The Effects of Borrower-Based Macroprudential Policy: An Empirical Application to Korea*

Thorsten Franz
Deutsche Bundesbank

The effects of borrower-based macroprudential policy (BB-MaPP) measures in the form of mandatory caps on loan-to-value (LTV) and debt-service-to-income (DSTI) ratios in the Korean real estate market are investigated using a sign-identified structural vector autoregressive (SVAR) model. Sign restrictions are drawn from a small open-economy dynamic stochastic general equilibrium (DSGE) model with collateralizable housing. While empirical results suggest only moderate effects of monetary policy on house prices in Korea, BB-MaPP measures have been successful in curbing real household credit and real house price growth. A historical decomposition also emphasizes the advantages of a targeted approach toward macroprudential regulation.

JEL Codes: E32, E44, E58, G28.

1. Introduction

In the wake of the global financial crisis, a large number of countries started to introduce macroprudential policies to counteract the buildup of financial imbalances. Especially boom-bust cycles in asset markets were identified as important predictors of upcoming financial distress. However, with the disastrous consequences of the financial crisis fresh in mind, doubt spread that the existing policy

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mix of monetary and microprudential instruments was enough to cope with these unsustainable buildups in asset markets, promoting the emergence of a macroprudential policy toolkit within many central banks. Residential housing—as the most important collateral of households—was identified as one of the main targets of these measures.[1] Nevertheless, the limited experience puts a huge constraint on investigating the effectiveness of macroprudential policies in curbing financial cycles. Most studies rely on either calibrated or estimated models or resort to cross-country panels. The first method imposes a large number of assumptions on the data-generating process, while the latter approach suffers potentially from endogeneity issues and a lack of comparability of macroprudential measures throughout countries.

In this paper, I follow Peersman and Straub (2009) and Sá and Wieladek (2015) by identifying a structural vector autoregressive (SVAR) model via sign restrictions drawn from a dynamic stochastic general equilibrium (DSGE) model. Using an SVAR model circumvents possible endogeneity issues, while structural identification via sign restrictions is based on the economic reasoning of a microfounded model without imposing its exact structure. In particular, a small open economy that allows for collateralizable housing is modeled for the Korean economy. The latter presents an interesting case study, as (i) mandatory caps on loan-to-value (LTV) ratios had already been implemented as early as 2002, followed later on by caps on debt-service-to-income (DSTI) ratios, and (ii) these borrower-based macroprudential policies (BB-MaPP) experienced a relatively high degree of time variation. Drawing robust sign restrictions from the model, I propose an identification for, among others, a BB-MaPP shock. Results from the SVAR analysis suggest that an exogenous tightening in these borrower-based measures is indeed effective in that it leads to lower real house prices and real household credit.

The use of BB-MaPP measures is generally motivated by the disastrous economic effects that credit booms can have if they go bust

[1] According to the International Monetary Fund's Global Macroprudential Policy Instruments Database, the number of countries that implemented some form of maximum LTV ratios increased from 10 in 2000 to 44 in 2013 for the 119 countries under investigation (for DSTI ratios, that number increased from 4 to 26).

(see, e.g., Schularick and Taylor 2012). In particular, the housing sector is perceived to be susceptible to initiating these malicious boom-bust cycles due to real estate prominently featuring on households' balance sheets and, as a consequence thereof, its preeminent role as collateral. Initial positive effects on house prices following laxer lending conditions are amplified as borrowing constraints loosen, leading to a buildup of leverage (see, e.g., Mian and Sufi 2011). As soon as the upswing in house prices comes to a halt, the chance of households starting to default on their loans increases, as happened in the United States at the start of the Great Recession. In the DSGE model, this financial accelerator mechanism is introduced in the fashion of Iacoviello (2005). Until recently, the monetary policy response in most countries to these boom-bust cycles was one of "benign neglect." While acknowledging the possible disastrous effects of asset price busts, Bernanke and Gertler (1999, p. 43) conclude: "Given a strong commitment to stabilizing expected inflation, it is neither necessary nor desirable for monetary policy to respond to changes in asset prices, except to the extent that they help to forecast inflationary or deflationary pressure."[2]

The general stance of policymakers changed over time, but conventional monetary instruments are still discarded by most to curb boom-bust cycles in asset markets due to their economy-wide consequences and potential other deficiencies (Crowe et al. 2013). Depending on the specific target in mind, a wide array of macroprudential instruments has been proposed and implemented instead (for an overview, see Galati and Moessner 2013). In real estate markets, LTV and DSTI regulations are the dominant choices of policymakers. Both instruments target the demand side by restricting highly leveraged households from receiving mortgage credit. In theory, mandatory caps on these ratios tighten the borrowing constraints of targeted households, leading on aggregate to a reduction in mortgage credit and housing demand, ultimately pushing down house prices. By restricting the borrowing ability of impatient households

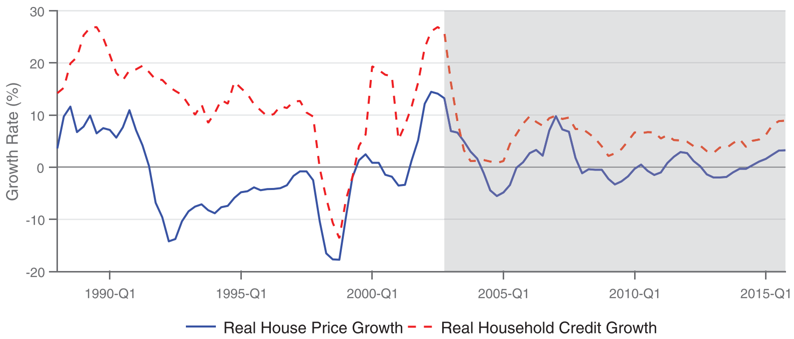
[2] In their defense, the nominal interest rate is considered as the only monetary policy tool, abstracting from macroprudential measures that were generally not part of the policy mix at that time; for more anecdotical evidence, see Crowe et al. (2013).

in the model to a fraction of their available collateral and introducing a policy rule that governs this fraction depending on household credit growth in the economy, similar to Lambertini, Mendicino, and Punzi (2013), an LTV environment is mimicked.

This setup allows the identification of an exogenous variation of the prevalent LTV ratio and borrows from the growing literature studying the welfare effects of macroprudential measures within DSGE models. Closed-economy approaches stress the relevance of the origin of shocks (Kannan, Rabanal, and Scott 2012), the importance of coordination between monetary policy and macroprudential policy (Angelini, Neri, and Panetta 2011), different welfare effects for borrowers and savers (Lambertini, Mendicino, and Punzi 2013), and the cost-effectiveness of LTV regulations (Alpanda and Zubairy 2017) but also the potentially greater effectiveness of DSTI regulations over LTV regulations (Gelain, Lansing, and Mendicino 2013). Open-economy approaches demonstrate the positive effects of decentralization of macroprudential policy (Quint and Rabanal 2014) and their usefulness under capital inflow shocks (Unsal 2013). The model implemented here is closest to Funke and Paetz (2013, 2018) in that it unifies the small open-economy setup developed by Galí and Monacelli (2005) with the financial accelerator in Iacoviello (2005). However, I deviate from this literature in utilizing the model merely to motivate robust sign restrictions and, ultimately, let the data speak in the SVAR approach. With that in mind, I aim to answer the question as to whether LTV and DSTI regulations have been successful in curbing cycles in the Korean real estate market.

Following a strong increase in house prices and credit growth in the early 2000s, with the Asian financial crisis still fresh in mind, Korean authorities first introduced a mandatory cap on LTV ratios. A glance at figure 1 suggests that these measures reduced volatility in real estate markets dramatically. Still, with the background of extensive housing supply policies in the late 1980s aimed at closing the large housing supply-demand gap as well as the financial crisis, this could simply be a consequence of a calming in the Korean real estate market. It is therefore essential to extract an exogenous variation in those policy measures for any causal statement to be credible. Past empirical research mostly relies on panel data and finds that LTV and DSTI caps are able to curb credit growth (Lim et al. 2011) and house prices (Kuttner and Shim 2016), but much

Figure 1. House Price and Household Credit Growth in Korea



Source: Bank for International Settlements.
Notes: The figure displays the quarterly year-on-year growth rates. The gray-shaded area depicts the time period where BB-MaPP measures have been actively applied in real estate markets.

more so during boom phases (Claessens, Gosh, and Mihet 2013). Vandenbussche, Vogel, and Detragiache (2015), on the other hand, detect no significant effects on house prices, while Cerutti, Claessens, and Laeven (2017) stress regulation avoidance in the form of cross-border lending. Using Korean household data, Igan and Kang (2011) provide evidence of the effectiveness of LTV and DSTI regulations in delaying property purchase decisions, but only tighter LTV ratios push down price expectations. Only recently, there have been time-series approaches that generally support the effectiveness of macro-prudential measures (Tillmann 2015) but also warn of contractionary economy-wide consequences (Kim and Mehrotra 2018). Both studies rely solely on zero restrictions, a restrictive identification strategy which is often not theoretically justifiable. The empirical novelty of my approach lies in the use of sign restrictions and the utilization of a newly compiled BB-MaPP index that is able to quantify changes in average regulation in Korea.[3]

While Kim and Mehrotra (2018) distinguish between macro-prudential and monetary policy shocks, assigning a structural

[3]Towbin and Weber (2016) also use sign restrictions to identify an LTV shock, but utilize actual LTV ratios for the United States, not macroprudential regulations.

identification to multiple shocks is more straightforward with sign restrictions. Thus, in addition to the BB-MaPP shock, I also uniquely identify a monetary policy shock, a housing demand shock, and a technology shock. Besides providing further insights, imposing additional sign restrictions helps pin down the structural shocks of interest (Paustian 2007). All four identified shocks turn out to have a more or less important influence on the Korean real estate cycle. Taking into account that BB-MaPP measures are generally targeted toward certain types of borrowers or specific areas, the comparably small quantitative average effect on the whole economy can translate into huge effects for affected households. The monetary policy shock, on the other hand, has only a surprisingly small and statistically not significant effect on house prices. This result can be reconciled with a smaller interest rate sensitivity of housing demand under tight downpayment requirements (Calza, Monacelli, and Stracca 2013). In contrast to Kim and Mehrotra (2018), economy-wide consequences are more persistent for the monetary policy shock, endorsing the targeted BB-MaPP measures in terms of cost-effectiveness.[4] The main results are also robust to splitting the BB-MaPP index into an LTV and DSTI index, alternative identification strategies, and different prior specifications. Overall, the comparably low volatility in real house prices and real household credit growth seen in figure 1 since 2002 in Korea might at least be partially due to the implementation of BB-MaPP measures.

The remainder of this paper is structured as follows: the next section outlines the DSGE model. In section 3, the econometric framework and data are described and a short overview of the Korean housing sector is given. Results of the empirical application are presented in section 4, while section 5 concludes.

2. The Model

The aim of the model is to produce impulse responses that allow for a robust sign identification of the impact responses in an empirical application. Under this premise, the model tries to capture

[4]Other potential costs of these BB-MaPP measures, such as leakages to the unregulated sector, regulatory arbitrage, and unwanted distributional effects, are ignored due to a lack of data availability.

the main mechanisms of LTV regulations and conventional monetary policy without trying to match moments of the Korean economy, keeping it as parsimonious as possible. Building on the small open-economy setup by Galí and Monacelli (2005), each single country is assumed to be negligibly small, such that foreign variables are exogenous. It is also assumed that the law of one price holds for all individual goods. In order to introduce LTV ratios into the model, the domestic economy is inhabited by patient and impatient households, who exhibit different discount factors, following Kiyotaki and Moore (1997). Impatient households always borrow, but they face a borrowing constraint which depends on the collateral they own and the prevalent LTV environment. As in Iacoviello (2005), both households demand consumption goods as well as real estate. They further allocate time to work in each of the two sectors. A model similar in vein is presented in Funke and Paetz (2013). The notation is as follows: a subscript h refers to the home economy, i refers to an individual foreign economy, and f refers to the continuum of foreign economies. A superscript i refers to a variable from country i's perspective, no subscript indicates a steady-state value, while a small letter with a hat is a variable in log-deviations from its steady state. In the following, the main features of the model are described and further details can be found in the appendix.

2.1 Households

2.1.1 Borrowers

The economy is inhabited by a fraction ω of impatient households (borrowers) and a fraction $(1-\omega)$ of patient households (savers). The representative impatient household spends income from allocating time to work in each of the two sectors on either nondurable consumption goods, C_t^b, or durable goods, D_t^b,[5] and maximizes

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \left\{ \log C_t^b + \gamma_t \log D_t^b - \frac{(N_{c,t}^b)^{1+\varphi}}{1+\varphi} - \frac{(N_{d,t}^b)^{1+\varphi}}{1+\varphi} \right\}, \qquad (1)$$

where β_b is the borrower's discount factor, φ is the inverse of the Frisch elasticity of labor supply, $N_{j,t}$ denotes hours worked in sector

[5] I use housing and durables interchangeably here.

$j = \{c, d\}$, and the stochastic weight, γ_t, enables housing demand (or, synonymous, preference) shocks to be modeled. Durable goods are different from nondurable goods in two ways: (i) they depreciate over time, $D_t^b = (1-\delta)D_{t-1}^b + I_{d,t}^b$, with depreciation rate δ and new housing investment, $I_{d,t}^b$, while nondurable goods, C_t^b, vanish completely each period, and (ii) they constitute collateral which the impatient household borrows against. The composite consumption index (an equivalent consumption index is defined for durable goods) is given by

$$C_t^b = \left[(1-\alpha_c)^{\frac{1}{\eta_c}} (C_{h,t}^b)^{\frac{\eta_c - 1}{\eta_c}} + \alpha_c^{\frac{1}{\eta_c}} (C_{f,t}^b)^{\frac{\eta_c - 1}{\eta_c}}\right]^{\frac{\eta_c}{\eta_c - 1}}, \tag{2}$$

where $\alpha_c \in [0,1]$ is an index of openness of the economy and η_j is a measure of substitutability between domestic and foreign nondurable goods. Households can choose from a variety of goods in the domestic economy and in each foreign economy as well as between different foreign economies.[6]

The budget constraint of borrowers in real terms (units of nondurable goods) is given by

$$C_t^b + q_t I_{d,t}^b + R_{t-1}\frac{b_{h,t-1}^b}{\Pi_{c,t}} = b_{h,t}^b + \frac{W_{c,t}^b}{P_{c,t}} N_{c,t}^b + \frac{W_{d,t}^b}{P_{c,t}} N_{d,t}^b, \tag{3}$$

where $q_t = \frac{P_{d,t}}{P_{c,t}}$ is the relative price of durable and nondurable goods, $\Pi_{c,t} = \frac{P_{c,t}}{P_{c,t-1}}$ is gross consumer price index (CPI) inflation, $b_{h,t}^b$ is the stock of real domestic debt, R_t is the gross nominal interest rate, and $\frac{W_{j,t}^b}{P_{c,t}}$ is the real wage rate in sector $j = \{c, d\}$.

Due to the lower discount factor of impatient households, borrowers will never save ($b_{h,t}^b > 0 \ \forall t$). As in Kiyotaki and Moore (1997), an endogenous limit is set to the amount of borrowing which depends on the expected future value of the stock of durables. Thus, the collateral constraint is given in real terms by

$$R_t b_{h,t}^b \leq m_t (1-\delta)\mathbb{E}_t[q_{t+1} D_t^b \Pi_{c,t+1}] \tag{4}$$

[6] These consumption indexes are all given by constant elasticity of substitution (CES) functions as in Funke and Paetz (2013).

with m_t being the time-varying maximum LTV ratio. The chosen discount factor ensures that the borrowing constraint is binding in steady state and the neighborhood thereof. This mechanism enables the effect of an exogenous variation in the LTV ratio on the household's behavior to be examined.

In comparison with nonconstrained households, the first-order conditions of the borrower's maximization problem differ in two ways: (i) the marginal utility of nondurable consumption additionally depends on the relaxation of the collateral constraint and (ii) the marginal utility of current consumption exceeds the marginal gain of shifting consumption to the next period.[7]

2.1.2 Savers

The utility function and demand schedules of patient households are analogous to those of impatient households. However, there are three main differences between patient and impatient households.

First, patient households always save and therefore do not face any borrowing constraint. Second, savers are able to trade bonds internationally on incomplete markets. Third, savers are the sole owners of firms and therefore generate income from profits ($PR^s_{j,t}$ with $j = \{c, d\}$). Thus, the saver's budget constraint in real terms (units of nondurable goods) reads

$$C^s_t + q_t I^s_{d,t} + R_{t-1}\frac{b^s_{h,t-1}}{\Pi_{c,t}} + R^*_{t-1}\Xi(\mathcal{E}_{t-1}b^*_{f,t-t})\frac{\mathcal{E}_t b^*_{f,t-1}}{\Pi_{c,t}}$$
$$= b^s_{h,t} + \mathcal{E}_t b^*_{f,t} + \frac{W^s_{c,t}}{P_{c,t}}N^s_{c,t} + \frac{W^s_{d,t}}{P_{c,t}}N^s_{d,t} + PR^s_{c,t} + q_t PR^s_{d,t}, \quad (5)$$

where R^*_{t-1} is the nominal gross foreign interest rate; $b^*_{f,t}$ is a basket of foreign bonds denoted in the respective foreign country's currency; $\mathcal{E}_t$ is the basket of nominal exchange rates, where the price of country i's currency is denoted in terms of domestic currency; $\Xi(\mathcal{E}_t b^*_{f,t})$ are international intermediation costs; and the other terms are analogous to the borrower's problem. In order to abstract from complete international risk sharing, international intermediation costs

[7]For an extensive discussion of the role of collateral constraints in DSGE models, see Monacelli (2009).

are introduced such that the servicing costs increase with the amount of foreign debt.[8] Under this setup, an uncovered interest rate parity holds except for a wedge due to the intermediation costs.

2.2 Firms

To allow for sticky prices in the model, intermediate goods are produced by a continuum of monopolistically competitive wholesale firms. These intermediate goods are then aggregated by retailers to produce final goods using a CES production function

$$Y_{j,t} = \left(\int_0^1 Y_{j,t}(k)^{\frac{\varepsilon_j - 1}{\varepsilon_j}} dk \right)^{\frac{\varepsilon_j}{\varepsilon_j - 1}}, \quad j = c, d, \tag{6}$$

where $Y_{j,t}$ is aggregate output in sector j.

Production of differentiated intermediate goods follows a linear technology with labor as the only input factor,

$$Y_{j,t}(k) = A_{j,t} N_{j,t}(k), \quad j = c, d, \tag{7}$$

where $A_{j,t}$ denotes sector-specific, stochastic labor productivity.

The monopolistically competitive intermediate firms set prices in a staggered fashion, following the scheme in Calvo (1983). A proportion of $(1 - \theta_j)$ randomly selected firms in sector j is able to reset prices in period t, while reoptimization is not possible for the remaining θ_j firms. Taking into account optimal price setting by each firm and the dynamics of the price index, a familiar-looking log-linearized Phillips curve can be derived for each sector:

$$\hat{\pi}_{j,h,t} = \beta \mathbb{E}_t \hat{\pi}_{j,h,t+1} + \kappa_j \hat{mc}_{j,h,t}, \quad j = c, d, \tag{8}$$

where $\kappa_j = \frac{(1-\theta_j)(1-\theta_j \beta_s)}{\theta_j}$ for $j = c, d$.

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[8]This modeling decision should not have a major impact on the results but is needed to circumvent unit-root behavior in the equilibrium dynamics (see Schmitt-Grohé and Uribe 2003).

2.3 Monetary Policy, Macroprudential Policy, and Shock Structure

As the primary goal of the Bank of Korea is price stability and it therefore adopts an inflation-targeting approach, the nominal interest rate is assumed to be pinned down by the Taylor principle,

$$R_t = R^{(1-\phi_r)} R_{t-1}^{\phi_r} \Pi_t^{(1-\phi_r)\phi_\pi} \varepsilon_t^{MP}, \tag{9}$$

where Π_t is gross inflation of all domestically consumed goods, ϕ_r is the persistence of the nominal interest rate, $\phi_\pi > 1$ gives the strength with which the nominal interest rate reacts to changes in inflation, and ε_t^m is a monetary policy shock with $\varepsilon_t^{MP} = \exp(e_t^{MP})$ and $e_t^{MP} \sim N(0, \sigma_{MP}^2)$.

Furthermore, similar to Lambertini, Mendicino, and Punzi (2013) or Rubio and Carrasco-Callego (2014), I impose a countercyclical rule on the LTV ratio, m_t, in the borrowing constraint of impatient households (4). The LTV ratio follows

$$m_t = m^{(1-\phi_m)} m_{t-1}^{\phi_m} \left(\frac{b_{h,t}^b}{b_{h,t-1}^b} \right)^{-(1-\phi_m)\phi_{LTV}} \varepsilon_t^{LTV}, \tag{10}$$

where ϕ_m is a smoothing parameter and ϕ_{LTV} is the policy parameter which defines the strength of the reaction of the LTV ratio toward changes in the growth of real domestic borrowing activity. To simplify matters, the LTV ratio changes continuously.[9] Analogous to the monetary policy shock, the stochastic component ε_t^{LTV} displays an exogenous variation in the LTV ratio that cannot be explained by changes in borrowing and is thus considered an LTV shock with $\varepsilon_t^{LTV} = \exp(e_t^{LTV})$ and $e_t^{LTV} \sim N(0, \sigma_{LTV}^2)$.

Two additional shocks are included in the model, namely a housing demand shock and a technology shock. As technology in the housing sector is to a large part invariable, I only allow for technology in the nondurables sector to be stochastic. Thus, households' weight

[9] Funke and Paetz (2018) model an LTV ratio that only changes when a certain threshold of a target variable is exceeded; for the purpose of the present study, a continuous rule is chosen, as (i) interest lies only in impact responses of the model and (ii) a nonlinear rule would generate asymmetries in the responses, which data availability prohibits in the empirical application.

of housing in the utility function and the nondurables technology parameter evolves with

$$\gamma_t = \gamma^{(1-\phi_\gamma)} \gamma_{t-1}^{\phi_\gamma} \varepsilon_t^\gamma \tag{11}$$

$$A_{c,t} = A_c^{(1-\phi_A)} A_{c,t-1}^{\phi_A} \varepsilon_t^A, \tag{12}$$

where shocks are distributed according to $\varepsilon_t^k = \exp(e_t^k)$ and $e_t^k \sim N(0, \sigma_k^2)$ with $k = \gamma, A$.

2.4 Calibration

Similar to Peersman and Straub (2009) or Sá and Wieladek (2015), I specify ranges for the structural parameters according to a uniform distribution to mimic quarterly data. This allows for a relative agnostic calibration of the model. Before generating impulse response functions (IRFs), random values are drawn for each structural parameter following its assigned distribution. This process is repeated 10,000 times to cover a large part of the parameter space.

Some specifications displayed in table 1 are worthy of elaboration: the degree of openness is chosen to always be larger in the nondurables than in the durables sector, as residential housing is mainly traded domestically. Sectors also differ in the magnitude of price stickiness. Firms in the durables sector are allowed to change prices more frequently following Iacoviello and Neri (2010). They even assume fully flexible prices in the housing sector. The reasoning is twofold: (i) due to the large cost involved on a per-unit basis, the incentive to negotiate prices individually for each good is high, and (ii) houses are often priced for the first time when they are sold.

Elasticities of substitution between domestic goods and goods of foreign countries reflect price markups in steady state between 1.1 and 1.5, while elasticities of substitution between domestic and foreign goods imply higher markups, following Sá and Wieladek (2015). There is not much guidance in the literature on the policy parameter of the LTV rule. It is set conservatively to lie between 0 and 0.9, which encompasses the welfare-maximizing values proposed in Rubio and Carrasco-Callego (2014). The smoothing parameter of the rule is considered to be high, taking into account the noncontinuous changes in reality. Lastly, I attribute standard normal distributions

Table 1. Parameter Ranges

Parameter	Description	Parameter Range
β_s	Discount factor patient households	[0.975, 0.995]
β_b	Discount factor impatient households	[0.950, 0.970]
γ	Steady-state weight of housing pref. in utility	[0.2, 0.5]
δ	Depreciation durables	[0.005, 0.030]
α_c	Degree openness nondurables sector	[0.25, 0.50]
α_d	Degree openness durables sector	[0.05, 0.15]
$\varepsilon_c, \varepsilon_d$	EOS between domestic goods	[3, 11]
ζ_c, ζ_d	EOS between goods of different countries	[3, 11]
η_c, η_d	EOS between domestic and foreign goods	[1.5, 2.5]
ω	Fraction of borrowers	[0.15, 0.50]
$(1-\theta_c)$	Prob. of readjusting prices (cons. goods)	[0.25, 0.50]
$(1-\theta_d)$	Prob. of readjusting prices (durables)	[0.75, 0.90]
φ	Inverse of Frisch labor supply elasticity	[0.1, 3]
ϕ_π	Central bank reaction to domestic inflation	[1.25, 2.5]
ϕ_{LTV}	Reaction LTV ratio to credit growth	[0, 0.9]
$\phi_\tau, \phi_\gamma, \phi_A$	Smoothing parameters	[0.5, 0.9]
ϕ_m	Smoothing parameter LTV rule	[0.75, 0.95]
m	Steady-state LTV ratio	0.7
λ	International intermediation costs	[0.005, 0.050]
$\sigma^2_{LTV}, \sigma^2_\gamma, \sigma^2_A, \sigma^2_{MP}$	Variance of log-linearized shocks	1

Note: Parameter ranges display the minimum value and maximum value of a uniform distribution; EOS: elasticity of substitution.

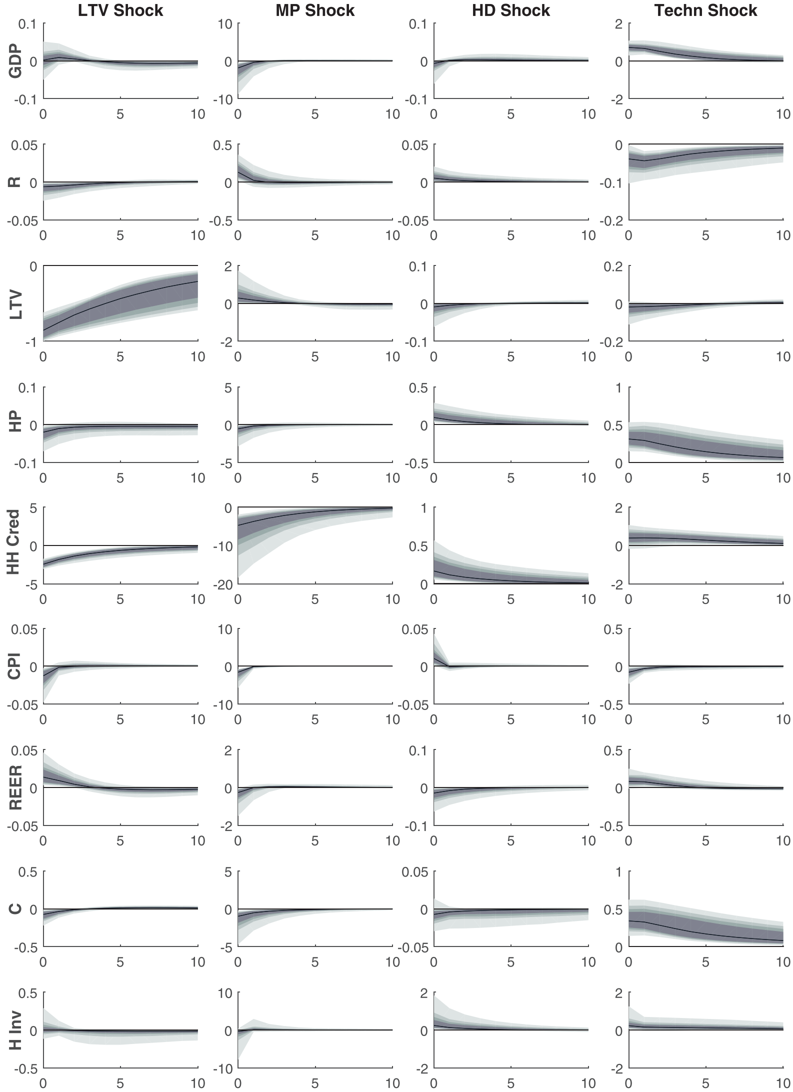
to all log-linearized shocks, since my interest lies only in qualitative responses.[10]

2.5 Impulse Responses and Sign Restrictions

The first column in figure 2 depicts a contractionary shock to the LTV ratio. On impact, the borrowing constraint of impatient households tightens, leading to a strong decrease in real borrowing activity. Impatient households lower their spending on housing as well as consumption. The decline in housing demand pushes down house prices. Compared with a model with fixed housing supply (e.g.,

[10]Note that since the model is log-linearized, the shock size does not have an influence on the sign of the responses.

Figure 2. Impulse Response Functions from the Model



Notes: Each column represents a shock: LTV, monetary policy (MP), housing demand (HD), and a technology (Techn) shock. Each row gives the response of the respective variable: real GDP (GDP), short-term nominal interest rate (R), LTV ratio (LTV), real house prices (HP), real household credit (HH Cred), consumer price index (CPI), the real effective exchange rate (REER), consumption (C), and housing investment (H Inv). The solid line gives the median response, and the shaded areas, from dark to light, the 84-16, 90-10, 95-5, and 99.5-0.5 percentiles.

Iacoviello 2005), adjustments on the supply side due to lower marginal costs dampen the effect on house prices slightly. Due to the role of real estate as collateral and the lower price stickiness, house prices react more strongly than prices of consumption goods. Still, while aggregate consumption decreases unambiguously, the direction of overall housing investment is not clear: the more favorable price level induces patient households to substitute part of their non-durables with durables consumption. Declining price levels prompt the inflation-targeting central bank to lower the nominal interest rate, bringing about a depreciation of the domestic currency. Coupled with the decrease in prices, this leads to an increase in the real effective exchange rate (REER), i.e., higher price competitiveness.[11] Interestingly, real gross domestic product (GDP) can go in both directions as the increase in foreign demand counteracts the generally contractionary responses.

A contractionary monetary policy shock (second column in figure 2), through the increase in the nominal interest rate, tightens the borrowing constraint of impatient households. Their initial decrease in consumption of both types of goods is amplified via the collateral constraint channel but partially weakened by the countercyclical LTV rule. Following the same line of reasoning as in the LTV shock, patient households substitute consumption for housing. This time, however, the increase in the nominal interest rate leads to an appreciation of the domestic currency. While lower demand pushes down consumer prices, overall the economy still exhibits a loss in price competitiveness and, thus, a decrease in the REER and less foreign demand. In comparison with the LTV shock, real GDP drops unambiguously.

The two remaining shocks are included, as they are potential drivers of real estate cycles, either directly (housing demand shocks) or via synchronized business and real estate cycles (technology shocks). A positive housing demand shock (third column in figure 2) pushes up housing investment at the cost of consumption. The collateral

[11]The REER is defined here such that an increase is equivalent to an improvement of domestic price competitiveness; also note that the decline in domestic prices is enough to push up the REER on impact even without the central bank's reaction.

Table 2. Sign Restriction

	BB-MaPP Shock	MP Shock	HD Shock	Techn Shock
REER	+	–	–	+
Real Res Inv		–	+	+
Inflation		–		–
Real Cons	–	–		+
BB-MaPP Index	+		+	
Interest Rate		+		
Real GDP				+
Real House Prices			+	
Real HH Credit				

Notes: Each column represents a shock: borrower-based macroprudential policy (BB-MaPP), monetary policy (MP), housing demand (HD), and a technology (Techn) shock. A "+" sign restricts the impact response for the variable to the respective shock to be non-negative for the first two quarters, while a "–" sign restricts the impact response of the variable of the respective shock to be non-positive for the first two quarters.

value of impatient households increases, amplified by the demand-driven boost in real house prices. Under some calibrations, their higher borrowing activity can even lead to an increase in nondurables consumption in line with Iacoviello and Neri (2010). Overall, consumer prices increase, triggering a rise in the nominal interest rate, leading to a decrease in the REER via the uncovered interest parity. Combined with the mitigating effect of the countercyclical LTV ratio on borrowing, the decrease in foreign demand might even dampen overall domestic production. A technology shock in the nondurables sector (fourth column in figure 2), on the other hand, is amplified by the open-economy setup as the declining price level coupled with lower nominal interest rates pushes up price competitiveness. Besides the direct increase in consumption, lower interest rates relax the borrowing constraint, initiating a demand-driven house price increase. Overall, we have a sharp increase in real domestic economic activity.

Table 2 depicts the sign restrictions that are imposed on the nine-variable Bayesian VAR (BVAR) for the first two quarters, all consistent with the DSGE model. Unique identification is achieved for all four shocks with the restrictions on the top five variables in the table above. The additional restrictions are imposed to pin down certain shocks more precisely. Thus, while, in general, the responses of real house prices and real household credit are left unrestricted, this is not the case for the housing demand shock, since a positive reaction of house prices is deemed an important identifier here.[12] The LTV ratio is replaced by a more general borrower-based index, which also includes regulations on DSTI ratios. It is assumed that caps on LTV and DSTI ratios generally work in the same direction from a macroeconomic perspective and both fulfill the sign restrictions imposed.[13] From a practical perspective, merging the two policies allows for more time variation in the index. Note that an increase in this index is tantamount to a tightening of one of the policies, switching signs compared with the LTV ratio in the model. More detail on this index is given in the appendix.

3. Econometric Framework and Data

3.1 Estimation, Identification, and Data

Consider the following VAR(p) model:

$$Y_t = c + A_1 Y_{t-1} + \cdots + A_p Y_{t-p} + u_t, \tag{13}$$

where $Y_t = (y_{1,t}, y_{2,t}, \ldots, \ldots y_{n,t})'$ is an n-dimensional vector of endogenous variables, c is an n-dimensional vector of constants, A_k are $n \times n$ matrices of coefficients, and u_t is n-dimensional Gaussian white noise with covariance matrix $\mathbb{E}(u_t u_t') = \Psi$. Where n and p are of modest size, the number of coefficients to be estimated can already become large, leading to a curse-of-dimensionality problem. Bayesian VARs have become a popular choice to overcome this problem by "shrinking" coefficients toward some prior belief. I follow the idea of the Minnesota prior proposed by Litterman (1986) which

[12] Iacoviello and Neri (2010) also name their housing preference shock "housing demand shock," precisely since it leads to an increase in house prices and housing investment; the sign-identified housing demand shock in Jarociński and Smets (2008) also imposes the restriction that house prices and residential investment move in the same direction.

[13] In reality, the transmission of the two regulations potentially exhibits differences; as shown, e.g., in Gelain, Lansing, and Mendicino (2013), with a hybrid borrowing constraint, labor supply is directly affected by the DSTI regulation; thus, in a robustness check, this assumption is relaxed and the effects of LTV and DSTI shocks are separated.

imposes the prior belief that most macroeconomic variables can be reasonably described to follow a random walk with drift. In general, the prior distribution of the coefficients is set to

$$\mathbb{E}\left[(A_k)_{ij}\right] = \begin{cases} \delta_i, & j = i, k = 1 \\ 0, & \text{otherwise} \end{cases},$$
$$\text{Var}\left[(A_k)_{ij}\right] = \begin{cases} \frac{\lambda^2}{k^2}, & j = i \\ \frac{\lambda^2}{k^2}\frac{\sigma_i^2}{\sigma_j^2}, & \text{otherwise}, \end{cases} \tag{14}$$

where $\delta_i = 1$ implies a random-walk prior. The hyperparameter λ controls the overall tightness of the prior: as $\lambda \to 0$, the prior belief becomes more and more important, dominating the actual data. For the constant, a diffuse prior is assumed. As the covariance matrix is assumed to be known in the original Minnesota prior, I follow Kadiyala and Karlsson (1997) by choosing a normal-Wishart prior that retains the general idea outlined above. In particular, the prior is implemented by adding dummy observations as in Bańbura, Giannone, and Reichlin (2010). This allows for easy extension of additional prior assumptions.[14]

The structural VAR model

$$\mathcal{A}_0 Y_t = \nu + \mathcal{A}_1 Y_{t-1} + \cdots + \mathcal{A}_p Y_{t-p} + e_t \tag{15}$$

with $e_t \sim N(0, I)$ as the structural innovations and the mapping $u_t = \mathcal{A}_0^{-1} e_t$ is then identified via sign restrictions pioneered by Faust (1998), Canova and Nicoló (2002), and Uhlig (2005). In order to identify $\mathcal{A}_0^{-1}$, the Cholesky decomposition of the covariance matrix, $\Psi = PP' = \mathcal{A}_0^{-1}\mathcal{A}_0^{-1'}$, delivers a solution which is multiplied by an orthogonal matrix Q, such that $\mathcal{A}_0^{-1} = PQ$ is not lower triangular.[15] Following Rubio-Ramírez, Waggoner, and Zha (2010), Q is

[14]In general, it also has the computational advantage that inversion of a square matrix of dimension $np + 1$ instead of a square matrix of dimension $n(np + 1)$ is necessary.

[15]The solution $\mathcal{A}_0^{-1} = P$ is viable and often used but imposes a recursive structure; while it is often not justifiable from an economic perspective, in a robustness check later on this identification is utilized.

drawn from a QR decomposition of an n-dimensional square matrix of standard normal distributed random variables, which allows Q to be chosen randomly from the space of orthogonal matrices. Then, for each draw from the posterior, only the draws of Q are kept, which fulfill the identified signs from the DSGE model in table 2. Since there is an infinite amount of possible Q matrices, only set identification is achieved. To choose the "proper" impulse responses, I follow the median target (MT) method proposed by Fry and Pagan (2011). For each posterior draw, the orthogonal matrix Q is selected, which minimizes the distance of standardized impulse responses to the median response function over all Q-draws.[16]

The BVAR model contains nine endogenous variables: real GDP, the CPI, a real house price index, real loans to households, the REER, real residential investment, and real consumption, all included in logs, as well as a BB-MaPP index and a short-term nominal interest rate[17] included in levels. Additional details and sources are given in table A.1. The creation of the BB-MaPP index makes use of the fact that both regulations change quite frequently over the sample period. Similar to the idea of Igan and Kang (2011), an average value for the mandatory LTV and DSTI ratios is calculated. Then, using the min-max principle to make both policy ratios comparable, they are added with equal weighting. More details on the creation of this BB-MaPP index can be found in the appendix.

Before estimation, the Minnesota prior has to be specified. First of all, it is assumed that all variables besides the REER follow a random walk with drift, while the latter is specified by a white-noise process. This is in line with Bańbura, Giannone, and Reichlin (2010). I also lean on their work in calibrating the shrinkage parameter λ: for a pre-sample period going from 1991:Q1 to 1999:Q4, a benchmark in-sample fit is set by calculating the relative in-sample fit of ordinary least squares estimates of a small VAR only including real GDP, the CPI, and real household credit to a counterpart where

[16]Note that the median response function over all Q-draws itself lacks structural economic interpretation, as the responses at different horizons are likely to come from different draws of Q.

[17]Note that the central bank's base rate does not fall below 1.5 percent during the sample period such that zero lower bound considerations can be disregarded.

prior specifications are imposed exactly. Then, for the full VAR,[18] λ is chosen such that the relative fit for the variables of the small VAR comes as close as possible to the benchmark fit. This procedure ensures that Bayesian shrinkage increases with the size of the VAR. For the baseline setup, λ is equal to 0.16, while the hyperparameter for the constant, ε, is given a small value to impose a diffuse prior.

The BVAR is then estimated for the period 2000:Q1 to 2015:Q4, including four lags and drawing 500 times from the posterior. For each draw, the sign-restrictions algorithm is executed until 20 admissible draws[19] are found, whereby the "correct" model is identified via the MT method as described above.

3.2 Housing Sector and Housing Policies in Korea

For a long time, the Korean real estate sector was characterized by a shortage of residential housing. Along with economic growth came housing supply-side policies in the late 1980s that successfully closed the supply-demand gap in the Korean real estate sector. While real house prices peaked around 1990, the Two-Million Housing Drive policy measure effectively increased yearly housing construction in Korea from around 250,000 up to 550,000 units, bringing house prices down to an affordable level.

Nowadays, affordability of housing in Korea is comparable to other emerging and advanced economies (see, e.g., Kim and Park 2016). However, the government is still active in curbing housing cycles and making housing accessible to a larger part of the population. After the Asian financial crisis, a short-run decrease in housing supply coupled with the expansion of mortgage credit led to a surge in house prices. Besides tax changes, the macroprudential policies under investigation here were introduced in the form of mandatory LTV ratios in 2002 and, later on, mandatory DSTI ratios in 2005 to effectively reduce housing demand. As documented in table A.2,

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[18] The full VAR for the pre-sample period abstracts from the BB-MaPP index, as no such policies were implemented during this time; thus, the shrinkage parameter λ is possibly set too high, as the pre-sample full VAR only includes eight instead of nine variables.

[19] Due to the large amount of imposed sign restrictions, there are some "unlucky" posterior draws where the acceptance rate is very low; in these cases, the algorithm stops after 15 million draws of Q to reduce computation time.

Table 3. Korean Housing Sector Data

	2001–05	2006–10	2011–15
Residential Investment to GDP (%)	5.06	4.57	3.86
Housing Construction Permits	541,844	432,982	571,435
Housing Supply Ratio (%)	101.64	109.80	116.10
Owner-Occupancy Ratio (%)		55.40	53.70
Jeonse-Occupancy Ratio (%)		22.13	20.70
Rent-Occupancy Ratio (%)		19.56	22.77
House Affordability Index	67.50	64.17	56.34
Real House Price Growth (%)	3.86	0.99	1.02

Sources: Ministry of Land, Infrastructure and Transport; Bank of Korea; Korea Housing Finance Corporation; Bank for International Settlements.
Notes: The housing supply ratio is simply the number of dwellings to the number of households and is only reported up until 2014; owner-occupancy ratio, Jeonse-occupancy ratio, and rent-occupancy ratio are only available for the years 2006, 2008, 2010, 2012, and 2014; the house affordability index is defined as the debt service burden by the median income household purchasing the median priced house using a standard mortgage loan; all variables are given as annual averages.

these regulations were adjusted regularly based on characteristics of the borrower, the loan, or the region of the real estate. Korean authorities also engaged in housing finance policies and, lately, direct demand-side policies in the form of housing benefits. A summary of important residential housing statistics in Korea is given in table 3.

One peculiar feature of the Korean housing sector is the existence of Jeonse contracts. The tenant makes a large deposit upfront but does not pay any monthly rent. At the termination of the contract, the deposit is fully refunded. The landlord generates profit by investing the deposit. There are also mixtures of standard monthly rental contracts and Jeonse contracts. Around 20 percent of occupied households are under these Jeonse contracts (see table 3). Internationally compared, the owner-occupancy ratio is rather low, partially due to the existence of Jeonse contracts, which are often considered as a step toward home ownership. For ease of purpose, I will abstract from these peculiarities of the Korean housing sector in the following.

For a more comprehensive, up-to-date overview of the Korean residential housing sector, see Kim and Park (2016).

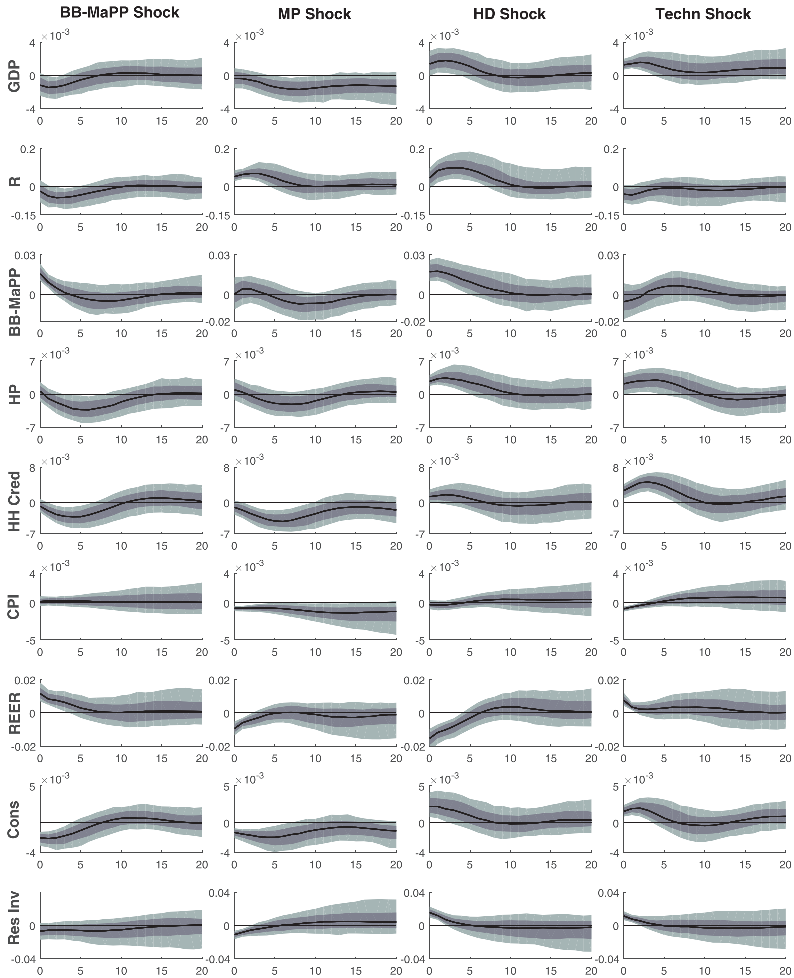
4. Results

4.1 Baseline Results

For the baseline estimation, impulse responses to all four shocks are depicted in figure 3. A one-standard-deviation BB-MaPP shock (first column) increases the BB-MaPP index by about 0.015 on impact, equivalent to either an average decrease in the mandatory LTV ratio by 0.43 percentage point or a decrease in the mandatory DSTI ratio by 0.45 percentage point. At first glance, these shocks seem considerably small, but macroprudential measures in Korea are often targeted only toward specific groups of potential homebuyers or certain areas. Thus, while shocks might seem small on an average level, they can be quite substantial for individual borrowers. In 2009, for example, LTV regulations for house purchases above 600 million won in the metropolitan area were tightened by 10 percentage points, displaying a shock for affected borrowers multiple times more then those considered here. While the BB-MaPP shock dies out surprisingly fast, it effectively pushes down real household credit and house prices, both by about 0.3 percent at their peak. Credit reacts directly on impact and reaches its peak response after one year. House prices, possibly due to some stickiness (see, e.g., Merlo and Ortalo-Magné 2004 for empirical evidence on house price stickiness), only become negative after one quarter and exhibit their peak response after around six quarters.

Interestingly, the decrease in real residential investment is economically large but statistically only significant on impact at the 68 percent level. Depending on the region under consideration, responsiveness of housing supply may differ considerably. It is also not clear whether and how a decrease in housing demand affects investment decisions of existing homeowners regarding, e.g., maintenance or improvements. As imposed by the sign restrictions, real consumption decreases. The reasoning is twofold: (i) a tighter regulation prevents some homeowners from refinancing their mortgages with a smaller equity stake to antedate consumption and (ii) potential homebuyers affected by the regulation could be forced to reduce consumption in order to raise the demanded downpayment. In line with the decrease in residential investment and consumption, real GDP also declines but only significantly so for a short period of time.

Figure 3. Impulse Response Functions to the Baseline Sign-Identified BVAR



Notes: Each column represents a shock: borrower-based macroprudential policy (BB-MaPP), monetary policy (MP), housing demand (HD), and a technology (Techn) shock. Each row gives the response of the respective variable: real GDP (GDP), short-term nominal interest rate (R), borrower-based macroprudential policy (BB-MaPP) index, real house prices (HP), real household credit (HH Cred), consumer price index (CPI), the real effective exchange rate (REER), real consumption (Cons), and real residential investment (Res Inv). Gray shaded areas give the 68 percent and 90 percent credibility intervals.

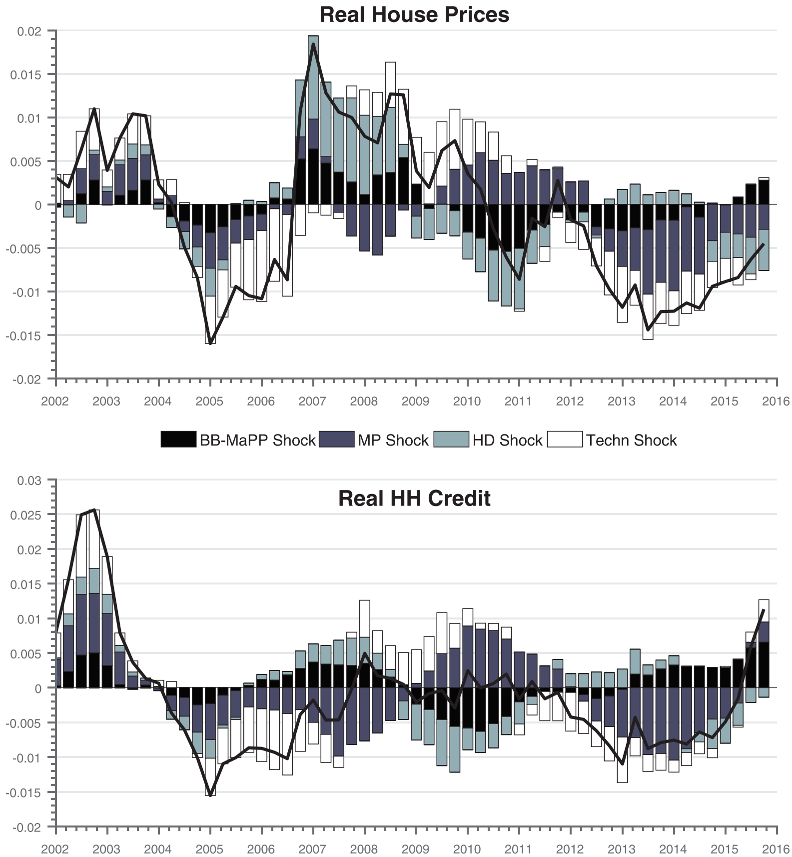
The overall contractionary response to the BB-MaPP shock triggers an interest rate decrease, mitigating the overall effects on the real economy. Most empirical studies are silent on these potential costs of macroprudential regulations. One exception is Kim and Mehrotra (2018), who similarly observe a decline in overall economic activity, but a much more persistent one. Additionally, they find that consumer prices are negatively affected by a tightening of macroprudential regulations. Since they pool all types of macroprudential measures, this might indicate that the negative aggregate demand effects of macroprudential regulations besides BB-MaPP are comparably stronger.[20]

A monetary policy shock (second column in figure 3) first of all leads to an increase of the nominal short-term rate by 6 basis points on impact. This is rather small but in line with, e.g., the interest rate response in Uhlig (2005), which is much smaller in a sign-restrictions approach than with recursive identification. Most strikingly, house price responses to the contractionary monetary policy shock are comparably small and not significant at the 90 percent level. This result can be motivated by a decreasing interest rate sensitivity of housing demand for increasing downpayment requirements (see Calza, Monacelli, and Stracca 2013). On impact, real GDP does not react significantly but exhibits a sustained decline in contrast to its reaction to the BB-MaPP shock. Otherwise, responses go in the accustomed directions.

Another potentially important driver of real estate cycles is housing demand shocks (third column in figure 3). As house prices increase, housing wealth as well as the collateral capacity of constrained homeowners increases, which can explain the increase in consumption (see also Iacoviello and Neri 2010). Surprisingly so, the increase in household credit is not significant at the 90 percent level and comparably small, contradicting the idea that the increased collateral capacity is primarily responsible for the consumption hike. The effect of the housing demand shock is relatively short-lived, possibly due to the strong counteracting response of the interest rate and the BB-MaPP index. Technology shocks—as an important

[20]The differences in responses to their study should be interpreted with some caution, as they estimate a panel SVAR with four countries (Korea is one of them) and use recursive identification.

Figure 4. Historical Decomposition



Notes: The solid line depicts the log-deviation of real house prices and real household credit, respectively, from their deterministic paths. The residual that comprises the five unidentified shocks in the BVAR is not reported to improve visibility.

driver of business cycle fluctuations—also contribute significantly to housing variables. These responses should capture part of the interdependency between real estate and business cycles.[21]

Figure 4 displays the historical decomposition of real house prices and real household credit, starting with the introduction of LTV

[21] House prices are generally procyclical, while residential investment leads the business cycle (see, e.g., Morris and Heathcote 2005).

regulations in 2002. The bars depict the historical contribution of each shock to deviations of the two time series from their deterministic path, i.e., the path the time series would have followed if no shocks had taken place. As is common, only the median contribution of each shock in each period is considered. For better visibility, the five unidentified "residual" shocks are ignored.[22] The following results should be taken with some caution, as the potential influence of the initial conditions as well as estimation uncertainty are ignored.

First, all four shocks contribute importantly to the evolution of the two time series. While housing demand shocks drove the small housing boom starting at the end of 2006, a tightening in macroprudential measures was co-responsible for a decrease in house prices and household credit afterward. At the same time, loose monetary policy in reaction to a weakening domestic economy during the ongoing global financial crisis worked in the opposing direction in the Korean housing market. This demonstrates the advantage of the targeted approach of BB-MaPP measures. According to the historical decomposition, house prices would have been 0.5 percent higher without the regulations. Considering that the three tightening measures in 2009 were all targeted only toward the Seoul metropolitan area and, especially, the speculative zones therein, the contribution to house prices within these areas was possibly much larger. At the current end of the sample, the role of housing demand seems to have diminished, while the influence of the two policy tools increased. A unification of the LTV and DSTI regulations, tantamount to an overall loosening of the policies, already takes effect in that it pushes both housing-sector variables.

All things considered, the baseline SVAR suggests that BB-MaPP measures are effective in curbing real estate cycles when deployed at the right time. Nevertheless, these targeted policies have economy-wide effects in the short run, although not as sustained as conventional monetary policy.

[22]At times, these shocks can have a large impact, but do not allow for any structural interpretation.

4.2 Robustness Checks

In the following, results are tested for the robustness toward splitting the BB-MaPP index, alternative identifications, as well as additional prior information. To keep the analysis concise, only impulse responses for the BB-MaPP shock and the monetary policy shock are presented.

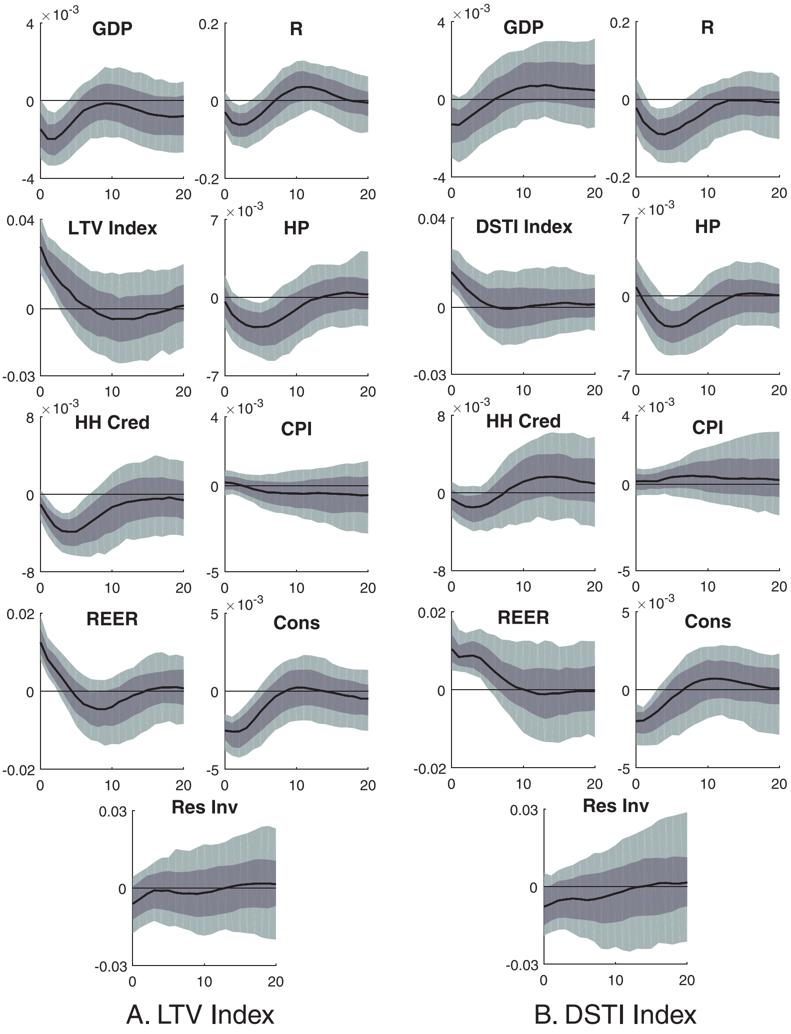
4.2.1 Splitting the BB-MaPP Index

One concern regarding the baseline results is the merging of LTV and DSTI regulations into one BB-MaPP index. While the assumption of similar effects of these two policies is common to increase time-series variation (see, e.g., Tillmann 2015, Cerutti, Claessens, and Laeven 2017, or Kim and Mehrotra 2018), previous research has shown that their effects might differ (see, e.g., Igan and Kang 2011 or Claessens, Gosh, and Mihet 2013). Gelain, Lansing, and Mendicino (2013), e.g., argue that DSTI caps might be superior in stabilizing household debt and house prices, since the latter are generally more volatile than income, in line with the empirical results in Claessens, Gosh, and Mihet (2013). Thus, in the following, I split the BB-MaPP index into an LTV and a DSTI index as described in the appendix.

Figure 5 reports the impulse responses to a one-standard-deviation LTV shock (A) and to a one-standard-deviation DSTI shock (B).[23] On impact, the shocks lead to a tightening of the LTV ratio by 0.79 percentage point and a tightening of the DSTI ratio by 0.47 percentage point. For most variables, responses are virtually identical, giving justification to the consolidated index used in the baseline setup. The most striking difference is the considerably stronger response of household credit in the case of the LTV shock. In line with this, Igan and Kang (2011) find stronger demand effects of LTV regulations than of DSTI regulations utilizing survey data. However, at odds with the present impulse response functions, they only detect a dampening in house prices expectations after stricter

[23]Changes in the impulse responses of the other shocks are negligible and are therefore not reported.

Figure 5. BVAR IRFs with LTV Ratio vs. DSTI Ratio



Notes: See note in figure 3. The BB-MaPP index is replaced by the LTV index in panel A and the DSTI index in panel B; a description of these indexes is given in the appendix.

caps on LTV ratios.[24] An alternative explanation could be a stronger decline in mortgage equity withdrawals by existing homeowners to finance consumption, which would also explain the slightly more marked reaction of real consumption in the case of the LTV shock. The stronger reaction of household credit following an LTV regulation also leads to a somewhat more pronounced fall in overall economic activity.

While I provide evidence for a similar reaction following both policies, results should be taken with some caution, as time-series variation is reduced to 11 changes in the LTV index and 10 changes in the DSTI index. Furthermore, DSTI regulations, at least in the beginning, were targeted to more specific types of borrowers—mostly in the speculative zones—while a wider audience was subject to LTV regulations in Korea. Differences in the effectiveness of the two regulations also boil down to the calibration of the measures and whether the targeted borrowers actually become constrained, which cannot be tested with the available data.

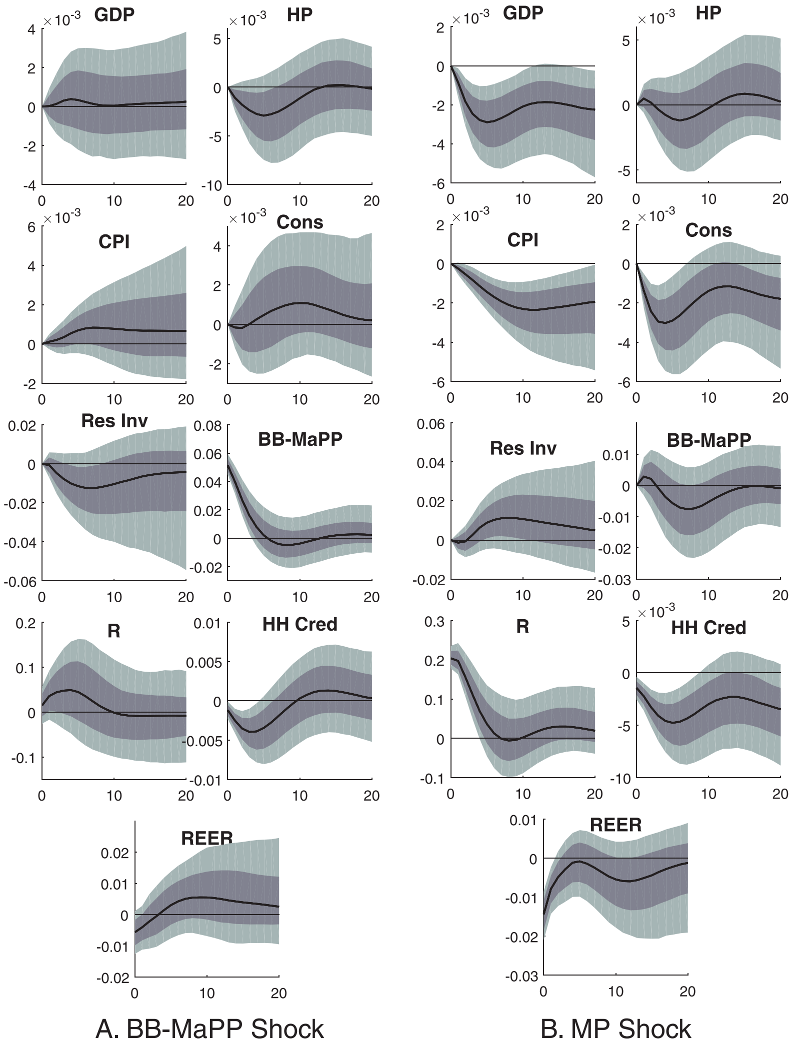
4.2.2 Alternative Identifications

To complement previous findings, a traditional recursive identification similar to Kim and Mehrotra (2018) is implemented. The approach follows Bernanke, Boivin, and Eliasz (2005) in dividing the variables into "slow-moving," "fast-moving," and shock variables. To keep matters simple, only a monetary policy and a BB-MaPP shock are identified, where the latter is ordered first as in Kim and Mehrotra (2018). Following Bańbura, Giannone, and Reichlin (2010), zero restrictions are imposed on the impact responses of the "slow-moving" variables—real GDP, real house prices, the CPI, real consumption, and real residential investment—while real household credit and the real effective exchange rate are considered to be "fast moving."

Impulse responses in figure 6 are mostly comparable to the ones from the sign-identified BVAR in figure 3, at least from a qualitative perspective. Real household credit as well as real house prices decline

[24]Igan and Kang (2011) argue that DSTI ratios are more closely related to the affordability channel: following a tighter regulation, only richer households with a lower price sensitivity qualify for a mortgage loan such that, despite the lower demand, the willingness to pay does not decrease.

Figure 6. BVAR IRFs with Recursive Identification



Notes: See note in figure 3. The BVAR is recursively identified using a Cholesky decomposition: GDP, HP, CPI, Cons, and Res Inv are defined as "slow-moving" variables, while HH Cred and REER are defined as "fast-moving" variables. The BB-MaPP shock is ordered before the MP shock.

Table 4. Alternative Sign Restriction

	BB-MaPP Shock	MP Shock	HD Shock	Techn Shock
Real Res Inv		−	+	+
Inflation		−		−
Real Cons	−	−		+
BB-MaPP Index	+		+	
Interest Rate	−	+	+	−
Real GDP				+
Real House Prices			+	
Real HH Credit				
REER				

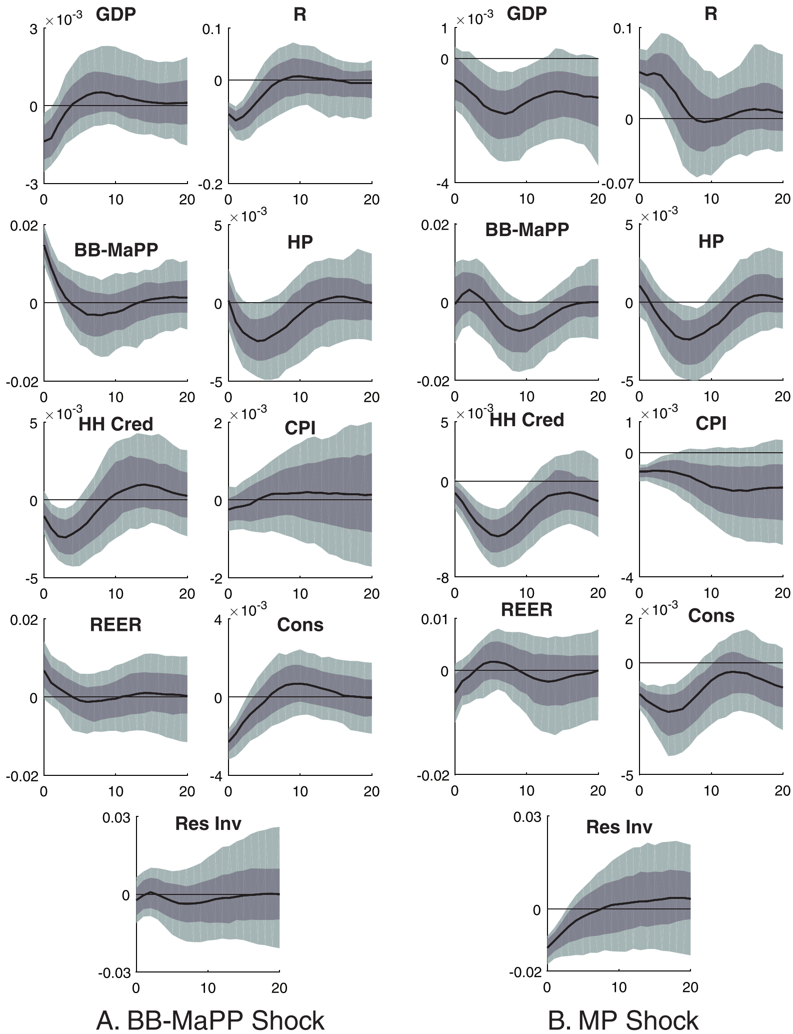
Notes: Each column represents a shock: borrower-based macroprudential policy (BB-MaPP), monetary policy (MP), housing demand (HD), and a technology (Techn) shock. A "+" sign restricts the impact response for the variable to the respective shock to be non-negative for the first two quarters, while a "–" sign restricts the impact response of the variable of the respective shock to be non-positive for the first two quarters.

after a contractionary BB-MaPP shock, although the latter response is only significant at the one-standard-deviation level. In the recursive identification, the effect of monetary policy on house prices is completely muted. The real effective exchange rate drops on impact, as imposed in the sign-identified approach for the monetary policy shock, but moves in the "wrong" direction for the BB-MaPP shock. This indicates that the negative sign imposed above might be debatable. Lastly, and in contrast to the findings of Kim and Mehrotra (2018), GDP is not affected by the macroprudential measures at all.

While in line with the model, the recursive identification rejects the imposed sign on the REER for the BB-MaPP shock. Additionally, empirical evidence suggests that the connection between macroeconomic fundamentals and exchange rates might be unstable over time (see, e.g., Bacchetta and van Wincoop 2013 or Fratzscher et al. 2015). Table 4 presents alternative sign restrictions consistent with the model that uniquely identify the four shocks without restricting the REER.

Figure 7 presents the impulse responses for the BB-MaPP and the monetary policy shock. Differences between these and the baseline results are mostly negligible. The reaction of house prices and household credit following a BB-MaPP shock are somewhat smaller,

Figure 7. BVAR IRFs with Alternative Sign Restrictions



Notes: See note in figure 3. The alternative sign restrictions imposed are given in table 4.

while there is no significant feedback to residential investment anymore. This can be rationalized by a stronger decline of the interest rate, which is now imposed by a sign restriction. Importantly, the REER still moves in the same direction as proposed by the model.

Besides the smaller reaction of the REER, responses to the monetary policy shock are virtually the same as in the baseline identification. Overall, figure 7 reinforces previous results and shows that these are not driven by the restriction on the REER, but warn against giving too strong a weight to the exact quantitative reaction of the variables of interest.

4.2.3 Additional Prior Information

In forecasting exercises, adding additional prior information generally improves the precision of the results (see, e.g., Bańbura, Giannone, and Reichlin 2010). Therefore, I further add two popular modifications to the standard Minnesota prior: the sum-of-coefficients (SOC) prior and the co-persistence (COP) prior.

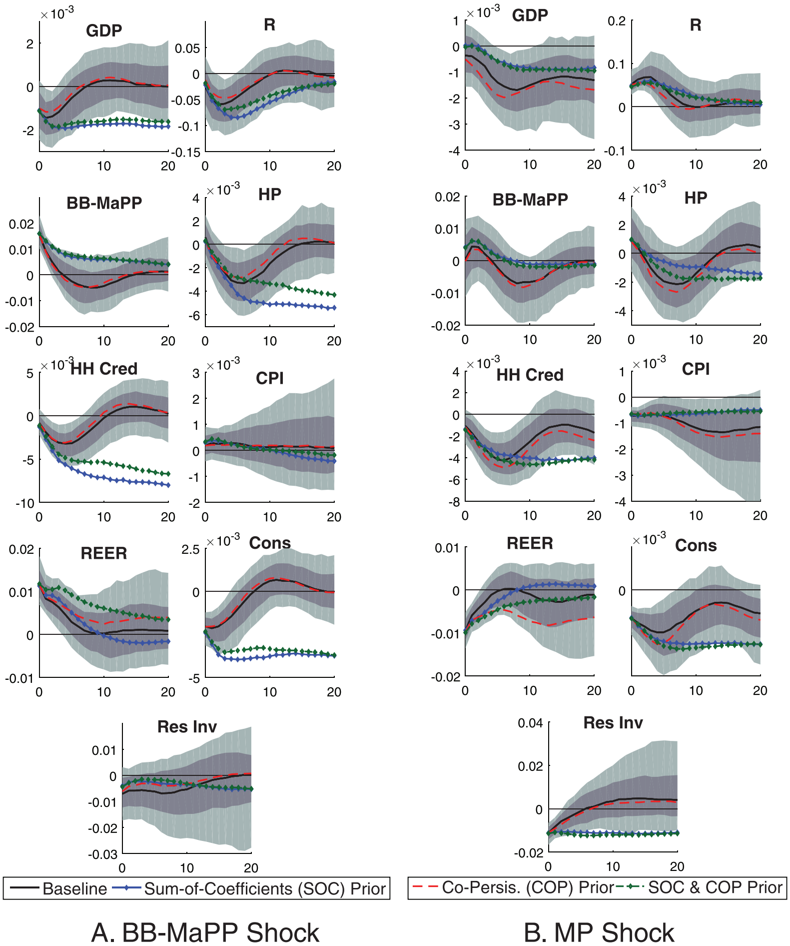
The SOC prior, proposed by Doan, Litterman, and Sims (1984), shrinks the long-run relationship in an error-correction representation of the BVAR in (13), $(I - A_1 - \cdots - A_p)$, toward zero. This "inexact differencing" imposes a unit root on each variable, y_t, but also rules out cointegration in the limit. To control for this shortcoming, Sims (1993) proposed the co-persistence prior. This prior imposes the belief that the dynamic behavior of the model is well presented by a no-change forecast. The idea is to bring the prior belief toward a form with unit-root nonstationarity in all variables but still allowing for possible cointegration relationships. Both priors can be easily added to the dummy observations (see, e.g., Bloor and Matheson 2010).[25] To abstract from the influence of a change in the overall tightness of the prior, λ is fixed at 0.16, the value of the baseline setup.[26]

Impulse responses for different prior specifications are reported in figure 8 for the BB-MaPP and the monetary policy shock. In general, differences in the results are of a qualitative, not a quantitative, nature. The COP prior on its own mostly mimics the baseline impulse responses. The SOC prior, on the other hand, imposes more

[25] The tightness of the priors is set to 10λ as Bańbura, Giannone, and Reichlin (2010) do for the SOC prior; Bloor and Matheson (2010) show that forecasting performance in their model is robust to different specifications.

[26] The in-sample fitting procedure described in section 3.1 would suggest a looser prior when including the additional prior information; however, results are nearly identical to the ones presented here.

Figure 8. BVAR IRFs with Alternative Prior Information



Note: See note in figure 3.

persistent responses but also introduces more posterior draws with explosive roots. Consequently, the higher persistence in the response of the BB-MaPP index after a BB-MaPP shock is followed by a stronger and more sustained contraction in household credit and house prices, triggering more substantial losses in GDP and consumption. Not surprisingly, the combined prior is dominated by the influence of the SOC prior and therefore largely follows its responses.

In general, the main results are independent of the choice of prior. However, as the inclusion of the COP and, especially, the SOC prior leads to more posterior draws which exhibit explosive roots, results in this subsection should be taken with a grain of salt. At least in the relatively small sample under investigation, conclusions drawn from the simple Minnesota prior seem to be more reliable.

5. Conclusion

In this paper, I estimate a sign-identified Bayesian SVAR model to analyze the effects of mandatory caps on LTV and DSTI ratios in the Korean real estate market. The sign restrictions are drawn from an agnostically calibrated small open-economy DSGE model that allows housing to be collateralizable. Results suggest that BB-MaPP measures, in effect since 2002 in Korea, have been successful in curbing real estate cycles in the form of household credit and house prices. Contractionary monetary policy shocks have only moderate effects on real house prices, in accordance with a weaker collateral constraints channel under strict downpayment requirements. A historical decomposition indicates that BB-MaPP measures helped in keeping the housing boom around the outbreak of the global financial crisis in check, while at the same time a loose monetary policy was able to stimulate the overall economy. Taken together, these results point to BB-MaPP regulations being a potentially important factor in the relatively stable house prices in Korea since their inception and emphasize the advantages of a targeted approach toward regulation. The study adds to the rather new branch of literature investigating macroprudential regulations empirically. By concentrating on a country with comparably long experience of BB-MaPP regulations, the construction of a new BB-MaPP index allows for the application of a VAR approach, thus circumventing potential problems of endogeneity inherent in previous panel data approaches.

The importance of investigating these regulations is obvious. A wide array of macroprudential policies has been proposed to dampen boom-bust cycles in asset markets, especially in real estate markets. Thus, understanding which policies are successful under which circumstances is crucial in defining the optimal policy mix. While this study makes a point for the implementation of mandatory LTV and DSTI regulations in real estate markets, a few shortcomings must be taken into account. First of all, results might not be directly transferable to other countries due to the peculiarities of the Korean housing market, such as Jeonse contracts and a rather active housing supply policy preceding the sample period under investigation. Secondly, by aggregating over the whole country, the study ignores possible heterogeneous effects of the regulations. Thirdly, potentially undesirable distributional effects are ignored. Lastly, the influence of tightening and loosening periods on real estate markets might be different.

These shortcomings already set the ground for possible future research. Nonlinearities with respect to the direction or timing of policies could be taken into account. With more granular data, the investigation of distributional effects of these regulations might also be possible. In general, data limitation is the most relevant confining factor of empirical research on macroprudential policies. However, in line with the growing international experience with macroprudential policies, this factor should become less of an obstacle.

Appendix

A.1 Additional Details on the Model

A.1.1 Households' First-Order Conditions

Impatient households maximize utility in (1) subject to the budget constraint (3) and the binding borrowing constraint (4), leading to the following first-order conditions (FOCs):[27]

$$q_t = \gamma_t \frac{C_t^b}{D_t^b} + m_t(1-\delta)\psi_t \mathbb{E}_t[q_{t+1}\Pi_{c,t+1}] + \beta_b(1-\delta)\mathbb{E}_t\left[\frac{C_t^b}{C_{t+1}^b} q_{t+1}\right] \tag{A.1}$$

$$R_t\psi_t = 1 - \beta_b \mathbb{E}_t\left[\frac{C_t^b}{C_{t+1}^b}\frac{R_t}{\Pi_{c,t+1}}\right] \tag{A.2}$$

$$\frac{W_{j,t}^b}{P_{c,t}} = C_t^b (N_{j,t}^b)^{\varphi}, \quad j = c, d, \tag{A.3}$$

[27]Note that the multipliers on the constraints (1) and (3) are defined as λ_t^b and $\lambda_t^b\psi_t$; ψ_t can then be interpreted as the marginal value of borrowing.

where (A.1) equates the marginal utility of nondurable consumption to the shadow value of durable services, equation (A.2) is a Euler equation incorporating the shadow value of borrowing of constrained households, and equation (A.3) links the real wage to the marginal rate of substitution between consumption and leisure in both sectors.

Patient households do not face a borrowing constraint and, thus, maximize utility subject only to their budget constraint:

$$q_t = \gamma_t \frac{C_t^s}{D_t^s} + \beta_s(1-\delta)\mathbb{E}_t\left[\frac{C_t^s}{C_{t+1}^s} q_{t+1}\right] \tag{A.4}$$

$$1 = \beta_s \mathbb{E}_t\left[\frac{C_t^s}{C_{t+1}^s}\frac{R_t}{\Pi_{c,t+1}}\right] \tag{A.5}$$

$$\frac{W_{j,t}^s}{P_{c,t}} = C_t^s (N_{j,t}^s)^{\varphi}, \quad j = c, d \tag{A.6}$$

$$1 = \beta_s \mathbb{E}_t\left[\frac{C_t^s}{C_{t+1}^s}\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\frac{R_t^* \Xi(\mathcal{E}_t b_{f,t}^*)}{\Pi_{c,t+1}}\right]. \tag{A.7}$$

Conditions (A.4–A.6) are the same as for impatient households when $\psi_t = 0$. The last condition in equation (A.7) equates marginal utility of consumption today with discounted marginal utility of consumption in the next period by saving in the international bonds market.

A.1.2 Inflation, Exchange Rate, and the Terms of Trade

The bilateral terms of trade in sector j between the domestic economy and country are given by i as $S_{j,i,t} = \frac{P_{j,i,t}}{P_{j,h,t}}$. Log-linearizing the price index around a symmetric steady-state satisfying purchasing power parity (PPP) and using the effective terms of trade, inflation in sector j can be expressed as

$$\hat{\pi}_{j,t} = \hat{\pi}_{j,h,t} + \alpha_j \Delta \hat{s}_{j,t}, \quad j = c, d. \tag{A.8}$$

Consumer prices, therefore, depend additionally on the terms of trade scaled by the openness of sector j compared with a closed economy.

Under the assumption that the law of one price holds for all individual goods, the price of imported goods is given in log-linearized form by

$$\hat{p}_{j,f,t} = \hat{e}_t + \hat{p}^*_{j,t}, \quad j = c, d, \tag{A.9}$$

where $\hat{e}_t$ is the nominal effective exchange rate (price of foreign currency in terms of domestic currency) and $\hat{p}^*_{j,t} = \int_0^1 \hat{p}^i_{j,i,t} di$ is the world price index.

Now, further define the bilateral real exchange rate for good i in sector j as $\mathcal{F}_{j,i,t} = \frac{\mathcal{E}_{i,t} P^i_{j,t}}{P_{j,t}}$, such that it becomes cheaper to consume good i in sector j domestically when $\mathcal{F}_{j,i,t}$ increases. Log-linearizing, integrating over all goods i, and using the derived expressions in (A.8) and (A.9), sector j's real effective exchange rate (REER) in log-deviation from its steady state reads

$$\hat{f}_{j,t} = (1 - \alpha_j)\hat{s}_{j,t}, \quad j = c, d. \tag{A.10}$$

The real effective exchange rate for the whole economy, $\hat{f}_t$, can then be derived as a weighted average over both sectors.

A.1.3 Incomplete International Asset Markets

In order to avoid unit-root behavior in the equilibrium dynamics due to an exogenously given interest rate on incomplete international asset markets, a debt-elastic interest rate is introduced on international bonds. Then, under the assumption that foreign consumers exhibit an FOC on foreign borrowing similar to equation (A.5) and zero steady-state foreign debt, the change in domestic consumption of savers can be linked to foreign consumption in log-linearized form by

$$\mathbb{E}_t \Delta \hat{c}^s_{t+1} = \mathbb{E}_t \Delta \hat{c}^*_{t+1} + (1 - \alpha_c)\mathbb{E}_t \Delta \hat{s}_{c,t+1} + \lambda \tilde{b}_{f,t}, \tag{A.11}$$

where $\tilde{b}_{f,t}$ is the absolute deviation of foreign debt converted to domestic currency from its zero steady state and λ displays the intermediation cost parameter.

Aggregating budget constraints over both households, foreign debt evolves according to

$$\tilde{b}_{f,t} = \frac{1}{\beta_s}\tilde{b}_{f,t-1} + C(\hat{c}_t - \hat{y}_{c,t}) + q\delta D(\hat{\imath}_{d,t} - \hat{y}_{d,t}), \tag{A.12}$$

where log-deviations from steady-state production are given by $\hat{y}_{j,t}$, $\hat{\imath}_{d,t}$ represents log-deviations from steady-state durables investment, and C and $q\delta D$ depict steady-state values of real consumption in the nondurables and durables sector.

A.1.4 Aggregation

Aggregate goods market clearing of domestic production in both sectors requires

$$Y_{c,t}(k) = C_{h,t}(k) + \int_0^1 C^i_{h,t}(k)di \tag{A.13}$$

$$Y_{d,t}(k) = I_{d,h,t}(k) + \int_0^1 I^i_{d,t}(k)di. \tag{A.14}$$

Under the assumption of symmetric preferences across countries, taking into account the demand schedules of domestic and foreign households, as well as aggregate production in sector j in (6), a similar derivation as in Galí and Monacelli (2005) gives

$$\hat{y}_{c,t} = (1-\alpha_c)\hat{c}_t + \alpha_c\hat{c}^*_t + \vartheta_c\hat{s}_{c,t} \tag{A.15}$$

$$\hat{y}_{d,t} = (1-\alpha_d)\hat{\imath}_{d,t} + \alpha_d\hat{\imath}^*_{d,t} + \vartheta_d\hat{s}_{d,t}, \tag{A.16}$$

where $\vartheta_j = \zeta_j + \eta_j(1-\alpha_j)$. Thus, aggregate domestic production in sector j depends on changes in domestic and foreign consumption, but also on changes in the terms of trade.

Aggregate real output is given by $Y_t = \frac{P_{c,h,t}}{P_{h,t}}Y_{c,t} + \frac{P_{d,h,t}}{P_{h,t}}Y_{d,t}$, where the producer price index is defined as $P_{h,t} = (1-\tau)P_{c,h,t} + \tau P_{d,h,t}$, with τ being the steady-state share of housing in aggregate production. Aggregate production in log-linearized form can then be shown to follow

$$\hat{y}_t = \frac{C}{Y}\lambda_y\hat{y}_{c,t} + q\frac{\delta D}{Y}\lambda_y\hat{y}_{d,t}, \tag{A.17}$$

where $\lambda_y = [(1-\tau)+\tau q]^{-1}$.

Table A.1. Data and Sources

Variable	Description	Source
GDP	Quarterly GDP at market prices, chained 2010 year prices, seasonally adjusted	Bank of Korea (BoK)
REER	Real effective exchange rate, 2010 = 100 (↑: increase in competitiveness)	Bank for International Settlements (BIS)
R	Overnight interbank call rate	BoK
BB-MaPP	Borrower-based MaPP index	See appendix
HP	Real residential property price index, 2010 = 100, seasonally adjusted	BIS
HH Cred	Real credit to households (outstanding), deflated by CPI, seasonally adjusted	BIS
CPI	Consumer price index, 2010 = 100, seasonally adjusted	BoK
C	Real household consumption, chained 2010 year prices, seasonally adjusted	BoK
Res Inv	Real residential investment, chained 2010 year prices, seasonally adjusted	BoK

A.2 Creation of a BB-MaPP Index

The starting point for the creation of a BB-MaPP index is to calculate an average regulatory LTV and DSTI ratio for the sample period. Building on the work by Igan and Kang (2011) and Shim et al. (2013), table A.2 depicts all changes in these regulations, starting with the inception of a mandatory LTV ratio in October 2002. Overall, there have been 11 changes in the LTV ratio (seven tightening actions and four loosening actions) and 10 changes in the DSTI ratio (six tightening actions and four loosening actions).

Since most of these changes are subject to certain characteristics of the borrower, the type of loan, or the real estate purchased, a weighting scheme is introduced in table A.3. Some of the values are directly taken from Igan and Kang (2011), while others are compiled using data from the Korea Housing Finance Corporation and the Korean Statistical Information Service. The general idea is to have an individual LTV and DSTI ratio for each possible combination of the given characteristics in table A.3 and the weight thereof. Weights depict the situation in Korea before the inception

Table A.2. LTV and DSTI Regulation Changes in Korea

Date	Type	Regulation Change	Direction
10/2002	LTV	60% for banks and insurance companies	Inception
05/2003	LTV	50% for house purchases in speculative zone with loan maturity of less than three years for banks and insurance companies	Tightening
10/2003	LTV	40% for apartments in speculative zones with loan maturity of 10 years and less for banks and insurance companies	Tightening
03/2004	LTV	70% in all regions for loan maturities of more than 10 years and amortized payments for all institutions	Loosening
06/2005	LTV	40% for house purchases with value above 600 million won in speculative zones with loan maturity of 10 years and less for banks and insurance companies	Tightening
08/2005	DSTI	40% for house purchases in speculative zones for singles less than 30 years or married couples where the spouse is in debt for all institutions	Inception
03/2006	DSTI	40% for house purchases with value above 600 million won in speculative zones for all institutions	Tightening
11/2006	LTV	50% for house purchases with value above 600 million won in speculative zones for all institutions	Tightening
11/2006	DSTI	40% for house purchases in speculative zones for all institutions	Tightening
02/2007	DSTI	40% to 60% for house purchases with value less than 600 million won for banks	Tightening
08/2007	DSTI	40% to 70% for nonbank financial institutions	Tightening
11/2008	LTV DSTI	All areas except the three Gangam districts removed from list of speculative zones	Loosening
07/2009	LTV	50% for house purchases with value above 600 million won in metropolitan area for banks	Tightening
09/2009	DSTI	40% for the three Gangam districts removed from the list of speculative zones, 50% for nonspeculative zones in Seoul, 60% for other metropolitan area for banks	Tightening
10/2009	LTV	Expand regulation to metropolitan area for all institutions	Tightening
08/2010	DSTI	Exemption of house purchases in nonspeculative zone in metropolitan area if debtor owns less than two houses for all institutions (until end of March 2011)	Loosening
05/2012	LTV DSTI	Three Gangam restricts removed from the list of speculative zones	Loosening
08/2014	LTV DSTI	70% LTV ratio and 60% DSTI ratio (unification)	Loosening

Table A.3. Weighting Scheme for BB-MaPP Index

	Loan Characteristic	Weight
Institution	Banks and insurance companies	0.80
	Nonbanks	0.20
Region	Seoul metropolitan area	0.48
	Nonmetropolitan area	0.52
Region 2	Speculative area (weight within Seoul metr. area)	0.70
	Nonspeculative area (weight within Seoul metr. area)	0.30
Maturity	Loan maturity $<$ 3 years	0.40
	Loan maturity 3–10 years	0.20
	Loan maturity $>$ 10 years	0.40
House Price	$<$ 600 million won	0.90
	$>$ 600 million won	0.10
House Type	House	0.50
	Apartment	0.50
Loan Type	Amortized payment	0.40
	Balloon payment	0.60
Age	$<$ 30 years and single and/or spouse in debt	0.15
	None of the above	0.85

Sources: Korea Housing Finance Corporation, Korean Statistical Information Service, Igan and Kang (2011).

of BB-MaPP measures in 2002, when possible, to avoid endogeneity problems. As a convention, LTV and DSTI ratios are set to 75 percent when no mandatory values are introduced.

In order to make LTV and DSTI ratios comparable, the min-max principle is used, where

$$LTV_t^{ind} = 1 - \frac{LTV_t - LTV_{min}}{LTV_{max} - LTV_{min}} \quad \text{and}$$

$$DSTI_t^{ind} = 1 - \frac{DSTI_t - DSTI_{min}}{DSTI_{max} - DSTI_{min}}$$

such that both indexes lie between zero and one, and a higher index is equivalent to a tighter regulation. Then, both indexes are combined by equal weighting so that the final borrower-based macroprudential index is given by

$$\text{BB-MaPP}_t^{ind} = 0.5 \cdot LTV_t^{ind} + 0.5 \cdot DSTI_t^{ind}.$$

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