경제학석사학위논문

Role of External Shocks in Small Open Economy:

a DSGE Approach with Collateral Constraints and Housing Market

대외 충격이 개방소국경제에 미치는 영향

-담보제약과 주택시장을 포함한 동태확률일반균형 모형 분석-

2016년 2월

서울대학교 대학원
경제학부 경제학 전공
박 혜 진

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이 논문을 경제학석사학위논문으로 제출함

2015년 10월

서울대학교 대학원

경제학부 경제학 전공

박혜진

박혜진의 석사학위논문을 인준함

2015년 12월

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Abstract

Role of External Shocks in Small Open Economy:
DSGE approach with collateral constraints and housing market

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This paper extends the DSGE model of Iacoviello (2005) with housing market and collateral constraints to small-open economy version to see how financial friction affects transmission mechanism of external shocks on small open economy. It constructs a structural quasi-closed economy model which stands for the external world in order to identify foreign structural shocks that affect small open economy. Then it incorporates the model with small open economy version whose measure is negligible compared to the large one. Using data of South Korea and the U.S. after 2000, this paper estimates model parameters with Metropolis-Hastings random walk sampling and compare the cross-correlations and forecasting error variance shares calculated based on the model to the empirical ones and results from Bayesian VAR with lagged block-recursive restriction estimated by Gibbs algorithm by Zha (1999). It turns out that the model is able to replicate forecasting error variance shares that structural shocks from the U.S. have on the cyclical fluctuations of output and interest rates in South Korea. However, the model underestimates the cross-correlation between Korean variables and lagged U.S. ones and highly underestimates the forecasting error share of U.S. shocks in inflation and housing price dynamics. In particular, the model does not reproduce highly positive and persistent co-movement of housing prices across countries and highly positive correlation between U.S. housing price and Korean output, which suggests modelling interdependent capital and housing market across countries is essential for further research.

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keywords : small open economy, DSGE, transmission mechanism, financial friction, collateral constraints, Bayesian estimation
Student Number : 2013-22853

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1 Introduction

South Korea has pursued export-oriented growth since its independence from Japan in 1945. Like many other developing countries, it has based its economy on the external demand and supply of commodities it needed to nurture domestic industries and households. This dependent economic structure of Korean economy has enabled it to achieve higher speed of economic growth, but at the same time, economic turbulences from external markets were considered to dominate the country's cyclical economic movements. For instance, the Asian financial crisis in the late 1990s and the global financial crisis in 2008 were the major economic recessions that the country has experienced in its modern history. Thus the South Korean case is obviously one of the most typical examples of emerging market small open economy.

External shocks have been emphasized as the major driving factor of high-frequency fluctuations in small open economy and the transmission mechanism of foreign shocks onto domestic economy has been one of the most prevalent research topics in international macroeconomics both theoretically and empirically. However, empirical regularities have often been different from what typical macroeconomic models predict. For instance, Backus et al. (1992) is one of the first works which underline the difficulty for international macroeconomic modelling to account for international business cycle. They report that the correlation between consumption levels across countries is significantly lower than one between production levels, which is not generally explained under the existence of international risk diversification and the equalization of price under trade[1]. Ambler et al. (2004) confirm the robustness of their results by extending sample country and period. All of them highlight the necessity of modelling further international transmission mechanism. This paper analyzes whether the typical extension of financial friction to small open economy setting can overcome such problems.

[1]When trade equalizes commodity prices across countries, a negative productivity shock in a country lowers the production of that country and accordingly the price gets higher, increasing production level in the other country. Given their emphasis on productivity shock, they predict that the correlation between output levels is negative in general.

This paper follows the tradition of Gali and Monacelli (2005), one of the first works that developed a novel framework to extend New-Keynesian framework to model small-open economy. This paper also adds the home bias of domestic consumption in Faia and Monacelli (2008). This assumption is especially critical in small open economy setting, as the domestic price dynamics of small open economy is completely equivalent to the international one without home bias. Moreover, Baxter and Crucini (1995) suggests that the introduction of restrictions on asset trade, such as international transaction of non-contingent bonds can reduce the positive correlation of consumption between implied by the model. Thus, I assume that the international capital market is incomplete and only non-contingent bonds are traded both domestically and internationally.

Many works have been done to estimate structural parameters of the New Open Economy Macroeconomics(NOEM), which is necessary to evaluate empirical performance of model. Ghironi (2000) use single equation non-linear OLS to estimate the parameters of two country NOEM. Lubik and Schorfheide (2006) introduces Bayesian framework to estimate DSGE parameters in open-economy setting, suggesting that the Bayesian approach can overcome potential misspecification and lack of identification. In line with their interest, Lubik and Schorfheide (2007) perform Bayesian estimation of small open economy model. However, their specification is not truly structural, as they assume external variables such as foreign output and inflation are following AR(1) process. They cannot deal with the endogenous expectation error of domestic agents and identify foreign shocks structurally.

Among those, Justiniano and Preston (2010) is noteworthy, as their work shows a simple method to identify the effects of structural external shocks on small open economy. They model Canadian economy using medium-scale DSGE framework as a small open economy of which equilibrium is determined by the U.S. one. In their analysis, all of the U.S. variables are determined within a quasi-closed DSGE model and the structural shocks on the U.S. economy are identified accordingly. Then they estimate structural parameters of the model and evaluate how high the cross-correlations are between U.S. and Canadian variables and how much forecasting error variance of Canadian economy is explained by the structural shocks from U.S. economy, according to their parameter estimates. Their results show the limited role of external shocks on Canadian variables: model-implied cross-correlations between foreign and domestic variables are mostly zero, unlike empirical evidence, and only about one or two percent of the forecasting error is explained by them, unlike VAR-form evidence.

On the other hand, there have been numerous works focusing on the role of durable goods such as housing and that of collateral constraints in closed-economy setting. Monacelli (2009) introduces durable goods and collateral constraints into the standard New-Keynesian model and suggest that the collateral constraints can match the model to empirical regularities on durable goods market without price rigidity. Iacoviello (2005) incorporates housing market and collateral constraint to housing into the financial-accelerator model of Moore and Kiyotaki (1997) based on calibration and partial estimation matching impulse response function. Later, Iacoviello and Neri (2008) estimate their extended model with Bayesian approach and their work successfully accounts for empirical patterns of U.S. economy. Christensen et al. (2009) extend the model to open-economy version and test the importance of financial accelerator channel empirically, but they focus on the implications of spillovers induced by housing markets. Furthermore, their external shocks are identified partially by assuming variable-specific AR(1) shocks of foreign variables while I concentrate on the international business cycle issue and elaborate transmission mechanism of external shocks structurally identified.

This paper is composed as follows. I derive the empirical evidence of international business cycle spillovers from the United States to South Korea after 2000 in section 2. In section 3, I modify the model of Iacoviello (2005) with housing market and collateral constraints into a small open economy version. Then I estimate the model parameters with Metropolis-Hastings algorithm and use the results to calculate cross-correlation between the U.S. and Korean variables and decompose forecasting error variance of Korean economy after 2000 in section 4. In section 5, I compare the model-based results to empirical results to get the implications of collateral constraints in the transmission mechanism of external shocks and to discuss limitations of the model.

2 Empirical Evidence

Thick lines in figure 1 show the sample cross-correlations between Korean and lagged U.S. variables at lags from zero to four. The dotted lines give the population sample-correlations estimated DSGE models, which are discussed in section 5. The contemporaneous correlations between Korean and U.S. output, inflation, nominal interest rates and housing prices are 0.2035, 0.3222, 0.7995 and 0.6864, respectively. Given that the two countries have less tight economic relations compare to that between Canada and the U.S., the numbers look reasonable. The sample cross-correlations between Korean and U.S. variables are seldom zero and correlation is particularly strong between interest rates of Korea and the U.S., between real estate price index between Korea and the U.S., and between Korean output and U.S. real estate price. As will discussed below, the highly positive correlation between interest rates is captured only partially by the DSGE model which induces uncovered interest rate parity between the two countries from households' optimality condition. Furthermore, the most counter-factual feature of the model is that the model predicts zero cross-correlation between U.S. housing price and Korean output and between housing prices of the two countries, while in reality, the correlation is strongly positive.

In order to identify the variance share of Korean series that can be attributed to U.S. shocks, I employ a structural vector-autoregressive model(SVAR) subject to the constraint that there is no feedback from shocks on Korean variable to the U.S. variable in lagged relations as well as in contemporaneous ones. As Justiniano and Preston (2010) and Zha

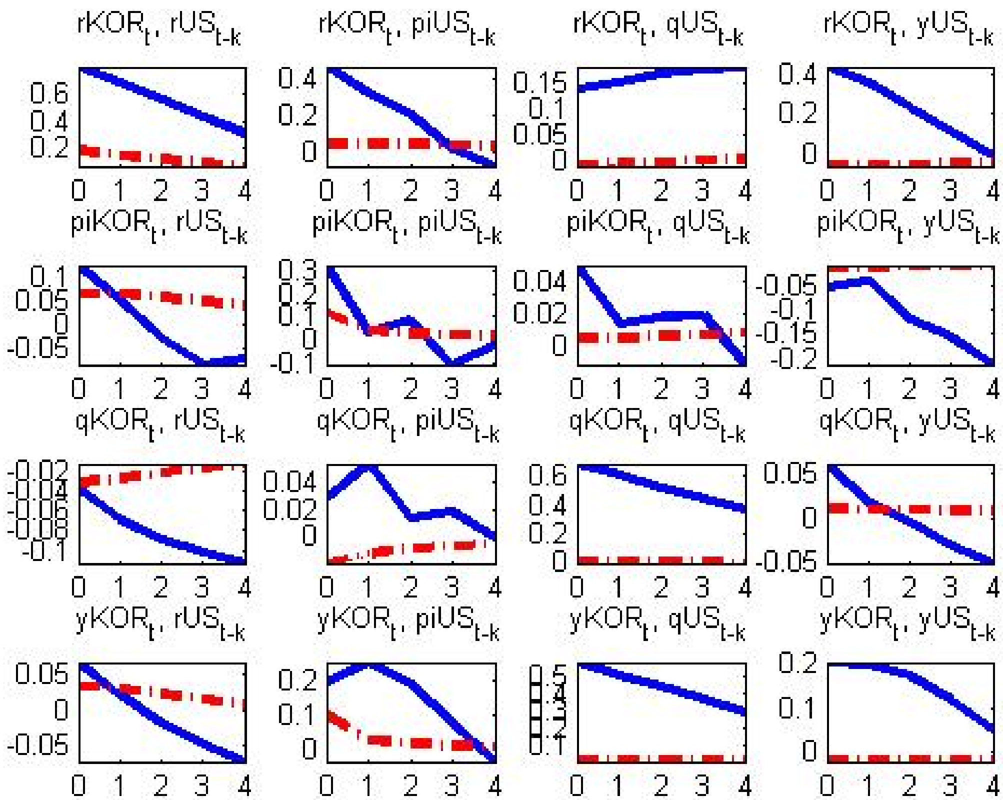

Figure 1: Data(thick blue) and DSGE population(dotted red) cross-correlations Korea-U.S.

(1999) note, this assumption is needed to avoid distortions of inference on the effect of the U.S. on the small open economy. This constrained SVAR is implementable with the efficient Gibbs algorithm of block-recursive structure, proposed by Zha (1999). After partitioning, the two blocks in SVAR are assumed as,

$$\begin{bmatrix} A_{KOR,KOR}(L) & A_{KOR,US}(L) \\ 0 & A_{US,US}(L) \end{bmatrix} \begin{pmatrix} y_t^{KOR} \\ y_t^{US} \end{pmatrix} = \begin{pmatrix} \varepsilon_t^{KOR} \\ \varepsilon_t^{US} \end{pmatrix}$$

where $A_{ij}(L)$ is the matrix lag-polynomials of block ij and y_t^{US} and y_t^{KOR} are the vector of output, inflation, interest rate and housing prices of the United States and of Korea, respectively. The orthogonal errors $[\varepsilon_t^{KOR}, \varepsilon_t^{US}]'$ have unit variance. I impose higher triangular structure in the contemporaneous impact matrices $A_{KOR,KOR}(0)$, and $A_{US,US}(0)$. This is equivalent to Cholesky decomposition of all reduced-form SUR covariance matrix.

Then I rearrange the blocks and this yields

$$y_t^i = C_i(L)y_t + v_i(t),\ i = 1, ..., n,\ \text{all } t,$$

$$\text{where } C_i(L) = \begin{cases} [I\,0] - A^{-1}_{KOR,KOR}(0)[A_{KOR,KOR}(L)\,A_{KOR,US}(L)], & \text{if } i = KOR \\ [0\,I] - A^{-1}_{US,US}(0)[0\,A_{US,US}(L)] & \text{if } i = US \end{cases}$$

I set the lag order 4 as in Justiniano and Preston (2010), Fernandez-Villaverde et al. (2007), and Del Negro et al. (2007) and use priors of which the coefficients get smaller at distant lags. I specify the priors of first lag as $A_{ij}(L) \sim N(0.9, 0.2)$ for $i = j$ and $N(0, 0.4)$ for $i \neq j$. Upon lag of order higher than 1, I assume a normal prior with zero mean and variances equal to 0.2 for the second order, 0.15 for the third order, and 0.1 for the forth order. The higher triangular elements of contemporaneous matrices are assumed to be distributed as $N(0, 10)$. The Gibbs algorithm is initialized at the posterior modes which maximizes the posterior probability density function and I run 3 chains, discarding, for each, the first 40,000 draws, and retaining 1 in 10 of the remaining 50,000. Then I evaluate the fraction of fluctuations in y_t^{KOR}, explained by the sum of all five U.S. stocks, at different forecasting horizons.

Table 1 shows the median and ninety percent posterior bands for estimated shares of the U.S. shocks on forecasting error variance of Korean variables. It shows some interesting features. First, shocks from the U.S. account for around fourteen or fifteen percent of unpredictable movements of Korean housing prices in all forecasting horizon, which is higher than that of Korean output ranging from seven to eight percent. This strong, and persistent impact of U.S. economy on Korean housing price can also be found in the panel of cross-correlation, figure 1. Second, unexpected movements of Korean inflation, interest rate, and output are somewhat dependent on the shocks from the U.S. and the degree of dependence

Table 1: Contribution of U.S. shocks on Korean variables: SVAR

Median Variance shares and [5, 95] posterior bands for all U.S. shocks

Series	1 quarter horizon		2 quarter horizon	
Output	0.0716	[0.0152, 0.2095]	0.0756	[0.0192, 0.2137]
Inflation	0.0841	[0.0126, 0.2332]	0.0886	[0.0175, 0.2361]
Interest rate	0.0609	[0.0100, 0.2049]	0.0646	[0.0130, 0.2082]
Housing Price	0.1439	[0.0537, 0.2777]	0.1521	[0.0619, 0.2843]
	4 quarter horizon		8 quarter horizon	
Output	0.0795	[0.0233, 0.2168]	0.0813	[0.0250, 0.2178]
Inflation	0.0926	[0.0217, 0.2384]	0.0936	[0.0230, 0.2835]
Interest rate	0.0693	[0.0179, 0.2113]	0.0706	[0.0193, 0.2124]
Housing Price	0.1606	[0.0701, 0.2919]	0.1631	[0.0723, 0.2938]

· Variance share is scaled over [0, 1] so that 0.01 corresponds to 1%.

gets slightly higher when it comes to forecasting on longer horizon. This pattern is common for all of the four Korean series and seems due to the higher persistence of U.S. shocks relative to Korean ones.

Overall, the existence of strong co-movements between Korean and U.S. business cycles can be inferred from investigations on forecasting error variance shares of U.S. shocks on Korean variables as well as that on the cross-correlation between Korean and the U.S. variables. Owing to these features, modelling cyclical fluctuations of Korea requires small open economy setting that is affected by the exogenous processes of international prices and of external demands.

3 Model

The model follows the specification of Iacoviello (2005) except some additional assumptions of the small economy. Note that the foreign economy is assumed to follow the model of Iacoviello (2005). In the model, there are three kinds of households: entrepreneurs, patient households, and impatient households. The difference in discount rate across households makes patient households lend money to entrepreneurs and impatient households in the steady state. The borrowers are subject to borrowing constraints proportional to their housing collateral values. Like Iacoviello (2005), I approximate optimality conditions linearly, which means the collateral constraints are binding around the steady state and rules out precautionary saving motives of borrowers.

3.1 Entrepreneurs

Entrepreneurs demand housing h_t at real housing price q_t as a factor of production and they get utilities only from consumption C_t. They employ domestic labor L' and L'' from patient and impatient households at wage rate w_t' and w_t'' respectively, accumulate capital K with investment I_t and sell intermediate goods Y_t to retailers or to the foreign sector. Since intermediate goods act as perfect substitutes, their price is given in the international market. As in Iacoviello (2005), their international price denominated in foreign currency P_t^{w*} is expressed in terms of final goods' price index(P_t^*) and the mark-up(X_t^*) in foreign market, i.e. $P_t^{w*} = P_t^*/X_t^*$.

Only they have access to the international asset market and can borrow d_t, denominated in foreign currency at gross international interest rate R_t^*. Note that foreign investors have no access to the domestic asset market. Entrepreneurs can borrow non-contingent bonds b_t in domestic market at gross domestic interest rate R_t. As in Iacoviello (2005), I add financial friction specified by Moore and Kiyotaki (1997) with slight modification. In other words, the total real obligations of the entrepreneurs from domestic and international asset market are limited proportionally to the rate m of their expected housing value next period. Here, I assume that if borrowers repudiate their debt obligations at $t+1$, the domestic and international lenders can take housing assets from borrowers with proportional transaction cost $(1-m)q_{t+1}h_t$.

Their lifetime maximization leads to

$$\max_{b_t, d_t, I_t, K_t, h_t, L_t', L_t''} \mathbb{E}_0 \sum_{t=0}^{\infty} \gamma^t \ln C_t$$

subject to

$$
\begin{aligned}
Y_t &= A_t K_{t-1}^{\mu} h_{t-1}^{\nu} L_t'^{\alpha(1-\mu-\nu)} L_t''^{(1-\alpha)(1-\mu-\nu)} \\
\frac{Q_t Y_t}{X_t^*} + b_t + Q_t d_t &= C_t + q_t(h_t - h_{t-1}) + \frac{R_{t-1}}{\pi_t} b_{t-1} + \left(\frac{R_{t-1}^* \phi_t}{\pi_t^*}\right) \\
&\times\ Q_t d_{t-1} + w_t' L_t' + w_t'' L_t'' + I_t + \xi_{K,t} \\
E_t(R_t^* \phi_{t+1} Q_{t+1} d_t + R_t b_t) &\leq E_t(m q_{t+1} h_t \pi_{t+1}) \\
I_t &= K_t - (1-\delta) K_{t-1}
\end{aligned}
$$

where A_t is the productivity level for intermediate goods, π_t the inflation rate of consumers' price index, $Q_t \equiv \frac{P_t^* S_t}{P_t}$ the real exchange rate and $d_t \equiv D_t / P_t^*$ the debt owed to the foreign investor, and $\xi_{K,t}$ is the capital adjustment cost.

The adjustment costs of capital accumulation is described as a quadratic form:

$$
\xi_{K,t} = \frac{\psi_K}{2\delta} \left(\frac{I_t}{K_t - 1} - \delta \right)^2 K_{t-1}
$$

The debt-elastic international interest rate is introduced here to pin down the steady-state equilibrium and to induce stationary linearized model, following Schmitt-Grohé and Uribe (2003). To be specific, the international interest rate faced by domestic borrowers increases with the real relative quantity of aggregate debt level of entrepreneurs owed to international lenders to the steady-state consumption level of foreign final goods C_F, as in Justiniano and Preston (2010).

$$
\phi_t = exp \left[\iota \left(\frac{Q_{t-1} \tilde{d}_{t-1}}{C_F} \right) \right]
$$

Consumption preferences in the home economy are given with home bias in domestic final goods consumption, following Faia and Monacelli (2008)

$$C_t \equiv \left[(1-\tau)^{\frac{1}{\rho}} C_{H,t}^{\frac{\rho-1}{\rho}} + \tau^{\frac{1}{\rho}} C_{F,t}^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}$$

where

$$C_{H,t} = \left[\int_0^1 C_{H,t}(z)^{\frac{\vartheta-1}{\vartheta}} dz\right]^{\frac{\vartheta}{\vartheta-1}}$$

$$C_{F,t} = \left[\int_0^1 C_{F,t}(z)^{\frac{\vartheta-1}{\vartheta}} dz\right]^{\frac{\vartheta}{\vartheta-1}}$$

Thus, the τ is interpretable as the degree of openness in H, ρ as the price elasticity of demand for home final goods composite, ϑ as the price elasticity of demand for each variety. For simplicity, I assume ρ is same across countries and so is ϑ.

The demand for each differentiated good is

$$C_{H,t}(i) = (P_{H,t}(i)/P_{H,t})^{-\vartheta} C_{H,t}$$

$$C_{F,t}(i) = (P_{F,t}(i)/P_{F,t})^{-\vartheta} C_{H,t}$$

where $P_{H,t} = \left(\int_0^1 P_{H,t}(z)^{1-\vartheta} dz\right)^{\frac{1}{1-\vartheta}}$, $P_{F,t} = \left(\int_0^1 P_{F,t}(z)^{1-\vartheta} dz\right)^{\frac{1}{1-\vartheta}}$.

The optimal allocation of expenditure across domestic and foreign goods implies demand functions given as

$$C_{H,t} = (1-\tau)(P_{H,t}/P_t)^{-\rho} C_t$$

$$C_{F,t} = \tau(P_{F,t}/P_t)^{-\rho} C_t$$

where $P_t = \left[(1-\tau)P_{H,t}^{1-\rho} + \tau P_{F,t}^{1-\rho}\right]^{\frac{1}{1-\rho}}$.

Henceforth, I assume that $I_t, C'_{H,t}, C''_{H,t}$ and the foreign counterparts have the same preference over z of the same parameter values τ, ρ, and ϑ.

First order conditions with respect to $b_{t+1}, d_{t+1}, I_t, K_{t+1}, h_t, L'_t, L''_t$ are

$$
\begin{aligned}
\frac{1}{C_t} &= \gamma R_t E_t \frac{1}{C_{t+1}\pi_{t+1}} + \lambda_t R_t \\
\frac{Q_t}{C_t} &= \gamma R^*_t E_t \frac{Q_{t+1}\phi_{t+1}}{\pi^*_{t+1} C_{t+1}} + \lambda_t E_t \phi_{t+1} R^*_t Q_{t+1} \\
u_t &= \frac{1}{C_t}\left(1 + \frac{\psi}{\delta}\left(\frac{I_t}{K_{t-1}} - \delta\right)\right) \\
u_t &= \gamma \frac{1}{C_{t+1}}\left(\frac{\psi}{\delta}\left(\frac{I_{t+1}}{K_t} - \delta\right)\frac{I_{t+1}}{K_t} - \frac{\psi}{2\delta}\left(\frac{I_{t+1}}{K_t} - \delta\right)^2\right) \\
&+ \gamma E_t\left[\frac{\mu Y_{t+1} Q_{t+1}}{C_{t+1} X^*_{t+1} K_t} + u_{t+1}(1-\delta)\right] \\
\frac{1}{C_t} q_t &= E_t\left[\frac{\gamma}{C_{t+1}}\left(\nu \frac{Y_{t+1} Q_{t+1}}{X^*_{t+1} h_t} + q_{t+1}\right) + \lambda_t m \pi_{t+1} q_{t+1}\right] \\
w'_t &= \frac{\alpha(1-\mu-\nu) Y_t Q_t}{X^*_t L'_t} \\
w''_t &= \frac{(1-\alpha)(1-\mu-\nu) Y_t Q_t}{X^*_t L''_t}
\end{aligned}
$$

Optimality conditions of unconstrained households for domestic and foreign bond holdings imply somewhat similar to the uncovered (real) interest rate parity condition:

$$\mathbb{E}_t\left[\left(\frac{1}{C_{t+1}\pi_{t+1}} + \lambda_t\right)\left(R_t - R^*_t (Q_{t+1}/Q_t)\phi_{t+1}\right)\right] = 0$$

3.2 Retailers

As in Iacoviello (2005), the retailers' problem follows Bernanke et al. (1999). There is a continuum of retailers indexed by $z \in [0,1]$. They buy tradable intermediate goods produced by entrepreneurs in a perfectly competitive market with price $P^w_t = S_t P^{w*}_t$, which is determined in the international market. Then they turn intermediate goods into differentiated final goods with no costs and sell final ones to domestic and foreign households. They can readjust their prices each period with probability θ. Then the profit is described as the function of competitively monopolistic price $P_{H,t}$ set at t.

$$\max_{P_{H,t}(z)} \sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left\{ \Lambda_{t,k} \frac{P_{H,t}(z) - P^w_{t+k}}{P_{t+k}} Y^f_{t+k} \right\}$$

where $\Lambda_{t,k} = \beta^k (C'_t / C'_{t+k})$ denotes the stochastic discount factor relevant to the patient households.

The demand is given by

$$Y^f_{t+k}(z) = \left(\frac{P_{H,t}(z)}{P_{H,t+k}} \right)^{-\vartheta} (C_{H,t+k} + C'_{H,t+k} + C''_{H,t+k} + I_t + C^*_{H,t+k} + {C^*_{H,t+k}}' + {C^*_{H,t+k}}'' + I^*_{H,t+k})$$

where $C^{(*)}_{H,t+k} = (1-\tau) \left(\frac{P_{H,t+k}}{P_{t+k}} \right)^{-\rho} C^{(*)}_{t+k}$, $C'^{(*)}_{H,t+k} = (1-\tau) \left(\frac{P_{H,t+k}}{P_{t+k}} \right)^{-\rho} C'^{(*)}_{t+k}$, $C''^{(*)}_{H,t+k} = (1-\tau) \left(\frac{P_{H,t+k}}{P_{t+k}} \right)^{-\rho} C''^{(*)}_{t+k}$, $I^{(*)}_{H,t+k} = (1-\tau) \left(\frac{P_{H,t+k}}{P_{t+k}} \right)^{-\rho} I^{(*)}_{t+k}$.

Note again that here I am assuming the price elasticity of demand for home composite is same across consumption and investment and between home and foreign.

The first order condition for profit maximization becomes

$$\mathbb{E}_t \left[\sum_{k=0}^{\infty} \theta^k \Lambda_{t,k} Y^f_{t+k} \left\{ \frac{P_{H,t}(z)}{P_{t+k}} - \frac{\vartheta}{\vartheta - 1} \frac{P^w_{t+k}}{P_{t+k}} \right\} \right] = 0$$

Using $P^w_{t+k}/P_{t+k} = Q_{t+k}/X^*_{t+k}$, this becomes

$$\sum_{k=0}^{\infty} \mathbb{E}_t \theta^k \left\{ \Lambda_{t,j} \left(\frac{P_{H,t}(z)}{P_{t+k}} - \frac{X}{X^*_{t+k}} Q_{t+k} \right) \right\} Y^f_{t+k}(z) = 0$$

where $X \equiv \frac{\vartheta}{\vartheta - 1}$ is the steady-state mark-up.

Due to the symmetry of firms, all firms set the same price. Thus, I would omit the firm index z in the optimal price from now on. In equilibrium, profits of retailers are given to unconstrained households and are equal to $F_t = Y^f_t (P_{H,t} - P^w_t)/P_t$.

The relation between X_t and X_t^* is described as

$$X_t = P_{H,t}/P_t^w = (P_{H,t}/S_t P_t^*)X_t^* = X_t^*/TOT_t$$

where $TOT_t \equiv \frac{P_t^*}{P_{H,t}^*} = \frac{S_t P_t^*}{P_{H,t}}$ is the bilateral terms of trade.

Note that the aggregate price level of home-produced goods evolves according to

$$P_{H,t} = (\theta P_{H,t-1}^{1-\vartheta} + (1-\theta)(P_t^*)^{1-\vartheta})^{1/(1-\vartheta)}$$

Log-linearising the two equations above and combining them gives forward-looking Phillips curve for the producer price index. Then the relation between producer price index and consumer index is described as

$$\frac{P_t}{P_{H,t}} = \left\{(1-\tau) + \tau TOT_t^{1-\rho}\right\}^{\frac{1}{1-\rho}}$$

and is used to derive the Philips curve for the consumer price index.

3.3 Unconstrained Households

Unconstrained households are those who have the highest discount factor. Their utility comes from consumption C_t', housing stock h_t' and real money holdings $\frac{M_t'}{P_t}$ and labor supply L_t' gives them disutility. They have negative domestic debt contracts b_t' so that they lend to entrepreneurs and constrained households to smooth intertemporal utility. The profits of retailers are rebated to unconstrained households.

$$\max_{b_t', d_t', h_t', L_t', \frac{M'}{P}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\ln C_t' + j_t \ln h_t' - \frac{(L_t')^\eta}{\eta} + \chi \ln \frac{M_t'}{P_t} \right)$$

subject to

$$C_t' + q_t(h_t' - h_{t-1}') + \frac{R_{t-1}}{\pi_t} b_{t-1}' = b_t' + w_t' L_t' + F_t + \left[-\frac{M_t' - M_{t-1}'}{P_t} \right]$$

Then first order conditions are

$$
\begin{aligned}
\frac{1}{C'_t} &= \beta R_t E_t \left(\frac{1}{\pi_{t+1} C'_{t+1}} \right) \\
\frac{q_t}{C'_t} &= \frac{j}{h'_t} + \beta E_t \left(\frac{q_{t+1}}{C'_{t+1}} \right) \\
\frac{w'_t}{C'_t} &= (L'_t)^{\eta' - 1}
\end{aligned}
$$

3.4 Constrained Households

Unconstrained households are virtually same as constrained households, with an exception that they are subject to the collateral constraints because they borrow in the steady state due to their lowest discount factor. Their choice variables are augmented with $''$ and the ratio of maximum debt level to collateral level is denoted as m''. Unlike entrepreneurs, they cannot borrow from foreign investors. Their lifetime utility maximization yields

$$
\max_{b''_t, d''_t, h''_t, L''_t, \frac{M''}{P}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta''^t \left(\ln C''_t + j_t \ln h''_t - \frac{(L''_t)^{\eta''}}{\eta''} + \chi \ln \frac{M''_t}{P_t} \right)
$$

subject to

$$
\begin{aligned}
C''_t + q_t(h''_t - h''_{t-1}) + \frac{R_{t-1}}{\pi_t} b''_{t-1} &= b''_t + w''_t L''_t + \left[- \frac{M''_t - M''_{t-1}}{P_t} \right] \\
E_t(R_t b''_t) &\leq E_t(m'' q_t h''_t \pi_{t+1})
\end{aligned}
$$

First order conditions are

$$
\begin{aligned}
\frac{1}{C''_t} &= \beta'' R_t E_t\left(\frac{1}{\pi_{t+1}C''_{t+1}}\right) + \lambda''_t R_t \\
\frac{q_t}{C''_t} &= \frac{j}{h''_t} + E_t\left(\frac{\beta'' q_{t+1}}{C''_{t+1}} + \lambda''_t m'' q_{t+1}\pi_{t+1}\right) \\
\frac{w''_t}{C''_t} &= (L''_t)^{\eta''-1}
\end{aligned}
$$

As utility is separable in money balances and the actual quantity of money has no implications for the rest of the world, the money balance part is ignored afterwards.

3.5 Monetary Policy and Shock Processes

Monetary policy is modelled to control the domestic interest rate R_t. The domestic interest rate systematically responds to inflation rates, domestic mark-up and exchange rate growth. The government adjusts it with the following Taylor-type rule.

$$
\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\phi_r}\left[\left(\frac{P_t}{P_{t-1}}\right)^{\phi_\pi}\left(\frac{X_t}{X}\right)^{\phi_x}\left(\frac{S_t}{S_{t-1}}\right)^{\phi_S}\right]^{1-\phi_r} e_{m,t}
$$

where ϕ_r measures interest rate inertia and $e_{m,t}$ is the white noise shock for monetary rule.

Productivity, cost-push, and housing demand shocks are modelled to follow AR(1) process, with autocorrelation coefficients ρ_A, ρ_u, and ρ_j and standard deviation of error terms σ_A, σ_u, and σ_j respectively.

3.6 Markets and Equilibrium

Equilibrium satisfies the following clearing conditions for domestic loan, real estate and final goods.

$$
\begin{aligned}
0 &= b_t + b_t' + b_t'' \\
1 &= h_t + h_t' + h_t'' \\
Y_t^f &= C_{H,t} + C_{H,t}' + C_{H,t}'' + I_{H,t} + C_{H,t}^* + {C_{H,t}^*}' + {C_{H,t}^*}'' + I_{H,t}^* \\
&= (1-\tau)\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}(C_t + C_t' + C_t'' + I_t) + \tau^*\,(TOT_t)^{\rho}\,Y_t^*
\end{aligned}
$$

where

$Y_{H,t} = \left(\int_0^1 Y_{H,t}(z)^{\frac{\vartheta-1}{\vartheta}}\right)^{\frac{\vartheta}{\vartheta-1}}$.

Also, note that as home is modelled as a small open economy, its supply and demand for assets and intermediate goods are of measure zero relative to the foreign economy. Thus they are not bound to be set at market-clearing level and they are determined relatively to foreign price conditions.

4 Bayesian Estimation

4.1 Estimation and Priors

Originally, Iacoviello (2005) calibrates most of the parameters, estimates the policy parameters firstly with OLS, and then estimates parameters such as factor shares(α), loan-to-values(m, m''), autocorrelation of shocks(ρ_A, ρ_j, ρ_u), and standard-deviation of error terms (σ_A, σ_j, σ_u) which minimizes the weighted sum of distances between model-implied impulse responses and empirical impulse responses.

However, I estimate almost all of the parameters with Bayesian approach, designed in An and Schorfheide (2007) and Smets and Wouters (2005). I first estimate posterior distribution of parameters determining U.S. equilibrium with U.S. output, price, housing price and interest rate data. Then given the modes estimates of U.S. parameters, I estimate the rest of the parameters related to the Korean equilibrium. This two-step procedure is primarily to reduce the computation burden but do not affect the results significantly, as the equilibrium of the United States is assumed to be independent of Korean one.

As Ireland (2004) and Iacoviello (2005) point out, the number of data series in the state-space representation should be equal to or lower than the number of structural disturbances in the model unless additional measurement error is added. For both the U.S. and the Korean economy, the structural shocks are technology shock, cost-push shock, housing-demand shock and monetary policy shock. Thus I selected 8 data series on U.S. and Korean economy: output, interest rate, housing prices and inflation rates from each of them for 2000:Q1 - 2014:Q4. Interest rates and inflation rates are demeaned while housing prices and output are linearly detrended. The data description can be found in the appendix. I evaluate the likelihood based on the state-space representation of model given parameters and Kalman-filter. Then posterior distribution of model parameters are estimated with random walk Metropolis-Hastings procedure.

The first column of table 3 and 4 describes the priors of the coefficients including the distribution type, mean and standard deviation. Most of the parameters are set to accord with earlier researches on Bayesian inference. But means and standard deviations of some parameters specific to Iacoviello (2005) are adopted from Iacoviello (2005) as estimates and their standard errors in case of U.S. ones. However, when I set priors of housing market and open economy parameters on Korean economy, I increase prior standard deviation to reduce its effect on posterior distribution. Some parameters which are not well identified in the model are calibrated following Iacoviello (2005) and Justiniano and Preston (2010). Calibrated parameters are presented in table 2.

4.2 Estimation Results

The results of the first step are presented in table 3 and the results of the second step are in table 4.

Table 2: Calibrated Parameters

Parameter	Description	Value
γ	discount factor(entrepreneur)	0.98
β	discount factor(saver)	0.99
β''	discount factor(borrower)	0.95
μ	variable capital share	0.3
ν	housing share	0.03
ψ	variable capital adjustment cost	2
δ	variable capital depreciation rate	0.03
X	steady-state mark-up	1.05
ι	elasticity of international interest rate	0.01

Estimation of structural parameters in DSGE framework has been performed in previous literature, so here I can compare the results with those from related literature. First, the Calvo price-setting parameter θ is estimated a lot lower than the literature, suggesting that the average firm changes price frequently every two quarters. In Justiniano and Preston (2010) or in Iacoviello and Neri (2008), Calvo parameters of final goods were far higher to reach around 0.8. This is because here the model does not distinguish imported goods from domestic goods. The parameter for imported goods is lower than that for domestic consumption goods. Thus, the lower estimate for θ reflects higher frequency of price adjustments for imported goods. Furthermore, some model-specific parameters are estimated quite differently from Iacoviello and Neri (2008). For instance the median wage share of patient households α, 0.6089 is lower than that in Iacoviello and Neri (2008) 0.79. This is because compared models have different production structure. In the model above, the housing supply is fixed while in Iacoviello and Neri (2008) labor can be used to supply real estate. Thus, if the wage share of unconstrained households in intermediate goods production is lower but that in housing production is higher, the model which identifies only intermediate goods production may yield lower estimate of the wage share. Moreover, the inverse Frisch elasticity of labor supply, η' and η'' is estimated higher than that in Iacoviello and Neri (2008). This difference seems originated from the different prior of the estimation above and that in Iacoviello and

Neri (2008). Other estimates including parameters shock processes and monetary policy look consistent with previous works.

On the flip side, only a few works have implemented Bayesian estimation of DSGE parameters on Korean data, which includes Kim (2014). The model of Kim (2014) is a small open economy version of standard New-Keynesian model including various temporary and trend sources of structural shocks. Much alike when we compare the US estimation results, the estimate of Calvo-pricing parameters θ is a lot lower than his estimate. The reason is, again, that the model fails to identify the price rigidity in domestic goods and imported goods as for Korean market. The latter is captured in the estimates of U.S. data. But the estimate, 0.5, is still significantly higher than what Kim (2014) finds, 0.231. Results on model-specific parameters are hard to compare with previous works. But compared to U.S. estimates, the country exhibits higher steady-state weight on housing services j. The estimates are consistent with the former notion that the country has higher degree of interaction between real estate market and macroeconomic fluctuations. Technology and cost-push shocks are not persistent compared to U.S. economy. But housing demand shocks are highly persistent in both countries.

5 Transmission Mechanism

5.1 Impulse Responses and Transmission Mechanism

Figure 2 shows responses of Korean interest rate, inflation, housing prices, and overall consumption with respect to unexpected increase in U.S. interest rate. Contractionary U.S. monetary shocks affect Korean economy in two ways[2]. First, lower demand for intermediate goods in the international market reduces the price for intermediate goods. Thus it reduces housing demand to produce intermediate goods, resulting in lower housing price. Second,

[2]Note that, because of endogenous reaction of monetary policy rule onto contemporaneous fluctuations of mark-up, inflation, and exchange rate, the negative ε_r shock increases interest rate.

Table 3: Prior and posterior moments of model parameters - U.S.

		Prior			Posterior		
Parameter	Description	Prior density	Mean	Sd	Median	Sd	[5, 95]
θ	Calvo prices	Beta	0.75	0.1	0.5419	0.0514	[0.4559, 0.6244]
α	patient households wage share	Beta	0.64	0.03	0.6089	0.0283	[0.5615, 0.6548]
m	loan-to-value entrepreneur	Beta	0.89	0.02	0.8125	0.0194	[0.7797, 0.8432]
m''	loan-to-value household	Beta	0.55	0.09	0.5932	0.0509	[0.4980, 0.6656]
j	steady-state weight housing services	Beta	0.1	0.02	0.1054	0.0186	[0.0782, 0.1391]
η'	inverse Frisch(savers)	Gamma	1.01	0.1	1.0354	0.0982	[0.8815, 1.2059]
η''	inverse Frisch(borrowers)	Gamma	1.01	0.1	0.8984	0.0912	[0.7587, 1.0559]
ϕ_r	Taylor lagged coefficient	Beta	0.6	0.2	0.7846	0.0383	[0.7115, 0.8346]
ϕ_x	Taylor mark-up coefficient	Gamma	0.25	0.13	0.0519	0.0281	[0.0201, 0.1090]
ϕ_π	Taylor inflation coefficient	Normal	1.8	0.3	2.1860	0.2556	[1.7775, 2.6156]
ρ_A	technology autocorrelation	Beta	0.8	0.1	0.9878	0.0065	[0.9747, 0.9955]
ρ_j	housing demand autocorrelation	Beta	0.8	0.1	0.9688	0.0079	[0.9544, 0.9805]
ρ_u	cost-push autocorrelation	Beta	0.8	0.1	0.9469	0.0237	[0.8992, 0.9753]
σ_A	technology standard deviation	Inv.gamma	0.01	0.01	0.0161	0.0019	[0.0135, 0.0196]
σ_j	housing demand standard deviation	Inv.gamma	0.01	0.01	0.0956	0.0192	[0.0687, 0.1322]
σ_u	cost-push standard deviation	Inv.gamma	0.01	0.01	0.0029	0.0009	[0.0019, 0.0047]
σ_r	monetary standard deviation	Inv.gamma	0.01	0.01	0.0017	0.0003	[0.0014, 0.0023]

· I draw 4 chains of 100,000 draws generated using Metropolis-Hastings algorithm and discard the initial 50,000 and retain on in every 5 subsequent draws. I monitor trace plots for convergence.

Table 4: Prior and posterior moments of model parameters - Korea

		Prior			Posterior		
Parameter	Description	Prior density	Mean	Sd	Median	Sd	[5, 95]
θ	Calvo prices	Beta	0.75	0.1	0.7218	0.1093	[0.5263, 0.8826]
α	patient households wage share	Beta	0.64	0.03	0.6512	0.0979	[0.4709, 0.7903]
m	loan-to-value entrepreneur	Beta	0.55	0.1	0.5657	0.1589	[0.2952, 0.8201]
m''	loan-to-value household	Beta	0.55	0.1	0.4758	0.1714	[0.1715, 0.7286]
j	steady-state weight housing services	Beta	0.2	0.1	0.3077	0.2027	[0.0586, 0.7265]
η'	inverse Frisch(savers)	Gamma	1.01	0.1	1.0556	0.1027	[0.8702, 1.2111]
η''	inverse Frisch(borrowers)	Gamma	1.01	0.1	1.0878	0.1827	[0.7965, 1.4126]
ρ	price elasticity of demand	Normal	0.9	0.1	0.9644	0.1312	[0.7446, 1.1823]
τ	openness	Beta	0.29	0.1	0.5014	0.1954	[0.1482, 0.8055]
τ^*	openness of foreign	Beta	0.001	0.0005	0.0023	0.0044	[0.0002, 0.0100]
ϕ_r	Taylor lagged coefficient	Beta	0.6	0.2	0.6072	0.2419	[0.1212, 0.8992]
ϕ_x	Taylor mark-up coefficient	Gamma	0.25	0.13	0.1676	0.0963	[0.0379, 0.3594]
ϕ_π	Taylor inflation coefficient	Normal	1.8	0.3	2.0510	0.2259	[1.6878, 2.4325]
ϕ_S	Taylor nominal exchange rate coefficient	Gamma	0.3	1	1.5677	0.4483	[0.8418, 2.3112]
ρ_A	technology autocorrelation	Beta	0.8	0.1	0.7692	0.1345	[0.4893, 0.9264]
ρ_j	housing demand autocorrelation	Beta	0.8	0.1	0.9764	0.0146	[0.9474, 0.9952]
ρ_u	cost-push autocorrelation	Beta	0.8	0.1	0.6427	0.2278	[0.1896, 0.9279]
σ_A	technology standard deviation	Inv.gamma	0.01	0.01	0.0144	0.0110	[0.0065, 0.0386]
σ_j	housing demand standard deviation	Inv.gamma	0.01	0.01	0.0843	0.0377	[0.0397, 0.1602]
σ_u	cost-push standard deviation	Inv.gamma	0.01	0.01	0.0061	0.0075	[0.0018, 0.0234]
σ_r	monetary standard deviation	Inv.gamma	0.01	0.01	0.0126	0.0130	[0.0027, 0.0423]

· I draw 4 chains of 100,000 draws generated using Metropolis-Hastings algorithm and discard the initial 50,000 and retain on in every 5 subsequent draws. I monitor trace plots for convergence.

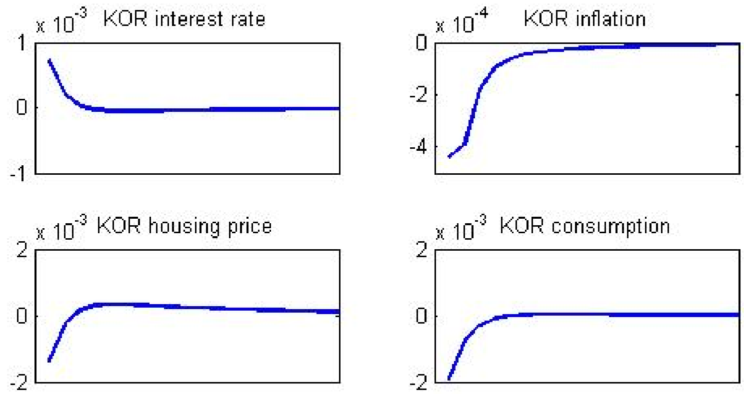

Figure 2: Impulse Responses - U.S. monetary shock

domestic interest rate is raised. Tightening collateral constraints, it decreases consumption of entrepreneurs and constrained households. Unconstrained households have two conflicting effects. As foreign demand for domestic final goods decrease as a result of decrease in overall consumption, demand for final goods gets lowered, thus unconstrained households earn lower profit. Furthermore, increase in domestic interest rate and decrease in house price make them decrease their current consumption. But as the housing price gets lowered and they begin to decrease their housing holding, consumption level of unconstrained households becomes higher. The former effect dominates in initial periods, which is reversed after two quarters. However, by cancelling out each other, effects on aggregate consumption and output become negligible after two quarter.

Note that U.S. monetary shock has the opposite effect on the housing prices of the U.S.. This is because, demand for intermediate goods increases after two quarters as the central bank decreases sharply interest rates in response to the negative deviation of inflation. Demand for real estate for production increases as people begin to consume more after some periods. It results in dynamic positive feedback between consumption and housing prices which Iacoviello (2005) mentioned. Increase in housing price raises consumption level of entrepreneurs and constrained households more than proportionally, which increases aggregate output level. Thus even if the contemporaneous correlation between U.S. and Korean output is positive given structural interest rate shocks, the lagged correlation is negative.

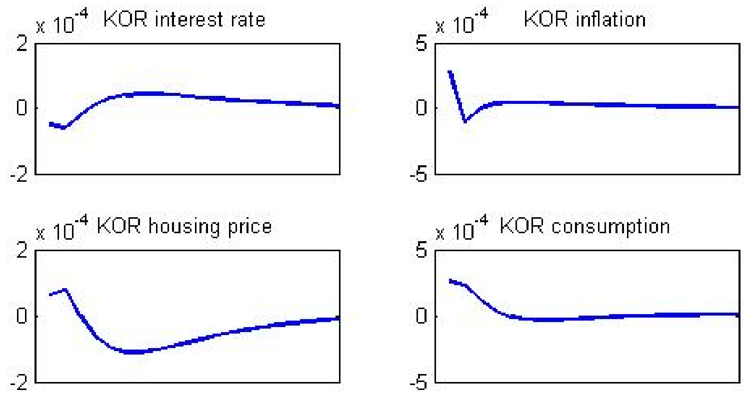

Figure 3: Impulse Responses - U.S. housing demand shock

Figure 3 shows impulse-responses of Korean variables as a function of U.S. housing demand shock. Positive shock on U.S. housing demand increases housing demand, stimulating consumption through looser collateral constraint. However, its effect on Korean economy is insignificant, as the perfectly competitive price of intermediate goods adjusts immediately and only interest rate channel lasts longer, of which the effect has limited extent. Thus the transmission mechanism is limited as for external housing demand shock. Given that most of housing price movements in Korea and the U.S. are explained by housing demand shock from each country, the orthogonality assumption on housing demand shocks causes lower correlations between real estate prices.

Figure 4 shows how U.S. cost-push shock affects Korean variables. As cost-push shock lowers demand for real estate for production as well as demand for intermediate goods and causes the central bank to increase interest rates in response to high inflation rate, the tightening collateral constraints reinforce decrease in overall consumption and output in both countries. This makes Korean output positively correlated to U.S. output both contemporaneously and in lagged relations.

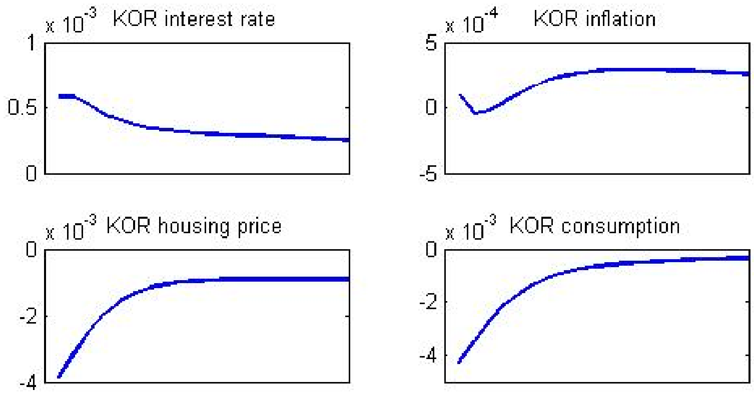

Figure 4: Impulse Responses - U.S. cost-push shock

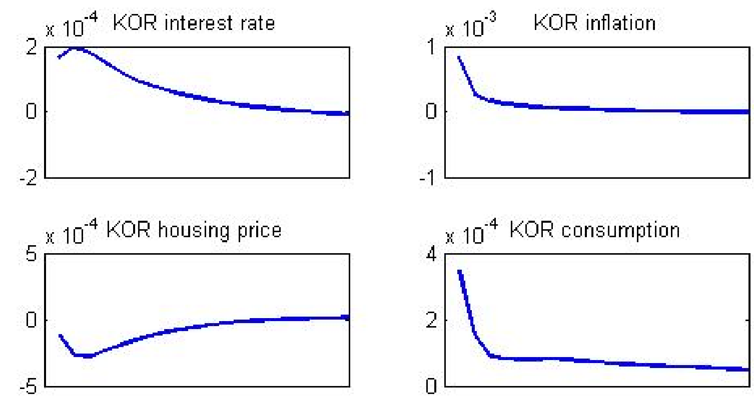

Figure 5: Impulse Responses - U.S. technology shock

Dynamic responses of Korean variables with regard to positive technology shocks in the U.S. are plotted in the figure 5. As income increases in the U.S., demand for housing and for final goods increases significantly in the country. At the same time, increase in the inflation and output increase interest rates in the country. Thus, the housing price increases and the marginal cost of supplying intermediate goods is raised, increasing their international prices. While this increases the output and demand for housing in Korea, increase in interest rates lowers overall consumption and demand for real estate of the country. These two cancel out each other so that the overall effect is negligible compared to to other shocks.

To sum up, cost-push shock from the U.S. is the only source that correlates Korean output and housing price positively to U.S. output and housing prices persistently. Other shocks such as monetary shock and housing demand shock produce either negative or zero correlation between them. However, as would be shown below, the cost-push shock itself has limited impact to account for the strong and positive correlations between Korean and U.S. variables.

5.2 Cross-correlation and Forecasting Error Decomposition

Forecasting error decomposition results based on the DSGE model are presented in table 5. Dotted red lines in figure 1 represents median of cross-correlations between Korean variables and lagged U.S. variables at lags zero to four implied by DSGE estimates. Both results exhibit some of the improvements that the model has achieved with collateral constraints and the weakness that it failed to overcome.

First, the model produces higher proportion of unexpected changes in Korean output explained by external shocks, than the data. Furthermore, some of the co-movements between Korean output and U.S. interest rates as well as ones between Korean output and U.S. inflation are reproduced in the model. Here, existence of housing market combined with collateral constraint strengthens the effects of foreign shocks in Korean economy. Relaxing collateral constraints of entrepreneurs and constrained households, increase in real estate price raises consumption level of those households at that period more than proportionally, which amplifies business cycle fluctuations. Bjørnland and Jacobsen (2010) note that the housing price plays an important role in the transmission mechanism of domestic monetary policy and domestic interest rate responds systematically to the fluctuation of house price. Here, this paper suggests that real estate price has impacts on how the external structural shocks influence domestic economy. However, the model predicts almost no cross-correlation between Korean and U.S. output as well as one between Korean output and U.S. housing price.

Second, the model manages to make some degree of international co-movement between countries, especially in terms of interest rates. However, the model produces lower degree of positive correlation between interest rates of Korea and the U.S. than the data while the share of U.S. shocks on unexpected movements of interest rate in Korea is comparable to the VAR results. These results imply the model misses some other aspects that the Bank of Korea considers when it determines domestic interest rates. Moreover, the model underestimates the forecasting error share of U.S. shocks on inflation and the cross-correlation between lagged U.S. variables and Korean inflation. Again, this shows the model fails to capture all of the structural decisions that the representative retailer takes when it sets its price. One of the most restrictive assumption in the model is that the foreign agent do not access to domestic bond market. When domestic capital market gets open, no arbitrage condition between domestic and foreign bond market equalizes interest rates and have implications on co-movements between inflation rates.

Third, the model fails to recover the impact that foreign shocks have on price dynamics of real estate in Korea. Data exhibits highly positive and persistent co-movements between real estate prices of two countries. SVAR results show that the variance share of shocks from the U.S. on Korean housing prices is higher than that on Korean output. All these results imply there are other unidentified mechanisms on which Korean real estate market is affected by external forces. In this model, real estate demand for production increases when international price for the homogeneous intermediate good increases. Housing demand also increases when interest rate falls and the real marginal value of housing to alleviate collateral constraint increases[3]. However, recently Justiniano et al. (2014) claims massive inflow of capital from saving glut resulted in housing market boom in 2000s in the United States. If housing boom in a country correlates itself positively with active foreign investments, which provides other countries with more liquidity, we would be able to explain cyclical co-movements of real estate prices across countries. This implies it is needed to elaborate further incentives

[3] In order to have positive relationship between house prices, we must have cost-push shock of the U.S., which decrease housing demand for production of intermediate goods in both countries. However, most of the housing price fluctuations are interpreted to result from its own housing demand shocks, which are assumed to be orthogonal to each other.

Table 5: Contribution of U.S. shocks on Korean variables: DSGE

Median Variance shares and [5, 95] posterior bands for all U.S. shocks

Series	1 quarter horizon		2 quarter horizon	
Output	0.1546	[0.0388, 0.3853]	0.1333	[0.0331, 0.3412]
Inflation	0.0185	[0.0058, 0.0575]	0.0155	[0.0043, 0.0506]
Interest rate	0.0744	[0.0170, 0.2023]	0.0474	[0.0123, 0.1333]
Housing Price	0.0177	[0.0033, 0.0695]	0.0214	[0.0044, 0.0757]
	4 quarter horizon		8 quarter horizon	
Output	0.1213	[0.0298, 0.3207]	0.1220	[0.0282, 0.3374]
Inflation	0.0119	[0.0029, 0.0435]	0.0087	[0.0019, 0.0355]
Interest rate	0.0345	[0.0094, 0.1051]	0.0335	[0.0084, 0.1360]
Housing Price	0.0224	[0.0048, 0.0738]	0.0250	[0.0054, 0.0852]

· Variance share is scaled over [0, 1] so that 0.01 corresponds to 1%.

of international capital flows.

6 Conclusion

In this paper, I analyze whether the structural DSGE model can account for the impacts external shocks have on cyclical behavior of South Korean economy. Unlike preceding work by Justiniano and Preston (2010) who assume New-Keynesian medium-scale DSGE and fail to recover the influences of U.S. disturbances on Canadian economy, this paper augments the model with house market and collateral constraints as specified in Iacoviello (2005). Then the paper estimates model parameters based on Metropolis-Hastings random walk algorithm in two steps: first, it estimates U.S. parameters with U.S. series, and second, given the posterior modes of U.S. parameters, it estimates Korean parameters. Then it decomposes forecasting errors of Korean variables based on the estimates and compares them with the shares from Bayesian VAR estimates with block-recursive restriction in lagged coefficients based on the efficient Gibbs sampling proposed by Zha (1999). Moreover, it calculates cross-correlations between lagged U.S. variables and Korean ones implied by the DSGE model and compares them with the empirical ones.

Results show that the existence of financial friction contributes to improving share of U.S. shocks on forecasting error of Korean output. However, still the model yields lower degree of correlation between U.S. variables and Korean ones, which suggests the importance of identifying further transmission mechanism of external shocks. Especially, the model predicts zero correlation of housing prices across countries, while it was strictly positive and persistent in the data. Moreover, increase in housing price in the U.S. shows no lagged correlation between Korean output according to the DSGE model, while the correlation is highly positive in the data. This implies the modelling and testing international business cycle require considerations on how the housing markets of various countries are related to each other. As increase in housing price would cause output and consumption to increase, the model that induces positive correlation between housing prices in a more interdependent capital markets across countries would be able to have higher degree of comovement between output of different regions.

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A Appendices

A.1 Data Description

All series of U.S. variables are downloaded from Federal Reserve Economic Data of Federal Reserve Bank of Saint Louis. Real output index of nonfarm business sector divided by population corresponds to output, log-difference of GDP implicit price deflator measures inflation, the effective federal funds rate is used as interest rates, and all-transactions house price index for the United States measures house prices of the economy.

All series of Korea are from Economic Statistics System of Bank of Korea. Production index of all nonfarm industries divided by population measures the output, log-difference of consumer price index corresponds to inflation rate, the official interest rate of Bank of Korea is used for interest rate, and the housing sales price index of Seoul measures real estate price.

Output and house price are expressed as log-deviation from its linear trend. Interest and inflation rates are demeaned to be treated as cyclical fluctuations.

A.2 Steady State

In this section, I identify the equations which describes the zero-inflation deterministic steady state of the small open economy, then prove that the collateral constraints of entrepreneurs and households with lower discount rate binds in the steady state. Note that under the symmetry of parameter values, the steady state risk-premium factor ϕ is equal to 1 and as P^w equalized across countries, the steady state relative price of home commodity composite is equal to 1 $P_H/P = P_H^*/P^* = 1$. Furthermore, the assumption $\beta = 1/R = 1/R^*$ along with debt-elastic interest rate requires $\phi = 1$ or $d = 0$ in the steady-state.

$$
\begin{aligned}
\pi &= 1 \\
R &= 1/\beta \\
\phi &= 1 \\
\lambda &= (\beta-\gamma)/C \\
\lambda'' &= (\beta-\beta'')/C'' \\
F &= (1-1/X)Y^f = (1-1/X)((1-\tau)(C+C'+C''+I)+\tau^* Y^*) \\
K &= \frac{\gamma\mu}{1-\gamma(1-\delta)}\frac{1}{X}Y \stackrel{\text{def}}{=} \zeta_1 Y \\
q &= \frac{\gamma\nu}{1-\gamma-(\beta-\gamma)m}\frac{1}{X}\frac{Y}{h} \stackrel{\text{def}}{=} \zeta_2\frac{Y}{h} \\
q &= \frac{j}{1-\beta}\frac{C'}{h'} \stackrel{\text{def}}{=} \zeta_3\frac{C'}{h'} \\
q &= \frac{j}{1-\beta''-m''(\beta-\beta'')}\frac{C''}{h''} \stackrel{\text{def}}{=} \zeta_4\frac{C''}{h''} \\
b &= \beta m q h \\
C &= \frac{\mu+\nu}{X}Y-\delta K-(1-\beta)mqh \to C = \left(\frac{\mu+\nu}{X}-\delta\zeta_1-(1-\beta)m\zeta_2\right)Y \stackrel{\text{def}}{=} \zeta_5 Y \\
b'' &= \beta m'' q h'' = \beta m''\zeta_4 C'' \\
C'' &= w''L''-(1-\beta)m''\zeta_4 C'' \\
w''L'' &= (1-\alpha)(1-\mu-\nu)Y/X \stackrel{\text{def}}{=} s''Y \\
C'' &= s''Y-(1-\beta)m''\zeta_4 C'' \to C'' = \frac{s''}{1+(1-\beta)m''\zeta_4}Y \stackrel{\text{def}}{=} \zeta_6 Y \\
w'L' &= (\alpha(1-\mu-\nu))Y/X \stackrel{\text{def}}{=} s'Y \\
C' &= w'L'+F+(1-\beta)(mqh+m''qh'') \\
\to C' &= (1-(1-\tau)(1-1/X))^{-1}\left\{(s'+(1-\tau)(1-1/X)(\zeta_5+\zeta_6+\zeta_1\delta))\,Y+\tau^*\,(1-1/X)\,Y^*\right\} \\
&\stackrel{\text{def}}{=} \zeta_7 Y+\zeta_8 Y^* \\
h &= \frac{\zeta_2 Y}{\zeta_2 Y+\zeta_3 C'+\zeta_4 C''}, h' = \frac{\zeta_3 C'}{\zeta_2 Y+\zeta_3 C'+\zeta_4 C''}, h'' = \frac{\zeta_4 C''}{\zeta_2 Y+\zeta_3 C'+\zeta_4 C''}
\end{aligned}
$$

A.3 Log-linearized Model

The entire economy have 50 parameters of which 23 variables of the large economy are entirely exogenous from the point of the small open economy. We define $\hat{\cdot}$ as a percentage deviation of a variable from its steady-state level. As the amount of money hold by households does not have implication on the dynamics of the rest of the economy, it is omitted in the linearised model. It is convenient to categorize the linearized optimality conditions in 6 parts.

A.3.1 Aggregate Demand

$$
\begin{aligned}
\hat{Y}_t^f &= \tau_{TOT}T\hat{O}T_t + \frac{(1-\tau)C}{Y^f}\hat{C}_t + \frac{(1-\tau)C'}{Y^f}\hat{C}'_t + \frac{(1-\tau)C''}{Y^f}\hat{C''}_t + \frac{(1-\tau)I}{Y^f}\hat{I}_t + \frac{\tau^*Y^*}{Y^f}\hat{Y}_t^* \\
\hat{C}'_t &= E_t(\hat{C}'_{t+1}) - \hat{R}_t + E_t(\hat{\pi}_{t+1}) \\
\beta\hat{C}''_t &= \beta'' E_t(\hat{C}''_{t+1}) - (\beta-\beta'')\hat{\lambda}''_t - \beta\hat{R}_t + \beta'' E_t(\hat{\pi}_{t+1}) \\
\beta\hat{C}_t &= \gamma E_t(\hat{C}_{t+1}) - (\beta-\gamma)\hat{\lambda}_t - \beta\hat{R}_t + \gamma E_t(\hat{\pi}_{t+1}) \\
\hat{C}_t &= E_t(\hat{C}_{t+1}) - \zeta(E_t(\hat{Y}_{t+1}) + E_t(\hat{Q}_{t+1}) - E_t(\hat{X}^*_{t+1}) - \hat{K}_t) + \psi(\hat{I}_t - \hat{K}_{t-1} - \gamma(E(\hat{I}_{t+1}) - \hat{K}_t)) \\
0 &= \hat{\phi}_{t+1} + \hat{Q}_{t+1} + \frac{\gamma}{\beta}\hat{\pi}_{t+1} - \frac{\gamma}{\beta}\hat{\pi}^*_{t+1} - \hat{Q}_t + \hat{R}^*_t - \hat{R}_t
\end{aligned}
$$

A.3.2 Housing Market

$$
\begin{aligned}
\hat{q}_t &= \gamma_e E_t(\hat{q}_{t+1}) + (1-\gamma_e)(E_t(\hat{Y}_{t+1}) - \hat{h}_t - E_t(\hat{X}^*_{t+1}) + E_t(\hat{Q}_{t+1})) \\
&+ m_e(\hat{\lambda}_t + E_t((\hat{\pi}_{t+1}) + E_t(\hat{C}_{t+1})) + \hat{C}_t - E_t(\hat{C}_{t+1}) \\
\hat{q}_t &= \gamma_h E_t(\hat{q}_{t+1}) + (1-\gamma_h)(\hat{j}_t - \hat{h}''_t) + m_h(\hat{\lambda}''_t + E_t(\hat{\pi}_{t+1})) + \hat{C}''_t - \beta'' E_t(\hat{C}''_{t+1}) \\
\hat{q}_t &= \beta E_t(\hat{q}_{t+1}) + (1-\beta)(\hat{j}_t - \hat{h}'_t) + \hat{C}'_t - \beta E_t(\hat{C}'_{t+1}) \\
0 &= h\hat{h}_t + h'\hat{h}'_t + h''\hat{h}''_t
\end{aligned}
$$

A.3.3 Borrowing Constraints

$$
\begin{aligned}
\frac{C_F}{b}\hat{d}_t + \hat{b}_t &= E_t(\hat{q}_{t+1} + \hat{h}_t + \hat{\pi}_{t+1} - \hat{R}_t - \frac{C_F}{b}(\hat{R^*}_t + \hat{\phi}_t + \hat{Q}_t)) \\
\hat{b}''_t &= E_t(\hat{q}_{t+1} + \hat{h}''_t + \hat{\pi}_{t+1} - \hat{R}_t)
\end{aligned}
$$

where $\hat{d}_t \equiv d_t/C_F$.

A.3.4 Aggregate Supply

$$
\begin{aligned}
\hat{\pi}_{H,t} &= \beta E_t \hat{\pi}_{H,t+1} - \kappa \hat{X}_t^* + \kappa \hat{Q}_t + \hat{u}_t \\
\rightarrow \quad \hat{\pi}_t &= \beta \hat{\pi}_{t+1} - \tau T\hat{O}T_{t-1} + \tau(1+\beta) T\hat{O}T_t - \tau\beta T\hat{O}T_{t+1} - \kappa \hat{X}_t^* + \kappa \hat{Q}_t + \hat{u}_t \\
\hat{Y}_t &= \hat{A}_t + \nu \hat{h}_{t-1} + \mu \hat{K}_{t-1} + \alpha(1-\nu-\mu)\hat{L}_t' + (1-\alpha)(1-\nu-\mu)\hat{L}_t'' \\
\hat{Y}_t &= \hat{X}_t^* - \hat{Q}_t + \eta' \hat{L}_t' + \hat{C}_t' \\
\hat{Y}_t &= \hat{X}_t^* - \hat{Q}_t + \eta'' \hat{L}_t'' - (\hat{\lambda}_t'' - \hat{R}_t)
\end{aligned}
$$

A.3.5 Flow of Funds/Evolution of State Variables

$$
\begin{aligned}
\hat{K}_t &= \delta \hat{I}_t + (1-\delta)\hat{K}_{t-1} \\
\frac{b}{Y}\hat{b}_t + \frac{C_F}{Y}\hat{d}_t &= \left(\frac{RC_F - C_F}{Y} - \frac{\mu+\nu}{X}\right)\hat{Q}_t + \frac{C}{Y}\hat{C}_t + \frac{qh}{Y}(\hat{h}_t - \hat{h}_{t-1}) \\
&+ \frac{I}{Y}\hat{I}_t + \frac{Rb}{Y}(\hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t) - \frac{(\mu+\nu)}{X}(\hat{Y}_t - \hat{X}_t^*) + \frac{RC_F}{Y}(\hat{R}_{t-1}^* + \hat{\phi}_t - \hat{\pi}_t^* + \hat{d}_{t-1}) \\
-\frac{b}{Y}\hat{b}_t - \frac{b''}{Y}\hat{b}_t'' &= \frac{\alpha(1-\mu-\nu)}{X}(\hat{X}_t^* - \hat{Y}_t - \hat{Q}_t) + \frac{C'}{Y}\hat{C}_t' + \frac{qh'}{Y}(\hat{h}_t' - \hat{h}_{t-1}') + \frac{Rb'}{Y}(\hat{R}_{t-1} - \hat{\pi}_t) \\
&- \left(\frac{Rb}{Y}\hat{b}_{t-1} + \frac{Rb''}{Y}\hat{b}_{t-1}''\right) - \frac{Y^f}{Y}\left(1 - \frac{1}{X}\right)\hat{Y}_t^f + \tau\frac{Y^f}{Y}T\hat{O}T_t + \frac{Y^f}{XY}(\hat{Q}_t - \hat{X}_t^*) \\
\frac{b''}{Y}\hat{b}_t'' &= \frac{C''}{Y}\hat{C}_t'' + \frac{qh''}{Y}(\hat{h}_t'' - \hat{h}_{t-1}'') + \frac{Rb''}{Y}(\hat{R}_{t-1} + \hat{b}_{t-1}'' - \hat{\pi}_t) - \frac{(1-\alpha)(1-\mu-\nu)}{X}(\hat{Y}_t + \hat{Q}_t - \hat{X}_t^*) \\
\hat{\phi}_t &= \iota(\hat{Q}_{t-1} + \hat{d}_{t-1}) \\
\hat{Q}_t &= (1-\tau)T\hat{O}T_t \\
\hat{X}_t^* &= \hat{X}_t + T\hat{O}T_t
\end{aligned}
$$

Note that adjustment costs do not have first-order effect in budget constraints.

A.3.6 Monetary Policy Rule and Shock Processes

$$\begin{aligned}
\hat{R}_t &= \phi_r \hat{R}_{t-1} + (1-\phi_r)(\phi_\pi \pi_t + \phi_x \hat{X}_t + \phi_S(\hat{Q}_t - \hat{Q}_{t-1} + \hat{\pi}_t - \hat{\pi}_t^*)) + \hat{\varepsilon}_{m,t} \\
\hat{j}_t &= \rho_j \hat{j}_{t-1} + \hat{\varepsilon}_{j,t} \\
\hat{u}_t &= \rho_u \hat{u}_{t-1} + \hat{\varepsilon}_{u,t} \\
\hat{A}_t &= \rho_A \hat{A}_{t-1} + \hat{\varepsilon}_{A,t}
\end{aligned}$$

where $\gamma_e \equiv \gamma + m(\beta - \gamma)$, $\gamma_h \equiv \beta'' + m''(\beta - \beta'')$, $m_e \equiv m(\beta - \gamma)$, $m_h \equiv m''(\beta - \beta'')$, $\zeta \equiv 1 - \gamma(1-\delta)$, $\kappa \equiv (1-\theta)(1-\beta\theta)/\theta$ and $\tau_{TOT} \equiv \left\{ \frac{\tau(1-\tau)\rho}{Y^f}(C + C' + C'' + I) + \frac{\tau^* \rho Y^*}{Y^f} \right\}$.

국문초록

대외 충격이 개방소국경제에 미치는 영향

-담보제약과 주택시장을 포함한 동태확률일반균형 모형 분석-

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이 논문은 주택시장과 담보제약을 도입한 Iacoviello (2005)의 동태확률일반균형 모형을 개방소국경제로 확장시켜 금융 마찰이 있는 경우 개방소국의 경기변동에 대한 대외 충격의 전파경로가 어떻게 변화하는지 살펴본다. 개방소국에 영향을 미치는 해외 구조충격을 식별하기 위해 대외 경제를 준(quasi) 폐쇄경제로 모형화하고, 이를 바탕으로 개방소국에 영향을 미치는 대외 구조충격을 식별한 뒤, 그 모형에 대국에 대해 측도가 영인 개방소국 경제를 도입한다. 2000년대 이후 한국과 미국의 데이터를 이용하여 이 논문은 메트로폴리스-헤이스팅스 무작위행보 표본추출 알고리즘을 이용해 모형의 구조 모수를 추정하고, 이를 바탕으로 모형에 의한 상호상관계수와 예측오차 분산분해 결과를 실제 자료의 상호상관계수와 Zha (1999)의 깁스 알고리즘으로 추정한 베이지언-벡터자기회귀모형에 기반한 예측오차 분산분해 결과와 비교한다. 분석결과 논문의 모형은 미국의 구조충격이 한국 산출량과 이자율의 예측오차 분산에 대해 갖는 비중에 근사한 분산분해 결과를 낸다. 하지만 모형은 한국과 미국 경기변수 간 상호상관계수와, 미국의 구조충격이 한국의 인플레이션과 주택가격 움직임에 대해 갖는 예측오차 비중을 과소평가한다. 특히, 모형은 국가 간 주택 가격이 가지는 매우 높고 지속적인 양의 상관관계와 미국 주택 가격과 우리나라 산출량 간 높은 양의 상관관계를 재현하지 못해, 앞으로의 연구에서 국가 간 자본 및 주택시장의 상호의존성을 높이는 작업이 필수적임을 시사한다.

……………………………………

주요어 : 개방소국경제, 동태확률일반균형, 전파경로, 금융마찰, 담보제약, 베이지언 추정

학 번 : 2013-22853