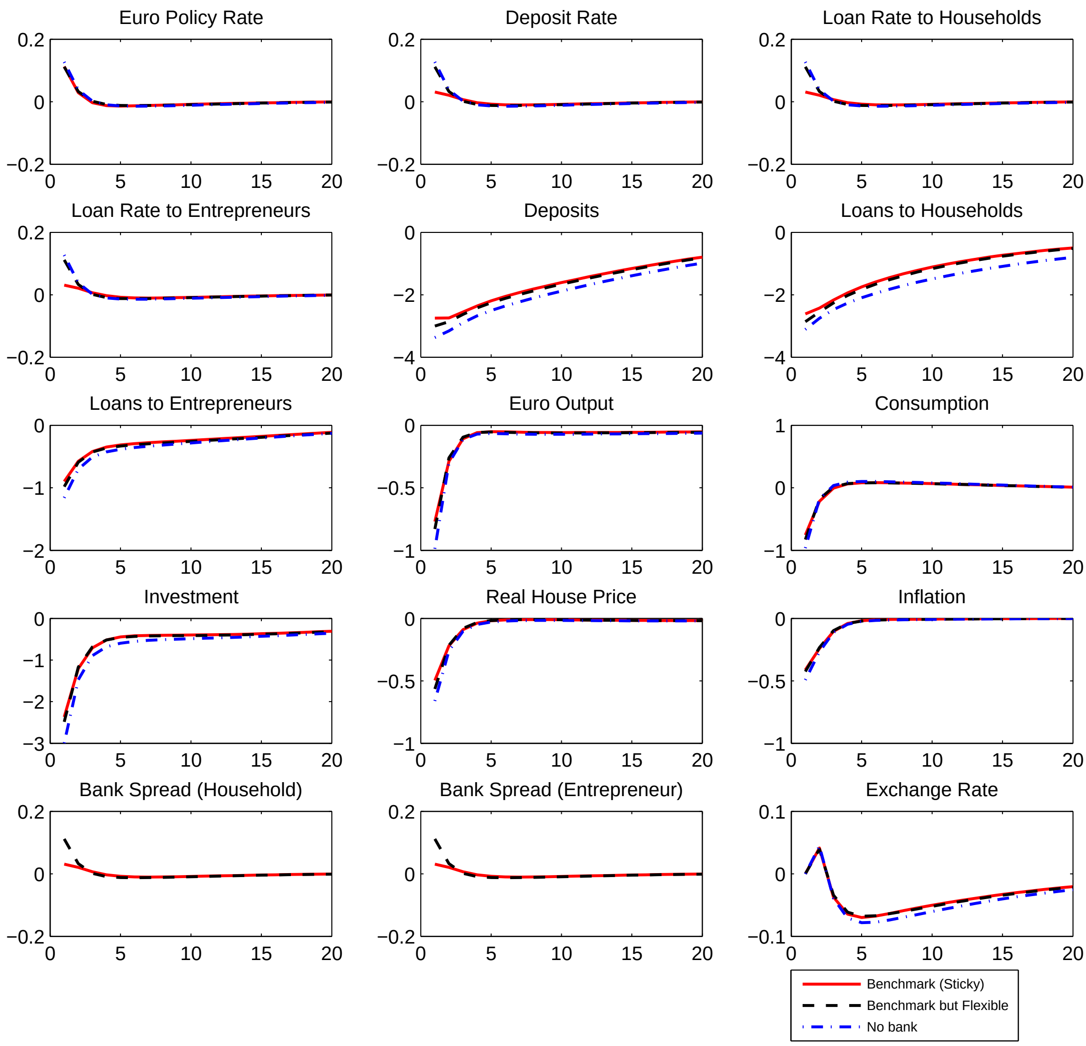

Figure 4.10: Euro Area Contractionary Monetary Shock on US

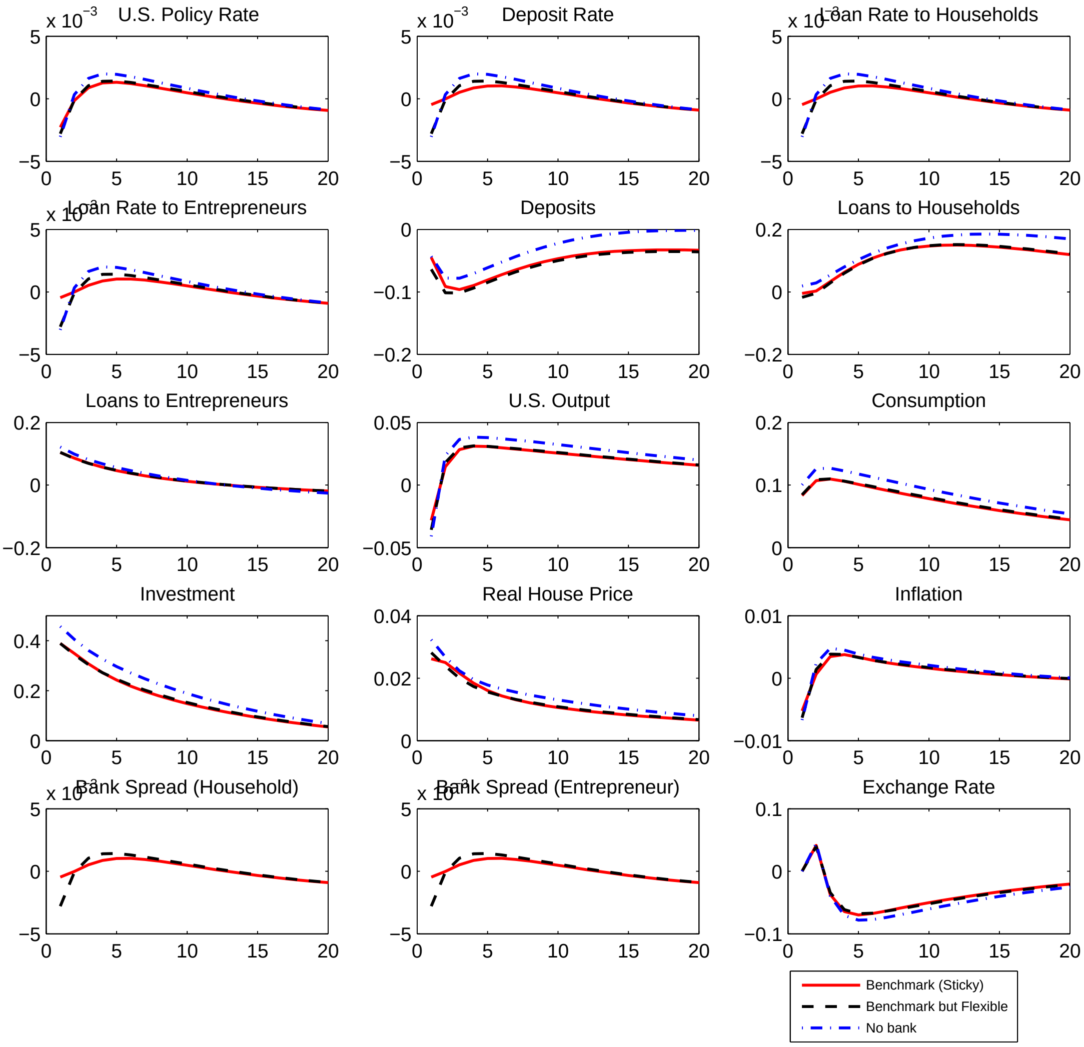

Figure 4.11: US Positive Technology Shock on US

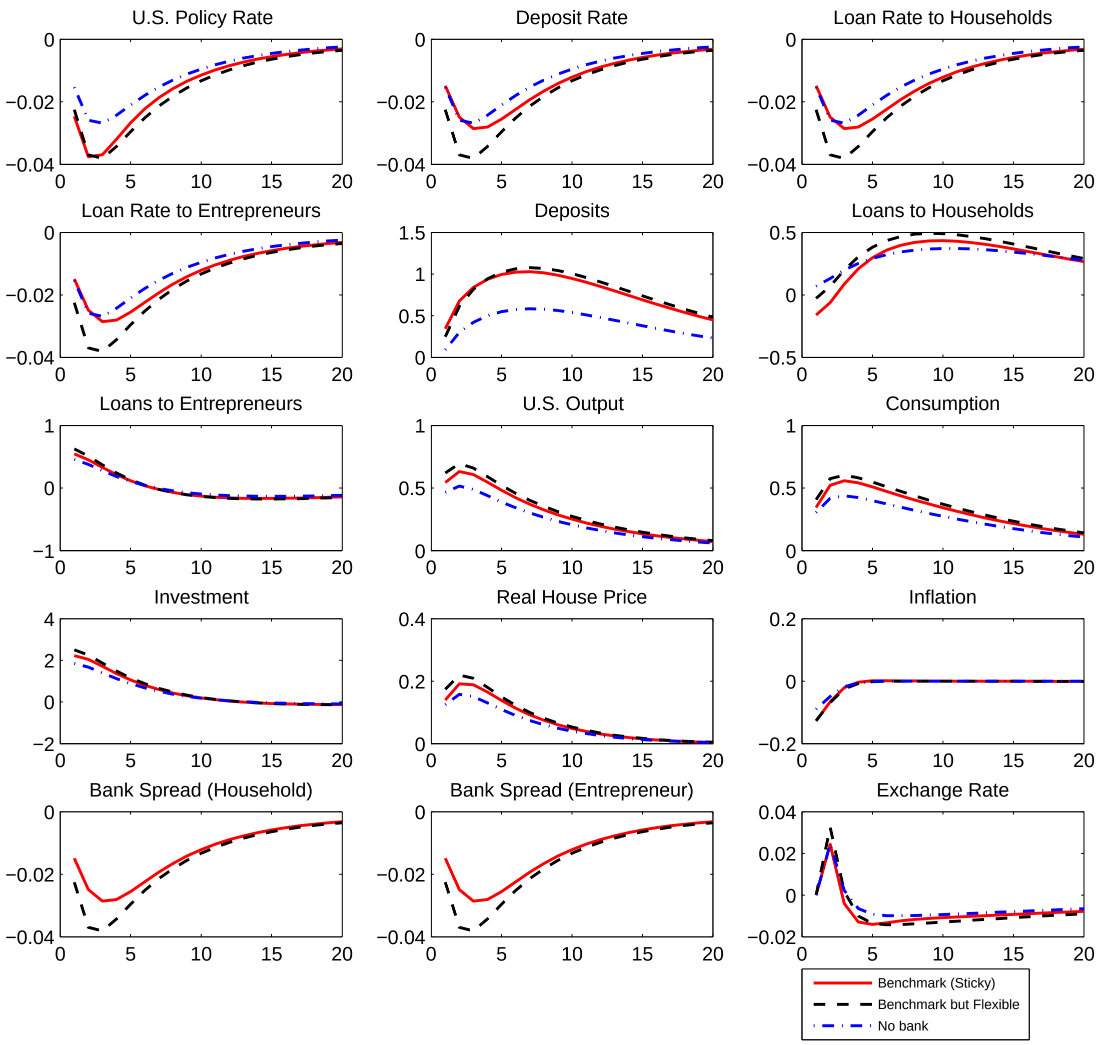

Figure 4.12: US Positive Technology Shock on Euro Area

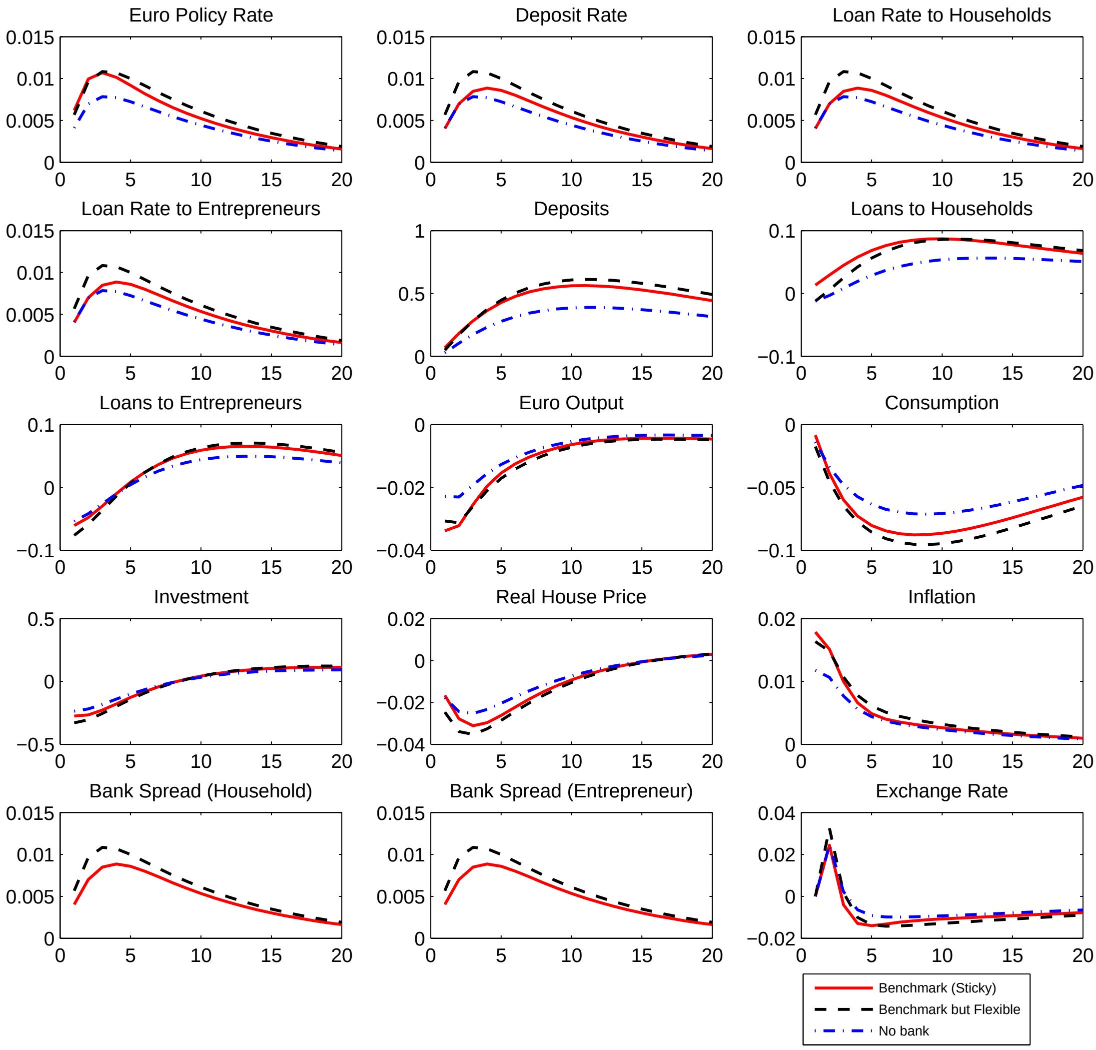

Figure 4.13: Euro Area Positive Technology Shock on Euro Area

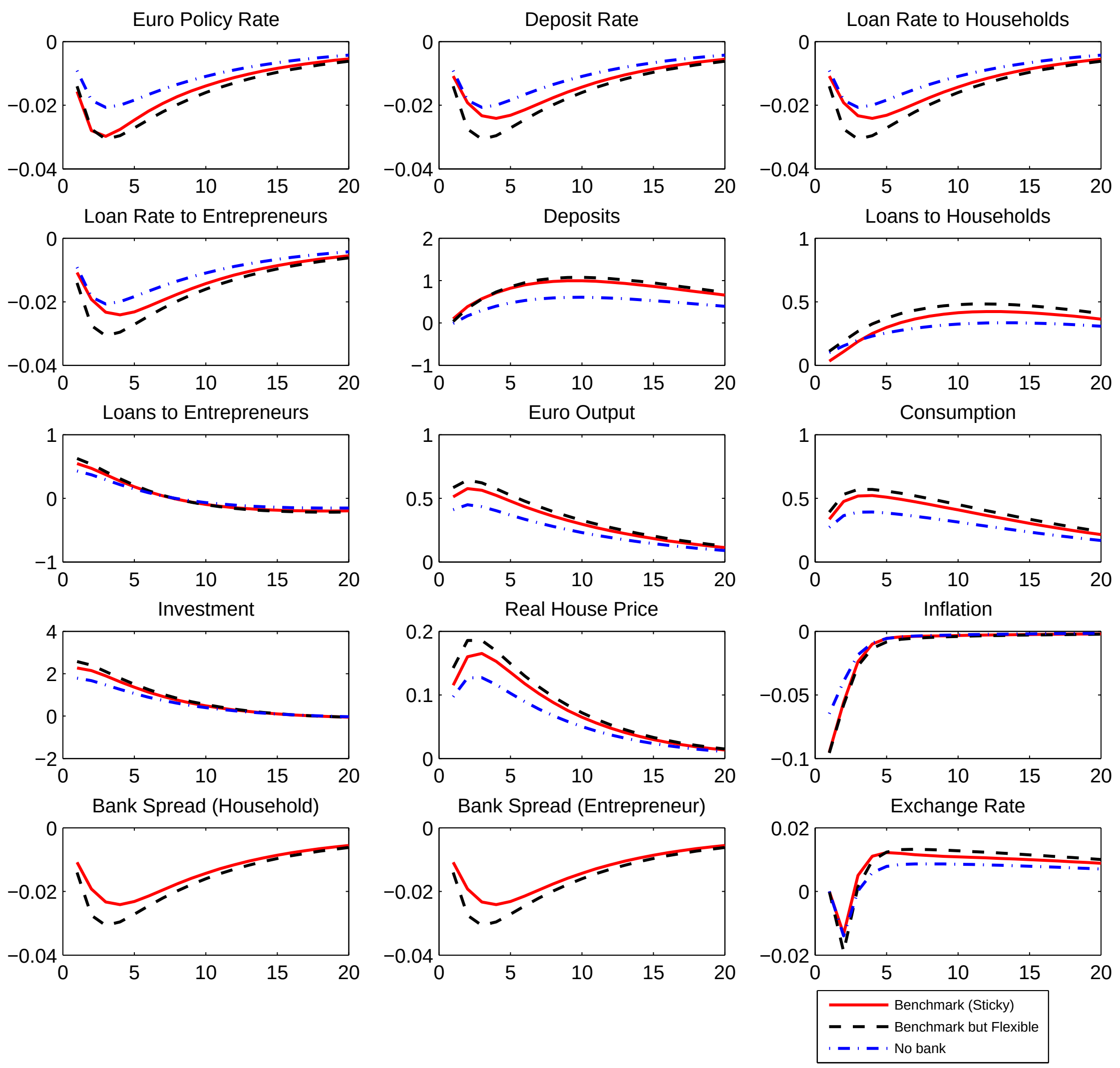

Figure 4.14: Euro Area Positive Technology Shock on US

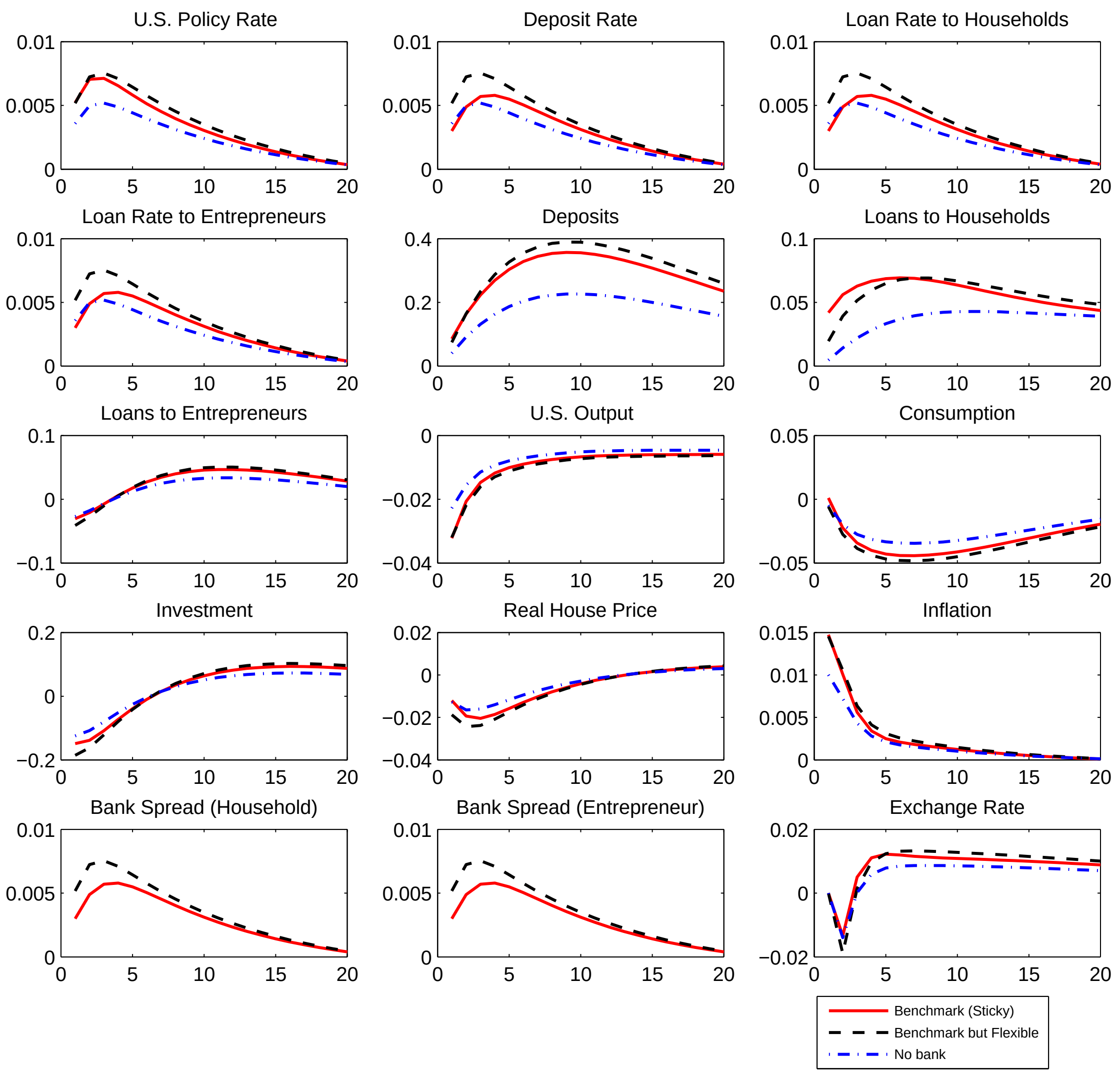

Figure 4.15: US Negative Financial Shock on US (Macroprudential Policy)

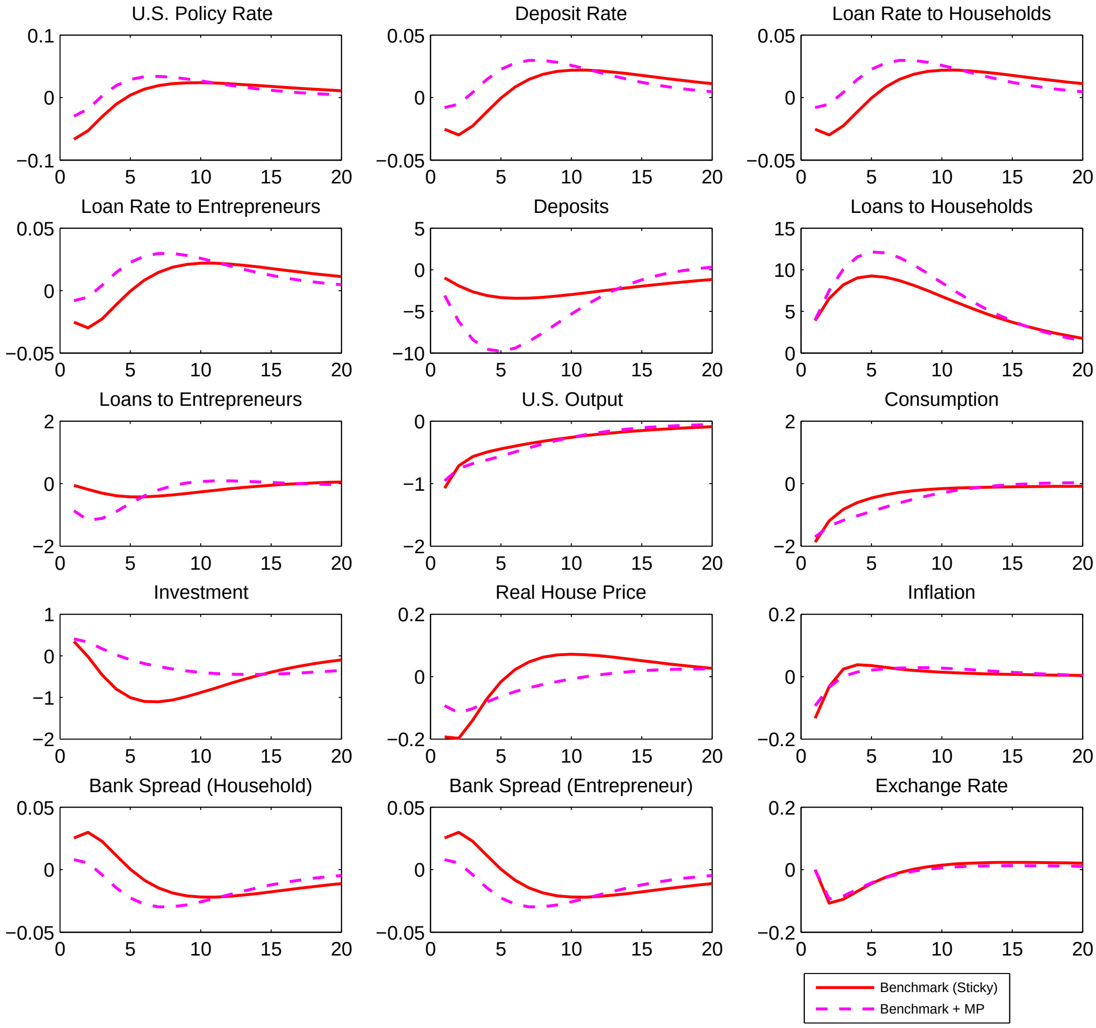

Figure 4.16: US Negative Financial Shock on Euro Area (Macroprudential Policy)

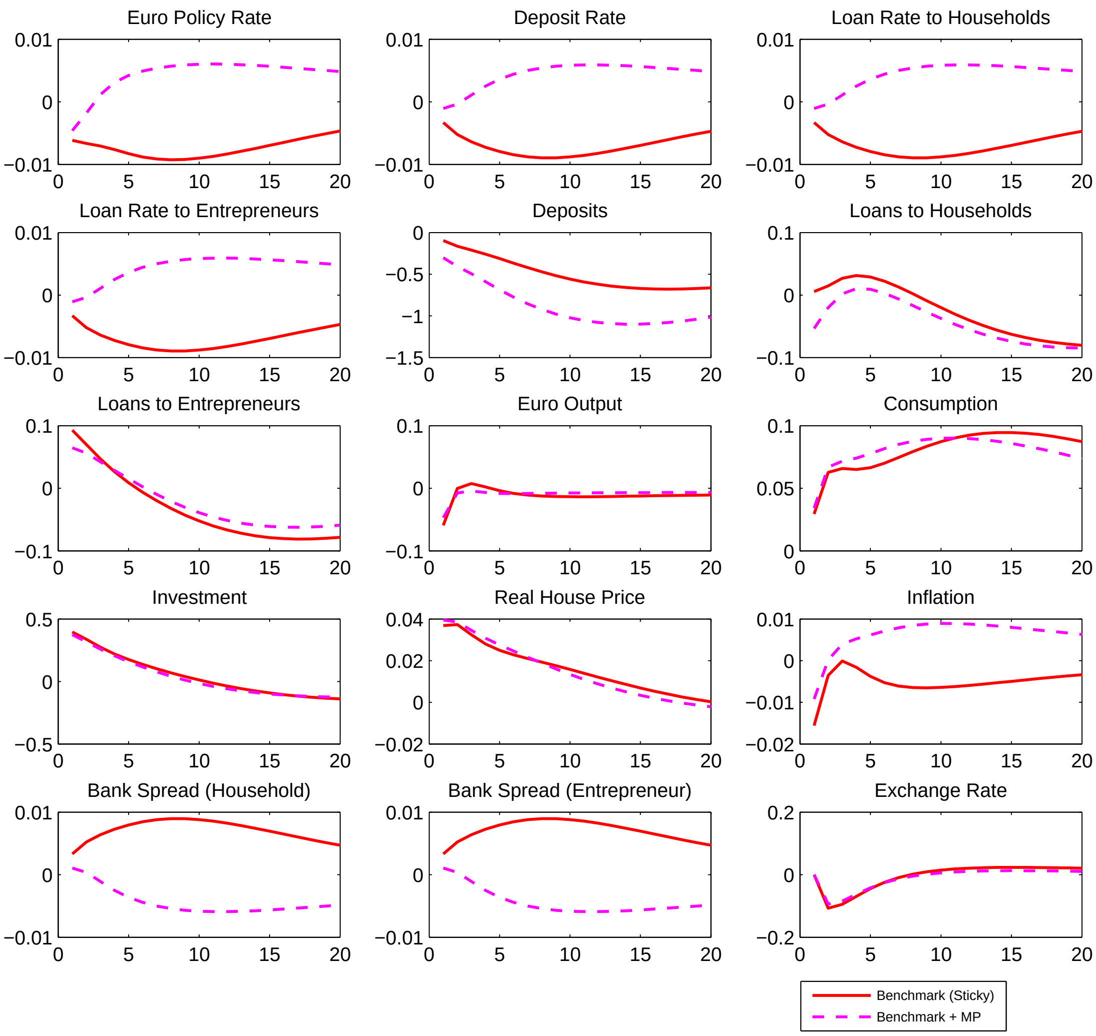

Figure 4.17: One Step Ahead Forecasting (US)

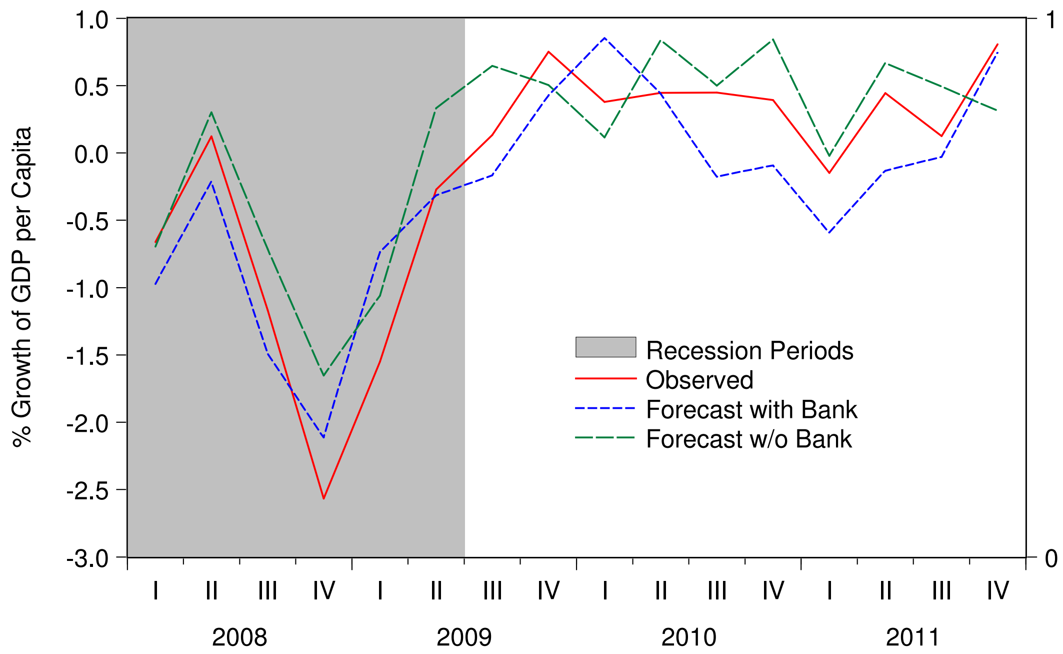

Figure 4.18: One Step Ahead Forecasting (Euro Area)

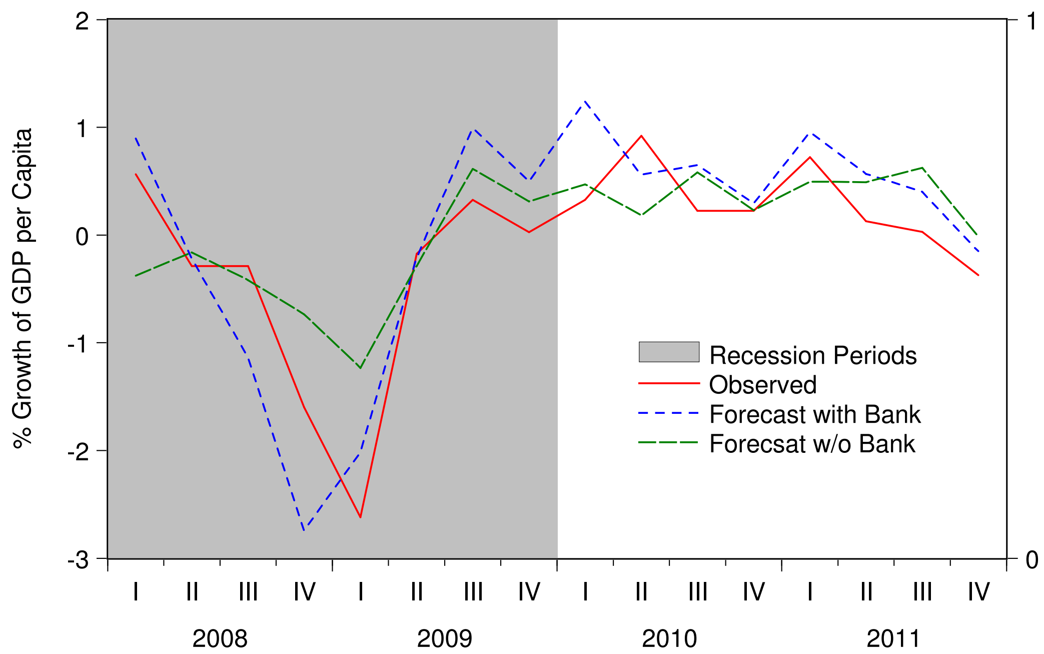

Table 4.1: Calibrated Parameters

Parameter	Value	Parameter	Value	Interpretation
α	0.28	α^*	0.25	Capital share in production
σ	0.3	σ^*	0.3	Share of labor to impatient household in production
υ	0.05	υ^*	0.05	House share in production
j	0.08	j^*	0.08	Weight on housing in utility
δ	0.035	δ^*	0.035	Depreciation rate of capital
ε	6	ε^*	6	Price markup in good market
λ_w	5	λ_w^*	5	Wage markup in labor market
δ_b	0.0982	δ_{b^*}	0.0982	Depreciation rate of bank capital
β_H	0.993	β_H^*	0.994	Discount factor of patient households
β_S	0.984	β_S^*	0.988	Discount factor of impatient households
β_E	0.985	β_E^*	0.987	Discount factor of entrepreneurs
β_B	0.992	β_B^*	0.993	Discount factor of banks
m_S	0.7	m_S^*	0.6	LTV ratio of house in impatient households
m_H	0.15	m_H^*	0.15	LTV ratio of house in entrepreneurs
m_K	0.15	m_K^*	0.15	LTV ratio of capital in entrepreneurs
γ	0.91	γ^*	0.91	$1-\gamma$ is the bank's capital asset ratio
ε_d	-10.26	ε_d^*	-20.03	Elasticity of substitution of deposit rate
ε_{bE}	2	ε_{bE}^*	2.23	Elasticity of substitution of loan rate to entrepreneurs
ε_{bS}	1.97	ε_{bS}^*	2.27	Elasticity of substitution of loan rate to impatient households
		χ	0.05	Risk premium

Table 4.2: Description of Estimated Parameters

Parameter	Interpretation
τ (τ^*)	Labor disutility of households
θ_w (θ^*_w)	Wage stickiness
θ_H (θ^*_F)	Price stickiness for domestic producers
θ_F (θ^*_H)	Price stickiness for importers
ξ_p (ξ^*_p)	Price indexation
ξ_w (ξ^*_w)	Wage indexation
Ψ_I (Ψ_{I^*})	Capital adjustment cost
θ_D (θ^*_D)	Deposit rate stickiness
θ_E (θ^*_E)	Loan rate stickiness to entrepreneurs
θ_S (θ^*_S)	Loan rate stickiness to impatient households
ϕ_π (ϕ_{π^*})	Taylor rule, inflation targeting
ϕ_y (ϕ_{y^*})	Taylor rule, output gap
ϕ_e (ϕ_{e^*})	Taylor rule, exchange rate
ϕ_s (ϕ^*_s)	Taylor rule, nominal credit growth
γ_η (γ^*_η)	Macroprudential policy instrument parameter
γ^r (γ^{r^*})	Steady state interest rate
γ^q (γ^{q^*})	Steady state house price
γ^π (γ^{π^*})	Steady state inflation
γ_{trend} (γ^*_{trend})	Steady state common trend
$(\rho_A, \varepsilon_A)/(\rho^*_A, \varepsilon^*_A)$	Technology shock
$(\rho_G, \varepsilon_G)/(\rho^*_G, \varepsilon^*_G)$	Government spending shock
$(\rho_I, \varepsilon_I)/(\rho^*_I, \varepsilon^*_I)$	Investment specific shock
$(\rho_n, \varepsilon_n)/(\rho^*_n, \varepsilon^*_n)$	Wage mark up shock
$(\rho_R, \varepsilon_R)/(\rho^*_R, \varepsilon^*_R)$	Monetary policy shock
$(\rho_z, \varepsilon_z)/(\rho^*_z, \varepsilon^*_z)$	Financial shock
$(\rho_{zh}, \varepsilon_{zh})/(\rho^*_{zh}, \varepsilon^*_{zh})$	Spread on deposit rate shock
$(\rho_{zs}, \varepsilon_{zs})/(\rho^*_{zs}, \varepsilon^*_{zs})$	Spread on loan to impatient household shock
$(\rho_{ze}, \varepsilon_{ze})/(\rho^*_{ze}, \varepsilon^*_{ze})$	Spread on loan to entrepreneur shock
$(\rho_h, \varepsilon_{\pi,h})/(\rho^*_f, \varepsilon^*_{\pi,f})$	Domestically-produced good price cost push shock
$(\rho_f, \varepsilon_{\pi,f})/(\rho^*_h, \varepsilon^*_{\pi,h})$	Import good price cost push shock
ε_{rp} (ε^*_{rp})	Country Risk premium shock
ω	Quarter to quarter percentage common trend of worldwide technology
$(\rho_\varpi, \varepsilon_\varpi)$	Worldwide technology shock
κ (κ^*)	Openness
η (ζ)	Substitutability of Goods
ε_E	PPP shock
ε_ϱ	Debt risk premium shock

Table 4.3: Priors and Posteriors (Benchmark)

	Prior Distribution			Posterior Distribution			
				U.S. and EA (1997:I - 2011:IV)		U.S. and EA (1997:I - 2007:IV)	
	Mean	S.d	Distribution	Mean	90 percent Interval	Mean	90 percent Interval
U.S.							
θ_H	0.7	0.1	Beta	0.7905	[0.7677,0.8105]	0.7411	[0.7101,0.7744]
θ_F	0.7	0.1	Beta	0.5558	[0.5260,0.5723]	0.4948	[0.4705,0.5272]
θ_w	0.7	0.1	Beta	0.8074	[0.7723,0.8375]	0.5840	[0.5597,0.6070]
ξ_p	0.4	0.15	Beta	0.5849	[0.5274,0.6468]	0.5190	[0.4545,0.5887]
ξ_w	0.3	0.1	Beta	0.2365	[0.1741,0.2890]	0.1770	[0.1271,0.2285]
θ_D	0.5	0.1	Beta	0.4533	[0.4032,0.5019]	0.4772	[0.4287,0.5179]
θ_E	0.5	0.1	Beta	0.6302	[0.6053,0.6491]	0.6625	[0.6416,0.6929]
θ_S	0.5	0.1	Beta	0.7171	[0.6719,0.7586]	0.7984	[0.7819,0.8193]
Ψ_I	5	1.5	Normal	4.1346	[3.6245,4.6036]	4.4557	[3.6583,5.1319]
τ	2	0.3	Gamma	1.9041	[1.8179,2.0142]	2.5199	[2.3618,2.6567]
ϕ_π	1.5	0.25	Gamma	1.1386	[1.1248,1.1557]	1.3442	[1.2775,1.4145]
ϕ_y	0.5	0.15	Gamma	0.5639	[0.5205,0.6193]	0.8300	[0.7611,0.8890]
ϕ_e	0.1	0.05	Gamma	0.1303	[0.1159,0.1450]	0.2025	[0.1889,0.2135]
γ^r	0.5	0.5	Gamma	0.4869	[0.3038,0.6721]	1.7789	[1.5960,1.9119]
γ^q	0.6	0.15	Gamma	0.5607	[0.5176,0.6194]	0.6414	[0.5744,0.7172]
γ_{trend}	0.3	0.1	Gamma	0.4950	[0.4698,0.5156]	0.3115	[0.2679,0.3515]
γ^π	6	2	Gamma	4.0171	[2.8654,5.1790]	2.5909	[1.8848,3.1592]
ρ_A	0.8	0.1	Beta	0.8463	[0.7933,0.8939]	0.8023	[0.7686,0.8321]
ρ_R	0.75	0.15	Beta	0.8840	[0.8673,0.8996]	0.8680	[0.8513,0.8860]
ρ_z	0.75	0.15	Beta	0.9169	[0.8744,0.9666]	0.9930	[0.9848,0.9997]
ρ_{zh}	0.6	0.15	Beta	0.6020	[0.5555,0.6516]	0.5223	[0.4660,0.5701]
ρ_{zs}	0.7	0.15	Beta	0.9292	[0.8681,0.9876]	0.9421	[0.9046,0.9761]
ρ_{ze}	0.7	0.15	Beta	0.8801	[0.8375,0.9126]	0.9059	[0.8380,0.9678]
ρ_{π_h}	0.75	0.15	Beta	0.9896	[0.9819,0.9961]	0.8767	[0.8341,0.9304]
ρ_{π_f}	0.75	0.15	Beta	0.8592	[0.8015,0.9200]	0.8079	[0.7719,0.9523]
ρ_G	0.8	0.1	Beta	0.8735	[0.8262,0.9268]	0.8023	[0.7712,0.8326]
ρ_I	0.75	0.15	Beta	0.8061	[0.7404,0.8624]	0.8950	[0.8361,0.9665]
ρ_n	0.75	0.15	Beta	0.9253	[0.8860,0.9695]	0.8396	[0.7743,0.9028]
ε_A	1	4	Inv Gamma	2.2671	[2.0788,2.4370]	1.6293	[1.4055,1.7968]
ε_R	0.2	4	Inv Gamma	0.1556	[0.1267,0.1865]	0.1323	[0.1116,0.1514]
ε_z	2.5	4	Inv Gamma	2.5105	[2.1444,2.9122]	1.7925	[1.5040,2.1193]
ε_{zh}	0.4	4	Inv Gamma	0.1878	[0.1561,0.2217]	0.1692	[0.1384,0.2060]
ε_{zs}	0.7	4	Inv Gamma	1.2719	[1.1516,1.3932]	0.4052	[0.3191,0.4856]
ε_{ze}	0.5	4	Inv Gamma	0.2974	[0.2406,0.3408]	0.2347	[0.1911,0.2700]
$\varepsilon_{\pi,h}$	0.5	4	Inv Gamma	0.4499	[0.3781,0.5093]	0.4403	[0.3546,0.5415]
$\varepsilon_{\pi,f}$	1	4	Inv Gamma	1.1601	[0.9995,1.3481]	0.7691	[0.5893,0.9466]
ε_G	0.2	4	Inv Gamma	0.1741	[0.1481,0.2019]	0.1438	[0.1137,0.1755]
ε_I	2	4	Inv Gamma	2.0249	[1.5750,2.4504]	1.6020	[0.9684,2.2723]
ε_n	1	4	Inv Gamma	1.0841	[0.7870,1.4564]	1.0809	[0.8236,1.3495]
ε_{rp}	0.5	4	Inv Gamma	0.7714	[0.6648,0.8802]	0.5845	[0.4809,0.7124]
Open							
κ	0.1	0.05	Beta	0.1769	[0.1577,0.1900]	0.1291	[0.1133,0.1528]
η	1	0.3	Gamma	1.5855	[1.4375,1.7110]	1.1729	[1.1162,1.2280]
κ^*	0.1	0.05	Beta	0.1601	[0.1497,0.1747]	0.2710	[0.2507,0.2850]
ζ	1	0.3	Gamma	1.4457	[1.3289,1.6034]	1.4515	[1.2973,1.5554]
ω	0.4	0.1	Normal	0.2306	[0.2016,0.2579]	0.1605	[0.1297,0.1923]
ρ_ϖ	0.8	0.15	Beta	0.8552	[0.8160,0.8978]	0.9065	[0.8833,0.9286]
ε_ϖ	0.5	4	Inv Gamma	0.2177	[0.1773,0.2568]	0.2024	[0.1630,0.2363]
ε_E	3.5	4	Inv Gamma	4.8614	[4.7176,4.9996]	4.7256	[4.4679,4.9989]
ε_ϱ	0.5	4	Inv Gamma	0.4680	[0.3792,0.5674]	0.4537	[0.3701,0.5505]

Table 4.4: Priors and Posteriors (Benchmark) continued

	Prior Distribution			Posterior Distribution			
				U.S. and EA (1997:I - 2011:IV)		U.S. and EA (1997:I - 2007:IV)	
	Mean	S.d	Distribution	Mean	90 percent Interval	Mean	90 percent Interval
EA							
θ_H^*	0.7	0.1	Beta	0.6741	[0.6479,0.7030]	0.6710	[0.6334,0.7004]
θ_F^*	0.7	0.1	Beta	0.6653	[0.6428,0.6945]	0.5630	[0.5338,0.5915]
θ_w^*	0.7	0.1	Beta	0.7126	[0.6703,0.7547]	0.8011	[0.7773,0.8260]
ξ_p^*	0.4	0.15	Beta	0.5784	[0.5494,0.6145]	0.5432	[0.4802,0.5949]
ξ_w^*	0.3	0.1	Beta	0.3599	[0.3365,0.3861]	0.2961	[0.2688,0.3228]
θ_D^*	0.5	0.1	Beta	0.4398	[0.3868,0.4862]	0.6373	[0.6146,0.6582]
θ_E^*	0.5	0.1	Beta	0.7748	[0.7497,0.7966]	0.8373	[0.8221,0.8613]
θ_S^*	0.5	0.1	Beta	0.8215	[0.8030,0.8412]	0.8258	[0.8095,0.8507]
Ψ_I^*	5	1.5	Normal	5.0806	[4.2580,5.6273]	4.9912	[4.5346,5.4460]
τ^*	2	0.3	Beta	2.0037	[1.9436,2.0606]	2.0375	[1.9655,2.1414]
ϕ_{π^*}	1.5	0.25	Gamma	1.4304	[1.3459,1.5103]	1.2735	[1.2328,1.3114]
ϕ_{y^*}	0.5	0.15	Gamma	0.7289	[0.6600,0.7896]	0.3905	[0.3500,0.4196]
ϕ_{e^*}	0.1	0.05	Gamma	0.0159	[0.0069,0.0255]	0.0341	[0.0242,0.0472]
γ^{r^*}	0.5	0.5	Gamma	0.4300	[0.2775,0.5896]	0.7132	[0.5734,0.8495]
γ^{q^*}	0.95	0.15	Gamma	0.9545	[0.9325,0.9805]	0.8861	[0.8461,0.9300]
γ_{trend}^*	0.46	0.1	Normal	0.3899	[0.3611,0.4223]	0.6208	[0.5802,0.6591]
γ^{π^*}	5	2	Gamma	3.9848	[3.5123,4.5406]	4.0438	[3.6279,4.4467]
ρ_A^*	0.8	0.1	Beta	0.7305	[0.6973,0.7727]	0.7004	[0.6647,0.7271]
ρ_R^*	0.75	0.15	Beta	0.8350	[0.8154,0.8514]	0.7963	[0.7694,0.8220]
ρ_z^*	0.75	0.15	Beta	0.9064	[0.8586,0.9586]	0.8741	[0.8209,0.9298]
ρ_{zh}^*	0.6	0.15	Beta	0.5815	[0.5353,0.6232]	0.6619	[0.6288,0.6976]
ρ_{zs}^*	0.7	0.15	Beta	0.6943	[0.6135,0.7733]	0.7881	[0.7541,0.8251]
ρ_{ze}^*	0.7	0.15	Beta	0.6864	[0.6499,0.7143]	0.7364	[0.6996,0.7786]
$\rho_{\pi_h}^*$	0.75	0.15	Beta	0.8616	[0.7908,0.9401]	0.9417	[0.9083,0.9815]
$\rho_{\pi_f}^*$	0.75	0.15	Beta	0.9987	[0.9976,0.9998]	0.9888	[0.9753,0.9992]
ρ_G^*	0.8	0.1	Beta	0.8385	[0.7742,0.9072]	0.8680	[0.8322,0.9094]
ρ_I^*	0.75	0.15	Beta	0.7378	[0.6888,0.7889]	0.7899	[0.7543,0.8289]
ρ_n^*	0.8	0.1	Beta	0.8638	[0.8349,0.8894]	0.9164	[0.8921,0.9414]
ε_A^*	1	4	Inv Gamma	1.2338	[1.0857,1.3695]	0.7002	[0.5806,0.8429]
ε_R^*	0.2	4	Inv Gamma	0.1133	[0.0942,0.1297]	0.1042	[0.0911,0.1155]
ε_z^*	1	4	Inv Gamma	0.8420	[0.6126,1.0269]	0.6677	[0.5833,0.7654]
ε_{zh}^*	0.4	4	Inv Gamma	0.1814	[0.1586,0.2045]	0.1611	[0.1271,0.1887]
ε_{zs}^*	0.7	4	Inv Gamma	0.5290	[0.4014,0.6109]	0.4984	[0.3819,0.6520]
ε_{ze}^*	0.5	4	Inv Gamma	0.5190	[0.4120,0.5965]	0.3965	[0.3389,0.4673]
$\varepsilon_{\pi,h}^*$	1	4	Inv Gamma	0.9122	[0.6437,1.1328]	0.7661	[0.5823,0.9657]
$\varepsilon_{\pi,f}^*$	0.5	4	Inv Gamma	0.5156	[0.4581,0.5860]	0.3561	[0.2888,0.4367]
ε_G^*	0.2	4	Inv Gamma	0.2184	[0.1879,0.2491]	0.1475	[0.1093,0.1918]
ε_I^*	1	4	Inv Gamma	0.9786	[0.7543,1.2018]	0.8234	[0.6223,1.0784]
ε_n^*	1	4	Inv Gamma	0.9886	[0.7606,1.2637]	0.9764	[0.8038,1.1894]
ε_{rp}^*	3.5	4	Inv Gamma	3.9869	[3.5363,4.3806]	3.6294	[3.1968,4.2094]

Table 4.5: Decomposition of Asymptotic Variance of Forecast Error (Benchmark)

U.S.	ε_R	ε_A	$(\varepsilon_{zh},\varepsilon_{zs},\varepsilon_{ze})$[1]	ε_z	$(\varepsilon_{\pi,h},\varepsilon_{\pi,f})$[2]	ε_G	ε_I	ε_{rp}	ε_n	ε_ϱ	ε_E	ε_ϖ	ε_{Euro}[3]
Y_t	3.56	20.16	(11.68,0.10,1.10)	37.41	(9.14,0.93)	0.07	4.97	0.11	0.00	0.07	2.71	4.74	3.25
R_t	1.33	1.99	(77.74,0.64,0.97)	8.56	(0.76,0.08)	0.05	1.29	0.01	0.00	0.01	0.83	5.08	0.66
π_t	10.17	6.53	(55.17,0.58,0.45)	2.23	(0.62,0.05)	0.04	0.54	0.06	0.00	0.03	0.77	20.90	1.86
q_t	11.96	14.03	(27.26,2.18,2.31)	8.84	(8.74,0.71)	0.03	5.62	0.17	0.00	0.02	2.44	9.80	5.92
$R_{P,t}$	2.42	9.54	(13.63,2.97,5.59)	23.51	(0.62,0.10)	0.16	7.82	0.09	0.00	0.05	4.61	19.06	9.88
$R_{S,t}$	0.32	1.27	(56.18,32.76,0.74)	3.12	(0.83,0.08)	0.01	1.04	0.01	0.00	0.01	0.61	2.53	0.49
$R_{E,t}$	0.24	0.95	(41.98,0.29,50.02)	2.33	(0.62,0.06)	0.03	0.78	0.01	0.00	0.01	0.46	1.89	0.33
Euro	ε^*_R	ε^*_A	$(\varepsilon^*_{zh},\varepsilon^*_{zs},\varepsilon^*_{ze})$[1]	ε^*_z	$(\varepsilon^*_{\pi,h},\varepsilon^*_{\pi,f})$[2]	ε^*_G	ε^*_I	ε^*_{rp}	ε^*_n	ε_ϱ	ε_E	ε_ϖ	ε_{US}[4]
Y^*_t	7.90	33.00	(7.79,0.20,1.98)	14.66	(0.35,9.36)	0.00	1.56	5.78	0.00	0.11	4.24	9.79	3.28
R^*_t	3.20	1.87	(60.33,1.19,0.43)	4.31	(0.02,0.70)	0.00	0.33	7.62	0.00	0.15	3.44	10.95	5.46
π^*_t	20.52	5.81	(38.09,0.96,0.17)	1.79	(0.03,0.98)	0.00	0.15	2.86	0.00	0.05	5.10	20.84	2.65
q^*_t	23.54	15.50	(18.52,5.20,1.51)	5.28	(0.24,9.98)	0.00	1.35	3.09	0.00	0.08	2.62	5.01	8.08
$R^*_{P,t}$	2.34	3.73	(6.26,2.49,1.09)	5.40	(0.05,2.15)	0.00	0.74	23.22	0.00	0.46	4.65	33.97	13.45
$R^*_{S,t}$	0.58	0.93	(33.50,41.73,0.27)	1.35	(0.01,0.54)	0.00	0.18	5.79	0.00	0.12	1.16	8.48	5.36
$R^*_{E,t}$	0.59	0.94	(35.79,0.63,40.91)	1.36	(0.01,0.54)	0.00	0.19	5.84	0.00	0.12	1.17	8.54	3.37

[1] The contributions of spread on deposit shock, spread on loan to household shock and spread on loan to entrepreneur shock

[2] The contributions of domestically-produced-goods price markup shock and import-goods price markup shock

[3] The contributions of shocks from the Euro Area

[4] The contributions of shocks from the United States

Table 4.6: Priors and Posteriors (Benchmark + Macroprudential Policy)

	Prior Distribution			Posterior Distribution			
				U.S. and EA (1997:I - 2011:IV)		U.S. and EA (1997:I - 2007:IV)	
	Mean	S.d	Distribution	Mean	90 percent Interval	Mean	90 percent Interval
ρ_R	0.75	0.15	Beta	0.9086	[0.8977,0.9218]	0.8632	[0.8471,0.8750]
ρ^*_R	0.75	0.15	Beta	0.8779	[0.8547,0.8945]	0.8178	[0.7940,0.8460]
ϕ_π	1.5	0.25	Gamma	2.2860	[2.1928,2.3653]	2.0982	[2.0344,2.1728]
ϕ_y	0.5	0.15	Gamma	0.0723	[0.0627,0.0839]	0.0546	[0.0500,0.0597]
ϕ_e	0.1	0.05	Gamma	0.1357	[0.1215,0.1510]	0.0688	[0.0461,0.0904]
ϕ_{π^*}	1.5	0.25	Gamma	2.0227	[1.9125,2.0968]	1.4436	[1.3949,1.5038]
ϕ_{y^*}	0.5	0.15	Gamma	0.0976	[0.0792,0.1169]	0.0426	[0.0362,0.0486]
ϕ_{e^*}	0.1	0.05	Gamma	0.0863	[0.0696,0.1142]	0.0611	[0.0470,0.0770]
ε_R	0.2	4	Inv Gamma	0.2016	[0.1746,0.2294]	0.1792	[0.1595,0.1978]
ε^*_R	0.2	4	Inv Gamma	0.1454	[0.1288,0.1746]	0.1164	[0.0950,0.1321]
ϕ_s	0.1	0.05	Beta	0.0356	[0.0224,0.0476]	0.0522	[0.0420,0.0653]
γ_η	1.5	0.3	Gamma	2.4999	[2.4367,2.6077]	2.4122	[2.2782,2.5748]
ϕ^*_s	0.1	0.05	Beta	0.0360	[0.0240,0.0473]	0.0434	[0.0309,0.0553]
γ^*_η	1.5	0.3	Gamma	2.1593	[2.0356,2.2895]	2.0936	[2.0154,2.1812]

Note: we apply the same priors in the benchmark model with macroprudential policy. Here we only report the posterior estimates of the coefficients in the Taylor rule and macroprudential policy instrument parameter.

Table 4.7: RMSE and Theil Inequality (One Quarter Ahead Forecasting)

Region	Models	RMSE	Theil(Total)	Theil(Bias)	Theil(Var)	Theil(Cov)
US	Benchmark (banks)	0.4171	0.2440	$4.5e^{-4}$	0.1155	0.8296
	Without banks	0.4242	0.2622	$1.2e^{-3}$	0.1959	0.5497
EA	Benchmark (banks)	0.5452	0.2808	$3.0e^{-4}$	0.1960	0.7891
	Without banks	0.5654	0.4077	$3.1e^{-4}$	0.3470	0.6303