LTV Ratio Regulations and House Prices in a Small Open Economy with Heterogeneous Households

Junhee Lee

Macro-prudential regulations, such as loan-to-value (LTV) ratio ceiling, are implemented in several economies to stabilize the financial market and macro-economy, in addition to conventional stabilization policies. This study constructs a small open economy model with heterogeneous households and house price fluctuations and examines the effects of LTV ratio regulation. Results of the model show that tightening the LTV ratio ceiling has considerable contractionary effects in a small open economy, but the effects are much smaller in a closed economy due to the general equilibrium effects of endogenous interest adjustment.

Keywords: Heterogeneous household model, House price, LTV ratio regulation, Small open economy

JEL Classification: E32, E44, F41

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I. Introduction

According to recent studies, the decline in house price and the subsequent deleveraging of household debt played an important role during the U.S. financial crisis in 2007-2008. For example, Mian and Sufi (2010) report that the expansion of credit and rising house values before the crisis created an unprecedented credit growth, which was a powerful predictor of the recession in 2007-2008. Not only the U.S. economy but also many economies around the world have experienced similar business cycle fluctuations due to household debt, as reported in Mian *et al.* (2017). Considering the developments, moderating the fluctuations in house price and household debt seems to be important for stabilizing the financial market and macro-economy. In response, countries such as Brazil, China, South Korea, Sweden, and Norway are adopting macro-prudential policies, such as loan-to-value (LTV), as reported in Jacome and Mitra (2015).

Studies that use dynamic stochastic general equilibrium (DSGE) models to analyze the role of house price and household debt in financial and macroeconomic stabilities have been conducted actively in recent years. A better understanding of the housing market in terms of economic stability with DSGE models may help explain recent economic crises correctly and provide more appropriate policy suggestions.

Recent studies that have used DSGE models mostly assume two fixed types of households, patient and impatient household, depending on the subjective discount rate. Iacoviello (2005) constructs a DSGE model with the two types of households in which impatient households borrow from patient households and household borrowing is limited to a certain fraction of house value (LTV ratio ceiling). The model is shown to fit the data better than the model without household borrowing and collateral constraints. Iacoviello and Neri (2010) estimate an extended version of Iacoviello's (2005) model using Bayesian methods and show the existence of a spillover effect from housing market fluctuation to non-housing consumption. Guerrieri and Iacoviello (2017) solve a version of Iacoviello's (2005) model with a nonlinear solution method and estimate it using Bayesian methods. They find that the decline in house prices has a stronger economic effect compared with the rise in house prices due to the asymmetric nature of collateral constraints. Justiniano *et al.* (2015) construct a model similar to that of Iacoviello and Neri (2010) and examine the model's transitional dynamics nonlinearly using the shooting method. They find that neither change of the ceiling of collateral constraints nor exogenous fluctuation in house prices can generate realistic movement in the housing, financial, and macroeconomic variables observed in the U.S. data during the 2000s. The result, which places less importance on the role of house prices and household debt in economic stability, somewhat contradicts previous results, such as those of Mian and Sufi (2010) and Guerrieri and Iacoviello (2017).

Departing from DSGE models with two fixed types of households, Guerrieri and Lorenzoni (2017) (GL (2017) hereafter) construct a model with idiosyncratic income shock and examine the interaction between household debt and economic stability. In their model, households are heterogeneous according to their individual income and asset holding, and they borrow or lend endogenously depending on their individual states. The model is more generalized than models with two fixed household types in that there can be as many types of households as individual states, and households can borrow or lend endogenously depending on their individual states.

In this study, a small open economy model with heterogeneous households and house price fluctuations is constructed and the effects of LTV ratio ceiling regulation are examined. Although the model is based on GL (2017), it has several differences as follows: First, the effects of LTV ratio regulation are examined in a small open economy. The effects can be different in a small open economy compared with a large closed economy due to the exogenously determined interest rate as in Mendoza (1991), Correia *et al.* (1995), and Neumeyer and Perri (2005). In addition, the effects of LTV ratio ceiling regulation in a small open economy are much greater than in a closed economy. Second, house price is allowed to fluctuate in the model. House price movement is considered important, because the boom and bust of house price have been key issues in recent discussions concerning household debt and economic stability, as in Mian and Sufi (2010), Justiniano *et al.* (2015), and Guerrieri and Iacoviello (2017). Moreover, macro-prudential policies, such as LTV ratio regulation, are frequently targeted toward stabilizing house price fluctuation in excess of general price movement. Thus, a house is assumed to be different from a consumption good in the model, and fluctuation in the (relative) house price is explicitly examined differently from GL (2017). Third, house only is assumed to be used as collateral in household borrowing, as LTV ratio regulation is usually tied to house value rather than the total value of durables in practice.

The remainder of the paper is organized as follows: Section II builds a small open economy model with heterogeneous households and house price fluctuations. Section III examines the steady states and transitional dynamics of the model. Section IV provides a summary of the results and a conclusion.

II. The Model Economy

The model is a one-good classical small open economy model, such as in Mendoza (1991), Correia *et al.* (1995), and Neumeyer and Perri (2005), except for heterogeneous households and collateral constraints in household borrowing. Households are heterogeneous across their individual states, namely, their labor income and asset holdings. Household borrowing is limited to a certain percentage of their house values (LTV ratio). The financial market is incomplete, and only a one-period maturity bond is traded. Interest rate is exogenous and determined outside the economy due to the assumption of a small open economy. Produced goods not consumed in the economy are exported abroad. House supply is fixed as in Iacoviello (2005).

A. Household

The household faces an idiosyncratic labor income shock and cannot fully insure against it due to the incompleteness of the financial market. Household borrowing has collateral constraints depending on the value of the house.

The i-th household maximizes

$$E_t\left[\sum_{\tau=0}^{\infty}\beta^{\tau}U\left(c_{i,t+\tau},h_{i,t+\tau},l_{i,t+\tau}\right)\right] \tag{1}$$

subject to budget constraint

$$c_{i,t}+p_{h,t}\left(h_{i,t+1}-h_{i,t}\right)+\frac{b_{i,t+1}}{\left(1+r_t\right)}\leq w_t\theta_{i,t}l_{i,t}+b_{i,t} \tag{2}$$

where $c_{i,t}$ is consumption; $h_{i,t}$, housing stock; $b_{i,t+1}$, bond holding; w_t, wage rate; $l_{i,t}$, labor hour; $p_{h,t}$, house price; r_t, exogenous interest rate; and $\theta_{i,t}$, idiosyncratic labor income shock. The idiosyncratic labor income takes a value in $\{\theta_1, \ldots, \theta_s\}$ and follows a Markov chain process. Household borrowing is subject to collateral constraint given as[1]

$$-b_{i,t+1} \leq \varpi p_{h,t} h_{i,t+1} \tag{3}$$

Following Hintermaier and Koeniger (2010), total wealth is defined as

$$a_{i,t} \equiv b_{i,t} + p_{h,t-1} h_{i,t} \tag{4}$$

The Bellman equation of the *i*-th household can be set up using the above definition:

$$\begin{aligned} &V\left(a_{i,t}, h_{i,t}, \theta_{i,t}\right) \\ &= \max_{b_{i,t+1}, h_{i,t+1}, l_{i,t}} U\left(c_{i,t}, h_{i,t}, l_{i,t}\right) + \beta E_{t,\theta} V\left(a_{i,t+1}, h_{i,t+1}, \theta_{i,t}\right) \end{aligned} \tag{5}$$

subject to the following constraints:

$$c_{i,t} = a_{i,t} + \left(p_{h,t} - p_{h,t-1}\right) h_{i,t} + w_t \theta_{i,t} l_{i,t} - p_{h,t} h_{i,t+1} - \frac{b_{i,t+1}}{1+r_t}, \tag{6}$$

$$a_{i,t+1} \geq \left(1-\varpi\right) p_{h,t} h_{i,t+1}, \tag{7}$$

$$a_{i,t+1} = b_{i,t+1} + p_{h,t} h_{i,t+1}, \tag{8}$$

$$h_{i,t+1} \geq 0 \tag{9}$$

Equation (6) represents the budget constraint; Equation (7), the collateral constraint; Equation (8), the total wealth definition; and Equation (9), the nonnegative house holding constraint.

First order conditions after substituting Equation (6) for $c_{i,t}$ in the Bellman Equation (5) are obtained as

[1] Households do not default unless house price drops more than $(1-\varpi)$ within a period, namely, 45% in a quarter with the calibration detailed below, due to the collateral constraint. Defaults are thus virtually impossible in the LTV regulation experiments detailed below.

$$\frac{1}{(1+r_t)} U_{c_{i,t}} = \beta E_{t,\theta} V_{a_{i,t+1}} + \mu_{i,t} \tag{10}$$

$$U_{c_{i,t}} p_{h,t} = \beta E_{t,\theta} V_{h_{i,t+1}} + \beta E_{t,\theta} p_{h,t} V_{a_{i,t+1}} + \mu_{i,t} \varpi p_{h,t} + \aleph_{i,t}, \tag{11}$$

$$-U_{l_{i,t}} = U_{c_{i,t}} w_t \theta_{i,t} \tag{12}$$

where $U_{c_{i,t}}$ and $U_{l_{i,t}}$ are partial derivatives of the utility function with respect to each subscript variable; $V_{a_{i,t+1}}$ and $V_{h_{i,t+1}}$, partial derivatives of the value function; and $\mu_{i,t}$ and $\aleph_{i,t}$ Lagrange multipliers associated with the collateral and nonnegative house holding constraints. Complementary slackness conditions are given as

$$\mu_{i,t} \left(a_{i,t} - (1-\varpi)\, p_{h,t} h_{i,t+1} \right) = 0, \tag{13}$$

$$\aleph_{i,t} h_{i,t+1} = 0, \tag{14}$$

Envelope conditions are given as

$$V_{a_{i,t}} = U_{c_{i,t}}, \tag{15}$$

$$V_{h_{i,t}} = \left(p_{h,t} - p_{h,t-1} \right) U_{c_{i,t}} + U_{h_{i,t}}, \tag{16}$$

The utility function is given as

$$U\left(c_{i,t}, h_{i,t}, l_{i,t}\right) = \log\left(c_{i,t}\right) + \alpha \log\left(h_{i,t}\right) - \chi \frac{l_{i,t}^{1+\eta}}{1+\eta}, \tag{17}$$

as in Iacoviello (2005) and Justiniano *et al.* (2015).

B. Production Firm

The production sector produces a good used for consumption and export. The production function is

$$y_t = n_t, \tag{18}$$

as in GL (2017), where y_t is output and n_t is labor input. The profit maximization problem can be written as

$$\xi_t = \max_{n_t}(y_t - w_t n_t), \tag{19}$$

subject to (18), whereℵ ξ_t is the maximized profit.[2]

C. Market Clearing Conditions and Net Export

The labor market clearing condition is

$$\int \theta_{i,t} l_{i,t} di = n_t, \tag{20}$$

The housing market clearing condition is

$$\int h_{i,t+1} di = \bar{h}, \tag{21}$$

where $\bar{h}$ is the fixed house supply as in Iacoviello (2005). Net export is given as

$$nx_t = y_t - c_t \tag{22}$$

Additionally, $nx_t = 0$ in the case of the closed economy.

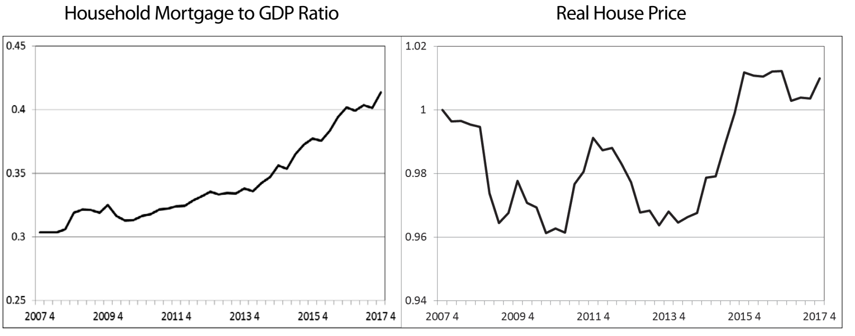
The economy has four markets, namely, goods, labor, housing and bond markets. As in the case in GL (2017), the labor and goods markets collapse into a single market due to the linearity of the production function, as specified in the Equation (18). Then, three markets need to be cleared in the case of a closed economy. Interest rate clears the bond market, and house prices clear housing market, and the remaining goods (or labor) market is then automatically cleared by Walras' law. In the case of a small open economy, interest rate is fixed, the bond market no longer clears, and the bond market can have excess demand or supply, resulting in net export deficit or surplus.

III. Model Analysis

A. Parameter Calibration and the Solution Method

The model is calibrated to Korean data as an example. Korea is a

[2] $w_t = 1$ is the optimality condition due to the linear production function in the Equation (18), and thus consumption good and labor are virtually same.



Note: Household mortgage to GDP ratio is the total mortgage loans to households by deposit-receiving financial intermediaries and Korea Housing Finance Corporation and Ministry of Land, Infrastructure, and Transport Fund divided by the nominal annual GDP. Real house price is constructed as house price index divided by consumer price index and normalized as one in 2007Q4. Data are obtained from the Bank of Korea except for the house price index, which is from the Kookmin Bank.

FIGURE 1
KOREAN HOUSEHOLD DEBT DATA

small open economy officially adopting the LTV ratio regulation. Korea has experienced an expansion in household borrowing since the early 2000s, and there has been growing concern due to the rising household debt. Korean financial authorities started LTV ratio regulation in September 2002 to mitigate the rising household debt and house prices and changed the LTV ratio ceiling within the 40-70% range depending on the housing market situation. A more detailed implementations of macro-prudential policies in Korea can be found in Igan and Kang (2011).

Figure 1 shows the household mortgage debt to GDP ratio and the real house price in Korea from 2007Q4 to 2017Q4.[3] The household mortgage debt to GDP ratio increases steadily from 30.36% in 2007Q4 to 41.37% in 2017Q4, and the real house price shows an upward trend beginning 2013Q4 when household mortgage debt starts to increase with an accelerated speed.

[3] The period is shown due to the availability of the household mortgage debt data.

In the calibration of the model, LTV ratio parameter ϖ is set at 55% considering the average LTV ratio ceiling, which currently ranges from 40% to 70% in practice. Labor curvature parameter η in the utility function is set at 1.0, as in Justiniano *et al.* (2015). Interest rate r is set at 0.5245%, implying an annual rate of 2.098%, which is slightly lower than the 2.5% set in GL (2017). The (real) interest rate is calibrated as average nominal interest rate on mortgage loan by mutual savings banks minus the nominal GDP growth rate. Housing service weight parameter α in the utility function is calibrated as 0.050 to match the average total value of house to annual GDP ratio over the period, which is 2.115, in the steady state. Labor weight parameter χ in the utility function is set at 7.173, so that the average household labor hour is 1/3 in the steady state. House price (p_h) is normalized as one in the steady state, and house supply amount parameter $\bar{h}$ is set at 4.162, so that the housing market clears in the steady state given the normalized price. Subjective discount rate β is set at 0.982, so that the total bond holding (or net export) is zero in the steady state. Idiosyncratic labor income shock $\theta_{i,t}$ is assumed to follow a five-state Markov chain process and obtained as an approximation of an AR(1) process using Tauchen's (1986) method. The coefficient and standard deviation of the AR(1) process are set at 0.81 and 0.301, respectively, as estimated in Kim and Chang (2008).

The solution and simulation method of the model are based on GL (2017) and Hintermaier and Koeniger (2010). The model is solved backward with an endogenous grid points method (EGM) given the prices and parameters and simulated forward with the distribution of individual states. Prices are updated in the direction of the market equilibrium by fine step, and the procedure is repeated until all markets are cleared. A detailed explanation of the algorithm is found in the Appendix.

B. Steady States

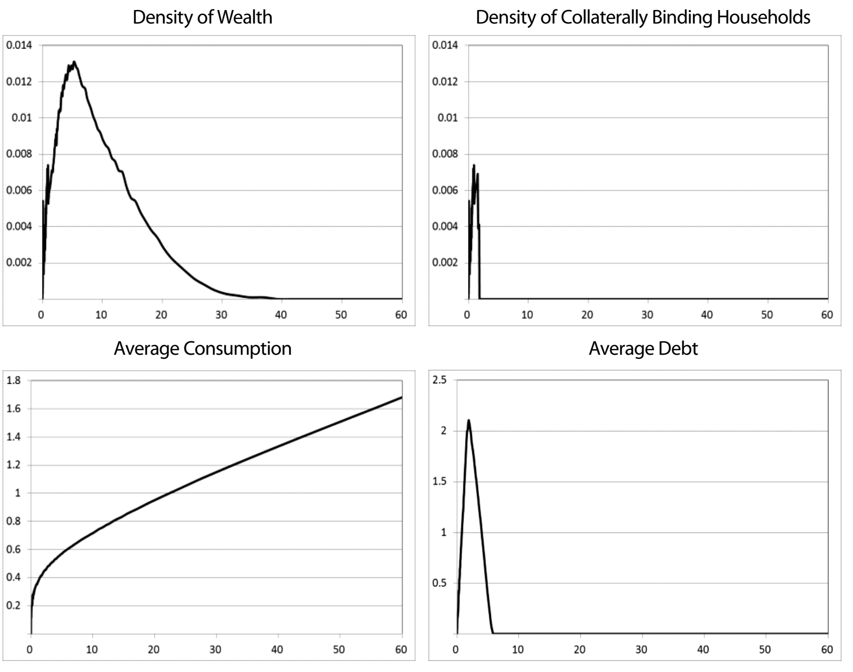
Some steady state values of the model are reported in Table 1. The relative measure of borrowing households ($m(b)$) is 74.0% of total households; thus, most households borrow from a smaller portion of relatively wealthy households. The household debt-to-annual GDP ratio ($d/4y$) is 44.3%. Average household mortgage debt-to-annual GDP ratio from 2007Q4 to 2017Q4 in the data is 34.2%, and the model steady

Table 1

Steady States

$m(b)$	$d/4y$	a
0.74	0.44	4.16
c	y	nxr
0.49	0.49	0.00

Note: $m(b)$, the relative measure of borrowing households; $d/4y$, household mortgage debt-to-annual GDP ratio; a, average total wealth; c, average consumption; y, average output; and nxr, net export-to-annual GDP ratio.



Note: Densities of wealth and collaterally binding households are marginal densities according to the state variable total wealth ($a_{i,t}$). Average consumption and debt are household consumption and debt according to the state variable total wealth ($a_{i,t}$) averaged over the other two state variables ($h_{i,t}$, $\theta_{i,t}$).

Figure 2

Averages and Densities in Steady States

state ratio is slightly higher than the data ratio.[4] Average consumption and output are the same as 0.49, and net export-to-annual GDP ratio is zero in the steady states.

Figure 2 represents the densities of household total wealth and collaterally binding households and the average levels of household consumption and debt along the total wealth dimension ($a_{i,t}$) in the steady states.[5] The density of wealth exhibits a right-skewed shape with a long tail. Thus, a large portion of households has a relatively small total wealth, whereas a small portion has a relatively large one. Density is highest when the total wealth level is around 5.25, although average total wealth level is around 4.16. The density of collaterally binding households is concentrated in the lowest part along the total wealth dimension. Density is highest when the total wealth level is around 0.94 and then becomes zero when the total wealth level is around 1.85. The average level of consumption shows a concave shape and increases with a decreasing rate as the total household wealth increases. The shape follows from usual consumption function, which exhibits a decreasing marginal propensity to consume. The average level of debt shows a hump shape and increases until the total wealth level is around 1.91 and decreases afterward, becoming zero when the total wealth level is around 5.88.

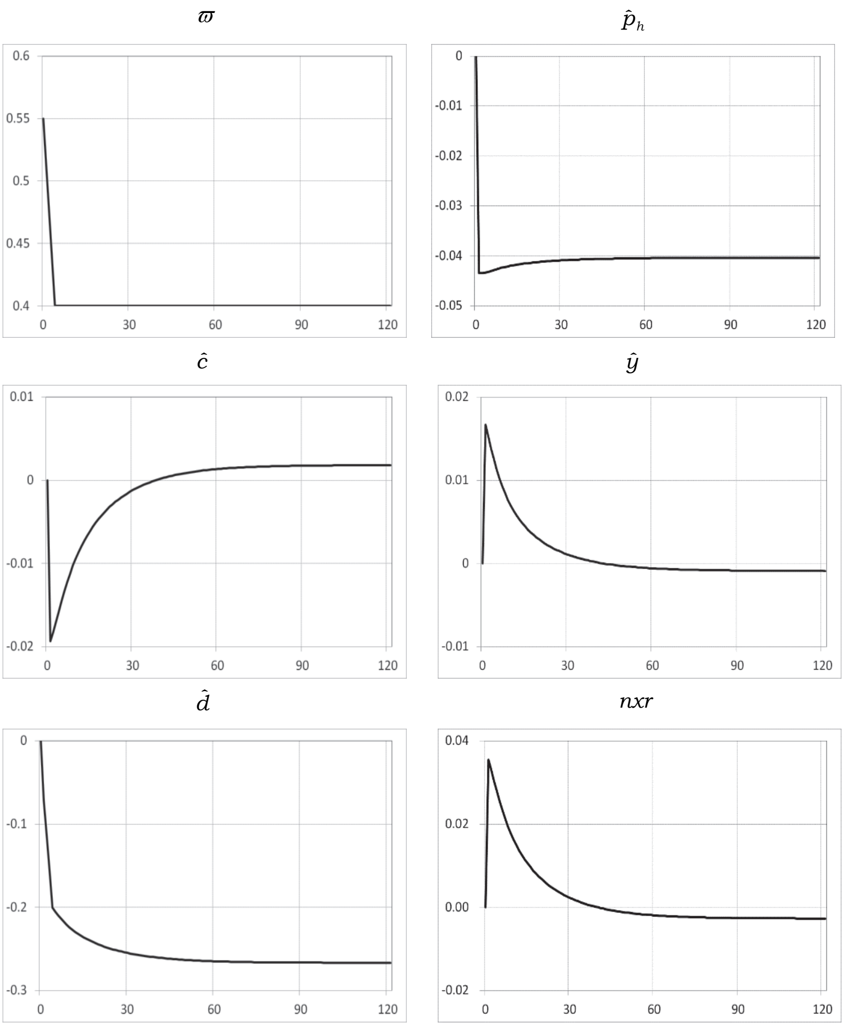
C. LTV Ratio Ceiling Tightening Transitional Dynamics

In this section, transitional dynamics of the model with LTV ratio ceiling tightening is examined. As an exercise, LTV ratio ceiling ϖ is reduced from 55% to 40% over four quarters in the model. The LTV ratio ceiling changed within the 40~70% range previously in Korea and thus the exercise can be considered moving from the moderate to the tightest level of LTV ratio regulation.

Results are reported in Figure 3. The first panel shows the change in the LTV ratio ceiling from 55% to 40%, which takes place over four quarters. The second panel shows the transitional dynamics of house price after the tightening of the LTV ratio ceiling. House price quickly

[4] Total household debt (including all household debt, not only mortgage debt)-to-annual GDP ratio is 69.7% over the period.

[5] The existence and uniqueness of the steady state distribution are shown in Huggett (1993).



Note: ϖ represents LTV ratio ceiling change; $\hat{p}_h$, $\hat{c}$, $\hat{y}$, $\hat{d}$ percentage deviation of house price, consumption, output, and household debt from their respective initial steady states; *nxr*, net export-to-output ratio.

Figure 3
Transition Dynamics to LTV Ratio Tightening

drops by 4.34% in the first quarter and then converges slowly to the new steady state. The third panel shows the transitional dynamics of consumption. Consumption decreases by 1.93% in the first quarter and then slowly increases to the new steady state, which is slightly higher than the initial steady state. The fourth panel shows the transitional dynamics of output. Output increases by 1.67% in the first quarter and then slowly decreases to the new steady state, which is slightly lower than the initial steady state. The fifth panel shows the transitional dynamics of household debt. Household debt drops sharply by 20.04% over the four quarters when LTV ratio ceilings are tightening and then slowly decreases further to the new steady state. The sixth panel shows the transitional dynamics of the net export-to-output ratio. The ratio increases by 3.54% in the first quarter and then slowly decreases to the new steady state, which is slightly lower than the initial steady state.

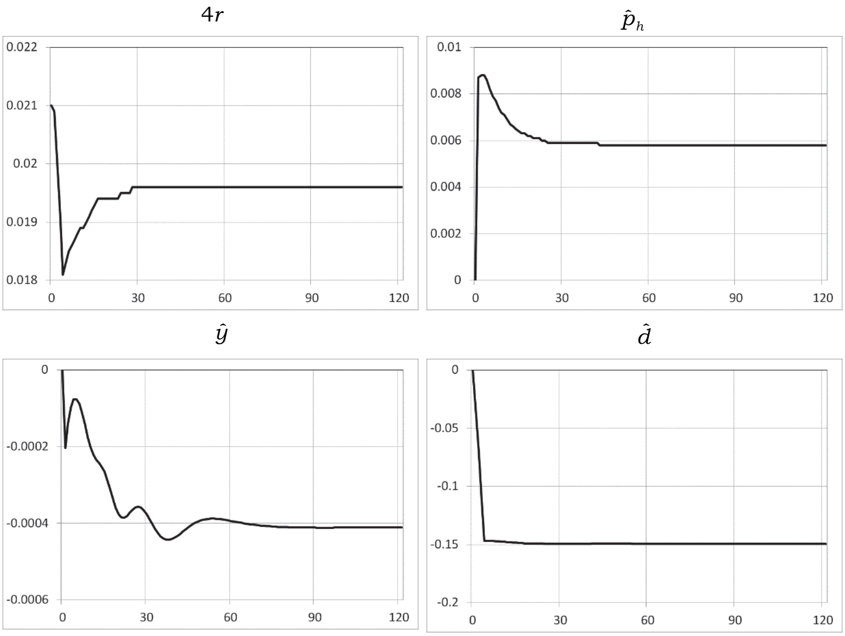
Over-all, the tightening of the LTV ratio ceiling has contractionary effects on the housing and financial markets as well as the overall economy from the transitional dynamics analysis. It deteriorates the borrowing condition of households, thus decreasing household debt, consumption, and house prices. Households work harder to avoid a consumption drop in the face of the worsening borrowing condition. The increased labor hour increases output, and net export increases as output increases and consumption decreases.

Thus, in general, the tightening of the LTV ratio ceiling achieves its common intended policy objectives in a small open economy, which are usually preventing excessive increase in household debt and house prices as well as deterioration in net export due to increasing household borrowing.

D. Closed Economy Case

In this section, the effects of the same LTV ratio ceiling tightening are examined in a closed economy. In a closed economy, interest rate is no longer exogenous but adjusts endogenously to attain bonds market clearing in the absence of foreign borrowing or lending. Thus, the key difference lies in the interest rate adjustment, and the analysis in this section can provide a comparison between the cases wherein interest rate is fixed and adjusted in the face of LTV ratio ceiling tightening.

In a closed economy, LTV ratio ceiling tightening reduces household borrowing demands, thus decreasing interest rate. The resulting interest rate decrease weakens the contractionary effects of LTV ratio ceiling tightening observed in the previous section. To examine the effects quantitatively, the transition dynamics in a closed and small



Note: $4r$ represents the annualized interest rate.

FIGURE 4
TRANSITION DYNAMICS IN A CLOSED ECONOMY

open economy, same except for the international borrowing possibility, are analyzed.

Results are shown in Figure 4. The first panel shows the transitional dynamics of interest rate after the LTV ratio ceiling tightening. Interest rate decreases and reaches the lowest level in the fourth period after tightening, which is 1.16% point lower in the annual term compared with the initial steady state. Then, it slowly converges to the new steady state, which is lower than the initial steady state. The interest rate undershoots for a while before converging to the new steady state.

The second panel shows the transitional dynamics of house price. House price rises to 0.88% in the second quarter after the tightening and then decreases to the new steady state, which is slightly higher than the initial steady state. The house price overshoots for a while before converging to the new steady state. Bond prices rise due to the reduced borrowing demands and interest rate drop; thus, funds are supplied out of the bonds market and to the housing market, resulting in the rise of house prices. In the absence of the interest rate drop, house price would have fallen, as in Figure 3.

The third panel shows the transitional dynamics of output. The maximum change of output is less than 0.05% in absolute value, which is very small. The output shows a jagged pattern between the first and second periods and then decreases to the new steady state.[6] The fourth panel shows the transitional dynamics of household debt. Household debt drops sharply by 14.69% until the fourth quarter and then slowly converges to the new steady state, which is 14.94% lower than the initial steady state. However, the decrease is smaller than that in Figure 3, as the interest rate decrease reduces the burden of household debt. The transitional dynamics of consumption, which is identical to the output in a closed economy, and net export ratio, which is zero in a closed economy, are not reported in Figure 4.

The closed economy transitional dynamics in this section can be compared with that in GL (2017), because the model in GL (2017) is also a closed economy model. In GL (2017), interest rate undershoots the steady states, output exhibits jagged dynamics and nondurable purchases show small movements in response to LTV ratio ceiling tightening, as is the case in the closed economy model in this section. Durable purchases rise considerably in GL (2017), whereas house price rises in the closed economy model in this section. The difference is due to the modeling assumptions. The model in GL (2017) assumes a single good, and durable and nondurable goods prices are the same. Thus, the relative price of durable goods does not change and the (relative) purchase of durable goods changes, whereas the closed economy model in this section assumes house (durable good) supply is fixed, and (relative) house price is adjusted to achieve housing market clearing.

The transitional dynamics in this section and in GL (2017) are both somewhat counterintuitive, however. That is, house price rises in this section, whereas house price drop is expected, and durable good (house) purchase rises in GL (2017), whereas durable good purchase drop is expected usually in response to LTV ratio ceiling tightening.

[6] The tolerance level for market clearing conditions is set at 0.01% in the computations of the transitional dynamics, and the jagged pattern around the period 30 is within the tolerance level and is thus negligible.

The counterintuitive results in both are due to the drop of interest rates in response to LTV ratio ceiling tightening. The comparison of the results from the small open economy in the previous section and the closed economy in this section evidently shows the role of interest rate adjustment in the rise of house price in the closed economy model. The rise in durable good purchase in GL (2007) is also caused by the drop of interest rates, as mentioned in GL (2017).

In terms of computations, the transitional dynamics in this section are more costly to obtain compared with the small open economy or the single good economy model in GL (2017). The closed economy equilibrium in this section requires housing and bond market clearing along the transitional dynamics, whereas the small open economy or GL (2017) requires only one market clearing regardless if it is housing or bond market.[7]

In summary, compared with a small open economy, the tightening of LTV ratio ceiling in a closed economy has much smaller effects on macroeconomic variables, such as output, and has somewhat counterintuitive policy effects on the housing market due to the general equilibrium effects of endogenous interest adjustment.

IV. Conclusions

The importance of household debt in financial and macroeconomic stabilities has been heavily recently after many economies worldwide underwent economic fluctuations following rapid household debt accumulation. Some countries have officially adopted macro-prudential regulations, such as LTV ratio ceiling control, to prevent excessive household debt and house price fluctuation.

In this study, the effects of LTV ratio ceiling regulation in a small open economy heterogeneous household model with idiosyncratic income shock are examined in comparison with a closed economy counterpart.

Results can be summarized as follows: First, the tightening of LTV ratio ceiling has quantitatively significant contractionary effects on the housing market and macroeconomic variables in a small open economy.

[7] In the implementations, the computation of the transitional dynamics in the closed economy requires around 6 times more iterations compared with the small open economy.

It worsens the household borrowing condition, and household debt, consumption and house price decrease accordingly. Thus, LTV ratio ceiling tightening achieves its commonly intended policy objectives and prevents an excessive increase in house price and consumption as well as deterioration in net export due to increased household borrowing. Second, LTV ratio ceiling tightening has quantitatively smaller or counterintuitive effects in a closed economy compared with a small open economy. The general equilibrium effects of endogenous interest decline after the LTV ratio ceiling tightening largely offsets the direct contractionary effects of the LTV ratio ceiling tightening on output and house price, and household debt only decreases significantly.

In summary, LTV ratio regulation is be more effective in a small open economy compared with that in a closed economy due to the exogenously determined interest rate. However, LTV ratio regulation might be as effective in a closed economy when interest rates are maintained to a fixed level with the help of other policy measures, such as fiscal or monetary policies.

Meanwhile, domestic borrowing condition changes due to events, such as credit crunches apart from intentional LTV regulation policies can also have more significant effects on a small open economy due to the exogenously determined interest rate. Thus, giving rise to another source of volatility for a small open economy, which can be safely offset in a large closed economy. More vigilant monitoring of credit and borrowing conditions and policy implementations are thus needed in a small open economy to maintain macroeconomic and housing market stability.

For future research, the interaction of macro-prudential and monetary policies as in Jung (2015) might be analyzed in a so-called heterogeneous agent new Keynesian (HANK) model as in Kaplan *et al.* (2018). Monetary policy can be utilized in a HANK model to maintain interest rates due to nominal rigidities, which are absent in the model in this study.

Appendix

In the appendix, the steady state of the model and transitional dynamics after the tightening of LTV ratio ceiling in the case of small open economy are explained. The closed economy case is similar. Models are solved backward using the EGM method and simulated forward with initial distribution. Market clearing prices, namely, interest rate and house prices, are found by making a small adjustment on prices in the direction of market clearing by comparing market supply and demand in each market. The EGM method is applied in a similar manner as in Hintermaier and Koeniger (2010). Below, ' represents the next period, and a number in parentheses such as (10) refers to an equation number in the text.

1. Steady States

1) ϖ, η, r and p_h are set as fixed values as in the text. Initial values for α, χ, $\bar{h}$, and β are given. (α, χ) will be adjusted to match target ratios, whreas $\bar{h}$ and β will be adjusted to clear markets. Labor income shock θ is approximated using the Tauchen method. The individual state is composed of total wealth, house holding, and labor income shock (a, h, θ). Individual state (a, h, θ) is discretized as $n_a \times n_h \times n_\theta$. In the implementation, $n_a \times n_h \times n_\theta$ is set at 180 × 150 × 5. a has grids over [0, 60], and h has grids over [0, 30].
2) Consumption policy function c and initial distribution over individual state (a, h, θ) are initialized. The consumption policy function is initialized to increase as a and θ increase in each dimension, and the initial distribution over individual state is initialized to be uniform over (a, h, θ).
3) EGM step
   A. Given consumption policy function c from the previous step and house holding state h, compute U_c and U_h using the utility function and calculate V_a and V_h using the envelope conditions ((15) and (16)). Use the Markov chain process of θ to update to $E_\theta V_a'$ and $E_\theta V_h'$.
   B. Define, $dif \equiv \beta E_\theta V_h' - E_\theta V_a' \left(\left(1+r \right) p_h - p_h \right)$, which is obtained by equating Equation (10) and (11) and assuming that Lagrange multipliers are all zero.
   C. Assume (a', θ) are given as usual in the EGM method. Find zero of dif over the possible h grid, to be denoted as the h'candidate.

i. If h' candidate > 0, $a'/(1-\varpi)p_h > h'$candidate, then $h'^{egm} = h'$candidate and $\beta E_\theta V_h'$, $\beta E_\theta V_a'$ are approximated around h'^{egm} by linear interpolation as $\beta E_\theta V_h'\_opt$, $\beta E_\theta V_a'\_opt$.

ii. If h'candidate ≤ 0, $a'/(1-\varpi)p_h > h'$candidate, then $h'^{egm} = 0$ and, $\beta E_\theta V_h'$, $\beta E_\theta V_a'$ are evaluated at $h'^{egm} = 0$ as $\beta E_\theta V_h'\_opt$, $\beta E_\theta V_a'\_opt$. $\aleph\_opt = \beta E_\theta V_a'\_opt\left((1+r)\,p_h - p_h\right) - \beta E_\theta V_h'\_opt$ is obtained from (10) and (11).

iii. If h'candidate > 0, $a'/(1-\varpi)p_h > h'$candidate, then $h'^{egm} = a'/(1-\varpi)\,p_h$ and $\beta E_\theta V_h'$, $\beta E_\theta V_a'$ are approximated around h'^{egm} by linear interpolation as $\beta E_\theta V_h'\_opt$, $\beta E_\theta V_a'\_opt$. $\mu\_opt = \beta E_\theta V_h'\_opt - \beta E_\theta V_a'\_opt\left((1+r)\,p_h - p_h\right) / \left((1+r)\,p_h - \varpi p_h\right)$ is obtained from (10) and (11)

D. Given (a', h, θ), find endogenous gridpoints of a, denoted as a^{egm}.

i. From (11) and the utility function, $c^{egm} = p_h\left(\beta E_\theta V_{hopt}' + p_h \beta E_\theta V_{aopt}' + \varpi p_h \mu_{opt} + \aleph_{opt}\right)^{-1}$.

ii. From (12) and the utility function, $l^{egm} = \left(w\theta\chi^{-1}\left(c^{egm}\right)^{-1}\right)^{\frac{1}{\eta}}$.

iii. From (8), $b'^{egm} = a' - p_h h'^{egm}$.

iv. From (6), $a^{egm} = c^{egm} - w\theta l^{egm} + p_h h'^{egm} + b'^{egm} / (1+r)$.

E. Use linear interpolation of c^{egm}, h'^{egm} over individual state (a, h, θ) to obtain policy functions c, h'. Then, the other policy functions are obtained easily using (6)-(12).

F. In step C, the case in which h'candidate ≤ 0, $a'/(1-\varpi)\,p_h \le h'$ is ignored. The case is when both nonnegative house holding constraint and collateral constraint are binding and treated as in Hintermaier and Koeniger (2010).

4) Simulation step: Simulate forward with the solved model and the previous distribution of individual state (a, h, θ) directly, as in GL (2017) without random draw.
5) Update (α, χ) to match target ratios and $\bar{h}$ and β to clear markets.
6) If target ratios and market clearing conditions are achieved, terminate the algorithm or proceed to the EGM step.

2. Transitional dynamics

1) Obtain the steady state for which LTV ratio parameter ϖ is 0.55 and 0.40. Assume the transition takes place for T periods, which is set at 120 in implementation. The steady state when ϖ = 0.55 is called the initial (period 0) steady state, and the steady state when ϖ = 0.40 is called the new (period $T + 1$) steady state.
2) Specify the ϖ transition, which is assumed to occur over four periods linearly in implementation. The initial guesses of house price for T periods are given, which are similar to the house price in the new steady state in implementation.
3) Apply the EGM step backward from period $T + 1$ to period 1 to solve the model, as in the steady state solution algorithm with slight modification due to the time script of the variables.
4) Simulate the solved model forward from period 0 to period T, as in the steady state solution algorithm to obtain updated distribution over individual state (a, h, θ) and consequent aggregate variables.
5) Update the house price for T periods by fine step in the direction of housing market clearance. Update the bond supply to match the bond demand.
6) Iterate steps 3) ~ 5) until housing market is cleared.

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