An Estimated DSGE Model with a Housing Sector for the Czech Economy

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Abstract

This paper uses an estimated DSGE model with an explicit housing sector to analyse the role of the housing sector and housing collateral for business cycle fluctuations in the Czech economy. The baseline results show that the development in the housing market has negligible effect on the rest of the economy. Counterfactual experiments indicate that the spill-overs increases with looser credit standards, if banks provide loans for higher value of houses. Similarly, with the higher loan-to-value ratios the transmission mechanism of monetary policy also seems to strengthen, with the key rates having bigger influence on the consumption and output. Looking at the development in house prices, the recent boom and bust is found to have been caused primarily by housing preference shocks (demand side shocks). Supply shocks are also found to have been significant, but to a much lesser extent.

Keywords	***JEL code***
Housing, loan-to-value ratio, DSGE model, collateral constraint, Bayesian estimation	*E37*

INTRODUCTION

The development of the housing market in recent years has attracted widespread attention, especially in the U.S., where it was considered to be a major trigger for the financial crisis. Even if the housing sector represents a relatively small part of the economy, it can have large impacts on macroeconomic variables. Compared to U.S. the situation in the Czech Republic was not so severe, but the connection between the housing market and the macroeconomy still deserves a detailed examination. Another motivation is recent announcement of the Czech National Bank (2014) about possibility of regulation of mortgage loans. Hence, the goal of this empirical paper is to offer a quantitative assessment of the links between the housing (or real estate) sector and the rest of the economy. Specifically, I focus on two issues. First, I intend to find out what impacts housing specific shocks have on the rest of the economy, and which other (non-housing) shocks have an impact on housing sector variables. Second, with regard to the influence of housing collateral on the monetary policy transmission mechanism, I aim to quantify the effects of changes in loan-to-value ratio for the ability of monetary policy to influence macroeconomic variables. Thus the paper also contributes to the debate about

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macroprudential monetary policy, concretely about setting limits on loan-to-value ratio.[2] The approach relies on an estimation of a DSGE model with housing sector using Czech data and Bayesian techniques. In order to answer the research questions, I perform several quantitative exercises using impulse responses and variance and shock decompositions.

The results show that there is no tight connection between the housing sector and the rest of the economy. Housing sector shocks (both demand and supply) do not spill over to the rest of the economy much, and thus their implications for macroeconomic variables can be considered to be quantitatively negligible. Moreover, housing sector variables are mostly driven only by housing sector shocks. Booms and busts in house prices are caused primarily by housing preference shocks (demand side shocks); productivity shocks originating in the housing sector contribute only partly, as does the non-housing supply shock. On the other hand, the housing collateral effect on the monetary policy transmission mechanism appears to be quite strong, especially for high loan-to-value ratio values. If households have better access to credit, the impact of monetary policy on consumption and output is substantially increased, while its impact on inflation is only moderately changed. Similarly, a higher loan-to-value ratio amplifies the spill-overs of housing preference shocks to macroeconomic variables, especially consumption and inflation. Hence, this result could justify the macroeconomic policy of setting caps on loan-to-value ratio in order to prevent negative impacts from development in the housing sector.

The rest of this paper is organized as follows: Section 2 introduces literature in the field of housing issues, Section 3 describes the structure of the model, Section 4 briefly comments on the data and estimation technique; the results of the estimation are presented in Section 5, and dynamical properties are discussed in Section 6; the final section concludes.

1 LITERATURE REVIEW

There is some empirical literature on the development of house prices in the Czech Republic. Most papers examine the relationship between fundamentals and house prices, some focus on under/over-valuation in real estate prices. These studies use econometric techniques and are aimed both at the Czech Republic (e.g. Zemčík (2011), Hlaváček and Komárek (2007)), and at a broader group of countries (as in Egert and Mihaljek (2008) or Posedel and Vízek (2011)). Brůha et al. (2013) examined the impact of housing prices on the financial position of households using microeconomic data and statistical methods.

My approach is different and uses a DSGE model.[3] The particular model comes from Iacoviello and Neri (2010) who applied it to the US economy. There are also many other papers that use DSGE models with the housing market and financial frictions: Iacoveillo (2005) developed a model for the U.S., Walentin (2014) estimated a model for Sweden, Aoki et al. (2004) for the UK, Roeger and in't Veld (2009) used a calibrated model for the EU, and Christensen et al. (2009) estimated a small open economy model for Canada.

The model from Iacoviello and Neri (2010) is a closed economy model, which might be considered a crude approximation for the Czech economy. However, one can learn important lessons even from such a model. Closed economy models were successfully estimated and analysed for the U.S. economy and Sweden – both of which are open economies. Furthermore, houses are non-tradable goods, and thus housing demand and housing supply are primarily determined by local forces; any influence from abroad is only indirect. Tonner and Brůha (2014) implement elements from Iacoviello and Neri (2010) into a calibrated forecasting model of the Czech National Bank. Their approach is slightly different from my research questions here, but they also

2 See Galati and Moessner (2011) for a literature review on macroprudential policy and Borio et al. (2001) for a discussion of practises in setting limits on loan-to-value ratio. Zamrazilová (2014) discusses unconventional monetary policy practises used by FED and ECB, Mandel and Tomšík (2014) examine alternative tools for the policy of the Czech National Bank.

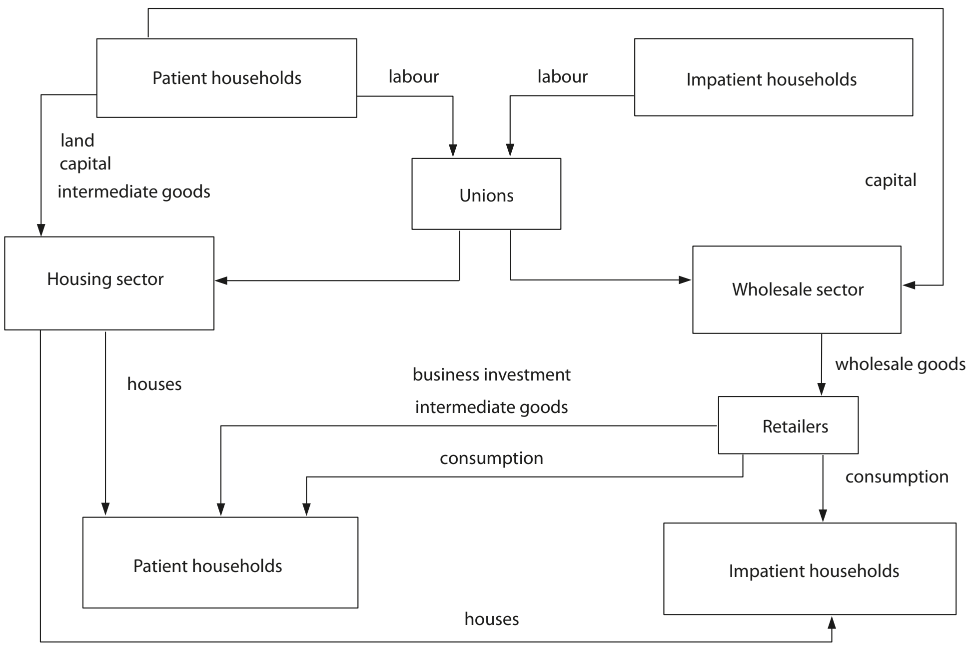
3 Dynamic Stochastic General Equilibrium models. For detailed exposition of DSGE models see e.g. Galí (2008), Woodford (2003) or Walsh (2010).

find a weak relationship between the housing sector and the aggregate economy. Thus, modelling the Czech economy as a closed economy can be regarded as reasonable approximation.

2 MODEL

The model is borrowed from Iacoviello and Neri (2010) and ranks among medium-scale models. This model contains financial friction in the form of collateral constraint. This mechanism originates from Kiyotaki and Moore (1997), and was further elaborated in Iacoviello (2005), who used houses instead of land as collateral. Here, I describe only the main behavioural equations of the model; more detailed exposition is quoted in the online Appendix (available at the website of this journal, see the online version of the *Statistika: Statistics and Economy Journal* No. 4/2016 at: <http://www.czso.cz/statistika_journal>). Figure 1 provides basic orientation in the model structure.

Figure 1 Model structure



Source: Author based on model of Iacoviello and Neri (2010)

2.1 Households

There are two types of households: patient (lenders) and impatient (borrowers). Patient households work, consume and accumulate housing. They also own capital and land, and supply funds to firms and to impatient households. Their utility function is:

$$E_0 \sum_{t=0}^{\infty} (\beta G_C)^t z_t \left(\Gamma_c \ln(c_t - \varepsilon c_{t-1}) + j_t \ln h_t - \frac{\tau_t}{1+\eta} \left(n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi} \right)^{\frac{1+\eta}{1+\xi}} \right), \tag{1}$$

where $c_t, h_t, n_{c,t}, n_{h,t}$ are consumption, housing, worked hours in the consumption sector and worked hours in the housing sector. β is discount factor, ε is habit in consumption, $\xi, \eta \geq 0$ are elasticities of substitution of worked hours in those two sectors. z_t, j_t and τ_t are shock to intertemporal preferences, housing preference shock and shock to labor supply, all modelled as AR(1) processes. G_c is the growth rate of consumption along the balanced growth path. The scaling factor $\Gamma c = (G_C - \varepsilon)/(G_C - \beta\varepsilon G_C)$ ensure that the marginal utility of consumption is $1/c$ in the steady state.

Budged constraint (in real terms) for patient households is:

$$
\begin{aligned}
& c_t + \frac{k_{c,t}}{A_{k,t}} + k_{h,t} + k_{b,t} + q_t h_t + p_{l,t} l_t - b_t = \frac{w_{c,t} n_{c,t}}{X_{wc,t}} + \frac{w_{h,t} n_{h,t}}{X_{wh,t}} \\
& + \left(R_{c,t} z_{c,t} + \frac{1-\delta_{kc}}{A_{k,t}} \right) k_{c,t-1} + \left(R_{h,t} z_{h,t} + 1 - \delta_{kh} \right) k_{h,t} + p_{b,t} k_{b,t-1} - \frac{R_{t-1} b_{t-1}}{\pi_t} \\
& + (p_{l,t} + R_{l,t}) l_{t-1} + q_t (1-\delta_h) h_{t-1} + Div_t - \phi_t - \frac{a(z_{c,t}) k_{c,t-1}}{A_{k,t}} - a(z_{h,t}) k_{h,t-1} \, .
\end{aligned} \tag{2}
$$

Patient households choose consumption c_t, capital in the consumption sector $k_{c,t}$ and housing sector $k_{h,t}$, amount of intermediate goods $k_{b,t}$ (priced at $p_{b,t}$) in the housing sector, housing h_t (priced at q_t), land l_t, (priced at $p_{l,t}$), hours in consumption and housing sector $n_{c,t}$ and $n_{s,t}$, capital utilization rates $z_{c,t}$ and $z_{h,t}$ and borrowing b_t (loans if b_t is negative) to maximize utility function (1) subject to the budget constraint (2). $A_{k,t}$ is investment--specific technology shock which represents the marginal cost of producing capital used in the non-housing sector. Loans are set in nominal terms and yield a riskless nominal return R_1. Real wages are denoted by $w_{c,t}$ and $w_{h,t}$, real rental rates by $R_{c,t}$ and $R_{h,t}$ and depreciation rates by δ_{kc} and δ_{kh}. The terms $X_{wc,t}$ and $X_{wh,t}$ denote markup between the wage paid by the wholesale firm and wage paid to the households by labour unions. $\pi_t = P_t/P_{t-1}$ is inflation rate in the consumption sector, Div_t are lump-sum profits from final goods firms and from labor unions, ϕ_t denotes total convex adjustment costs for capital and $a(.)$ is the convex cost of setting capital utilization rate z.

Impatient households also consume, work and accumulate housing and their utility function is similar to that of patient households:[4]

$$
E_0 \sum_{t=0}^{\infty} (\beta' G_C)^t z_t \left(\Gamma_{c'} \ln(c_t' - \varepsilon' c_{t-1}') + j_t \ln h_t' - \frac{\tau_t}{1+\eta} \left((n_{c,t}')^{1+\xi'} + (n_{h,t}')^{1+\xi'} \right)^{\frac{1+\eta'}{1+\xi'}} \right). \tag{3}
$$

However, they do not accumulate capital and do not own finished-goods producing firms or land (their dividends come only from labor unions). Their budget constraint is as follows:

$$
c_t' + q_t h_t' - b_t' = \frac{w_{c,t}' n_{c,t}'}{X_{wc,t}'} + \frac{w_{h,t}' n_{h,t}'}{X_{wh,t}'} + q_t (1-\delta_h) h_{t-1}' - \frac{R_{t-1} b_{t-1}'}{\pi_t} + Div_t'. \tag{4}
$$

The impatient households are credit constrained and use their houses as collateral for loans. Their maximum borrowing b_t' is given by the expected present value of their home times the loan-to-value (LTV) ratio:

$$
b_t' \le m E_t \left(\frac{q_{t+1} h_t' \pi_{t+1}}{R_t} \right). \tag{5}
$$

[4] The variables of impatient households are denoted with apostrophe ('), the meaning is the same as in case of patient households.

This setting implies that variation in housing values shifts the borrowing constraint and thus affects their borrowing capacity and spending. There is also another channel for propagation of financial shocks into the real part of the economy: the debt-deflation effect. Debt is quoted in nominal terms,[5] which is based on empirical grounds from low-inflation countries. The transmission mechanism then works as follows: positive demand shock increases the price of assets (housing), which increases the borrowing capacity of constrained households and allows them to spend more. The rise in prices reduces the real value of their debt obligations, which further increases value of their net worth. Borrowers have a higher propensity to spend than lenders, and thus net demand is positively affected. This mechanism, connected to housing wealth, works as an accelerator of demand shocks.

2.2 Firms

The production side of the model economy is divided into two sectors with different rates of technological progress. The firms hire labor and capital services and buy intermediate goods from households to produce wholesale goods Y_t and new houses IH_t. Their optimization problem is:

$$\max \frac{Y_t}{X_t} + q_t IH_t - \left(\sum_{i=c,h} w_{i,t} n_{i,t} + \sum_{i=c,h} w_{i,t}' n_{i,t}' + \sum_{i=c,h} R_{i,t} z_{i,t} k_{i,t-1} + R_{l,t} l_{t-1} + p_{b,t} k_{b,t} \right), \tag{6}$$

subject to the production functions:

$$Y_t = \left(A_{c,t} \left(n_{c,t}^{\alpha} n_{c,t}'^{\,1-\alpha} \right) \right)^{1-\mu_c} \left(z_{c,t} k_{c,t-1} \right)^{\mu_c} \tag{7}$$

$$IH_t = \left(A_{h,t} \left(n_{h,t}^{\alpha} n_{h,t}'^{\,1-\alpha} \right) \right)^{1-\mu_h-\mu_b-\mu_l} \left(z_{h,t} k_{h,t-1} \right)^{\mu_h} k_{b,t}^{\mu_b} l_{t-1}^{\mu_l}. \tag{8}$$

The wholesale good is produced using technology (7) with labor and capital inputs only. New houses IH_t are produced using technology (8) with labour, capital, land and the intermediate input k_b. The terms $A_{c,t}$ and $A_{h,t}$ denotes productivity in the non-housing and housing sector. Parameter α measures labor income share of patient households.

2.3 Retailer and labour unions

There are nominal wage rigidities in both housing and non-housing sectors, and price rigidity in the retail sector. The rigidities come from the existence of labour unions and retailers that have some market power and can influence setting of the wages and prices. The rigidities are modelled in Calvo (1983) style with partial indexation to previous inflation. Optimization problem of the retailers results in hybrid New Keynesian Phillips curve:

$$\ln \pi_t - \iota_\pi \ln \pi_{t-1} = \beta G_C (E_t \ln \pi_{t+1} - \iota_\pi \ln \pi_t) - \frac{(1-\theta_\pi)(1-\beta G_C \theta_\pi)}{\theta_\pi} \ln(X_t / X) + u_{p,t}, \tag{9}$$

where X_t is a markup over marginal cost, X is the steady state markup, θ_π is the fraction of firms that cannot change the price every period and index it to previous inflation with elasticity ι_π, and $u_{p,t}$ is cost-push shock. Wage setting is analogous to price setting and the optimization problem of labor unions results in four wage Phillips curves (for each type of household in each production sector) that are similar to equation (9).

[5] Expression $R_{t-1} b_{t-1}' / \pi_t$ in equation (4).

2.4 Monetary authority

Monetary authority sets the interest rate R_t according to (linearized) monetary rule with response to past interest rate, inflation and output growth:

$$R_t = r_R\ R_{t-1} + (1-r_R)[r_\pi \pi_t\ + r_Y(y_t - y_{t-1}) + \overline{rr}] + u_{R,t} - s_t\ , \tag{10}$$

where $\overline{rr}$ is the steady-state real interest rate, $u_{R,t}$ is monetary policy shock and s_t is shock to inflation target.[6]

2.5 Market clearing and equilibrium condition

The non-housing sector produces consumption, business investment and intermediate goods. The housing sector produces new houses that are added to existing stock. The equilibrium conditions for product market and housing market are:

$$C_t + IK_{c,t}/A_{k,t} + IK_{h,t} + k_{b,t} = Y_t - \phi_t \tag{11}$$

$$H_t - (1-\delta_h)H_{t-1} = IH_t\ , \tag{12}$$

where $C_t = c_1 + c_t'$ is aggregate consumption, $H_t = h_1 + h_t'$ is aggregate stock of housing, and $IK_{c,t} = k_{c,t} - (1-\delta_{kc})\ k_{c,t-1}$ and $IK_{h,t} = k_{h,t} - (1-\delta_{kh})\ k_{h,t-1}$ are two components of business investment.

2.6 Growth rates

The technological progress is allowed to be different across the sectors. The net growth rates of technology in housing sector ($A_{h,t}$), consumption goods sector ($A_{c,t}$) and investment goods sectors ($A_{k,t}$) are denoted as $\gamma_{A,H}$, $\gamma_{A,C}$ and $\gamma_{A,K}$, respectively. Growth rates of the real variables along balanced growth path are then determined by:

$$G_C = G_{IK_h} = G_{q \times IH} = 1 + \gamma_{AC} + \frac{\mu_c}{1-\mu_c}\gamma_{AK} \tag{13}$$

$$G_{IK_c} = 1 + \gamma_{AC} + \frac{1}{1-\mu_c}\gamma_{AK} \tag{14}$$

$$G_{IH} = 1 + (\mu_h + \mu_b)\gamma_{AC} + \frac{\mu_c(\mu_h + \mu_b)}{1-\mu_c}\gamma_{AK} + (1-\mu_h-\mu_l-\mu_b)\gamma_{AH} \tag{15}$$

$$G_q = 1 + (1-\mu_h-\mu_b)\gamma_{AC} + \frac{\mu_c(1-\mu_h-\mu_b)}{1-\mu_c}\gamma_{AK} + (1-\mu_h-\mu_l-\mu_b)\gamma_{AH}\ . \tag{16}$$

The trend growth rates of $IK_{h,t}$, $IK_{h,t}/A_{k,t}$ and $q_t IH_t$ are all equal to the trend growth rate of real consumption G_c. Business investment G_{IK_c} grows faster than consumption, as long as $\gamma_{A,K} > 0$ and the trend growth rate in real house prices G_q offsets differences in the productivity growth between the consumption, G_c, and the housing sector G_{IH}. The equilibrium model equations are linearized around balanced growth path before the estimation.

3 DATA AND ESTIMATION

The model is estimated using the data for the following model variables: consumption (C_t); residential investment (IH_t); non-residential investment (IK_t); real house prices (q_t); inflation (π_t); nominal interest rate (R_t); hours worked and wage inflation in housing (NH_t,Wh_t) and in the wholesale sector (NC_t, WC_t). I use quarterly data from the Czech Statistical Office and Czech National Bank databases for the period 1998:Q1–2013:Q2.

[6] This shock is quite suitable for the Czech economy because during the period used for estimation the Czech National Bank changed the targeting variable once (net inflation to headline CPI inflation) and adjusted the targeting band several times.

The beginning of the sample period was determined by the availability of data on house prices, the ending of the sample was chosen with the aim to avoid complications with zero lower bound on interest rates. Time series for C_t, IH_t, IK_t and q_t are in levels and are assumed trend stationary; the trend is estimated within the model. Other time series are demeaned.[7] As the data for the labour market in the housing sector (NH_t,WH_t) might not be very reliable, measurement error for these two series was added.

Some of the model parameters are calibrated according to Iacoviello and Neri (2010) and data from national accounts.[8] One of the calibrated parameters important for the analysis is loan-to-value ratio (LTV). Iacoviello and Neri (2010) calibrate LTV ratio to 0.85 for United States; the same value uses Walentin (2014) for Sweden while Christensen et al. (2009) calibrate it to 0.80. There is not much of empirical evidence about the value of this parameter for the Czech economy. Hloušek (2012) reports estimates of LTV ratios from DSGE model with both constrained households and entrepreneurs. His estimate for households is 0.79 and for entrepreneurs 0.51. Therefore, I set loan-to-value ratio to m = 0.75, taking into account that only constrained households are in the present model and also given the fact that the Czech mortgage market is less developed.

The rest of the model parameters were estimated using Bayesian techniques. The posterior distribution of the parameters was obtained using the Random Walk Chain Metropolis-Hastings algorithm. 1 000 000 draws in two chains with 500 000 replications each were generated, and 80% of replications were discarded so as to avoid influence of initial conditions and to calculate moments of posterior distribution from the draws of converged chains. The convergence was verified using MCMC diagnostics. All computations were carried out using Dynare toolbox (Adjemian et al., 2011).

4 ESTIMATION RESULTS

This section discusses the results of the estimation and examines the behaviour of the model. Table 1 shows prior means, standard deviations and posterior means together with 95% probability intervals for selected estimated deep parameters.[9] The priors for the parameters are mostly set according to the Iacoviello and Neri (2010) as their model exhibits some non-standard features (e.g. labour share of unconstraint households). Many other priors are quite standard in DSGE literature and are also commonly used in empirical studies for the Czech economy. Among those, only the prior mean for capital adjustment cost is set to a lower value of 5 (instead of 10) with reference to Slanicay (2013).

Parameters ε and ε' represent habit formation in consumption, for patient and impatient households respectively. The posterior mean of ε (0.42) is lower than the posterior mean of ε' (0.52). On average, these numbers indicate quite a weak habit in consumption. Typical values obtained for the Czech economy are usually much higher, around 0.8 (see e.g. Slanicay, 2013). Capital adjustment cost is more important in the consumption goods sector; the mean of the parameter $\phi_{k,c}$ is much higher than the prior, and is higher than its counterpart in housing sector, parameter $\phi_{k,h}$. The labour income share of constrained households ($1–\alpha$) was estimated at 0.28. This is slightly higher than the values found in empirical studies for the U.S. economy (0.21) or Sweden (0.18); see Iacoviello and Neri (2010) and Wallentin (2014).

A much higher estimate was obtained by Hloušek (2012) for the Czech economy (0.55) and Christensen et al. (2009) for Canada (0.38). However, these latter two papers used a different model structure. Estimated

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[7] The exception is nominal interest rate, which was detrended using the Hodrick-Prescott filter to obtain more easily interpretable data series. The time series for interest rate exhibits a visible decreasing trend. If it were to be demeaned, the interest rate would be below "equilibrium" level for almost the whole period from 2002–2013 (with a brief exception in 2008), which might not correspond to the view of the Czech National Bank at the time.

[8] For full set of calibrated parameters, see online Appendix (available at the website of this journal, see the online version of the *Statistika: Statistics and Economy Journal* No. 4/2016 at: <*http://www.czso.cz/statistika_journal*>).

[9] Results for other parameters and shocks are quoted in online Appendix (available at the website of this journal, see the online version of the *Statistika: Statistics and Economy Journal* No. 4/2016 at: <*http://www.czso.cz/statistika_journal*>).

values of Calvo parameters indicate that price and wage rigidities are almost equally important. This is in contrast to empirical studies for the Czech economy revealing that wages were more rigid than prices, e.g. Hloušek and Vašíček (2007) or Andrle et al. (2009). Again, the different sector structures of the models could explain this phenomenon. Parameters in the Taylor rule show that the Czech National Bank pays great attention to interest rate smoothing, $r_R = 0.91$, and to output growth, $r_Y = 0.23$. Even if the prior mean for r_Y was set to 0, which corresponds to strict inflation targeting, the information in the data was stronger. On the other hand, the posterior mean of the parameter of inflation $r_\pi = 1.34$ is slightly lower than the mean of the prior, which is usually used in calibrated models.

Table 1 Prior and posterior distribution of structural parameters

Parameter	Prior distribution			Posterior distribution		
	Density	Mean	S.D.	Mean	2.5%	97.5%
Habit formation						
ε	beta	0.50	0.08	0.42	0.33	0.52
ε'	beta	0.50	0.08	0.52	0.38	0.65
Capital adjustment cost						
$\phi_{k,c}$	gamma	5.00	2.50	9.10	0.09	10.97
$\phi_{k,h}$	gamma	5.00	2.50	4.58	1.76	7.34
Labour income share						
α	beta	0.65	0.05	0.72	0.65	0.80
Taylor rule						
r_R	beta	0.75	0.10	0.91	0.89	0.93
r_π	normal	1.50	0.10	1.34	1.17	1.50
r_Y	normal	0.00	0.10	0.23	0.09	0.37
Calvo parameters						
θ_π	beta	0.67	0.05	0.73	0.67	0.79
$\theta_{w,c}$	beta	0.67	0.05	0.76	0.72	0.80
$\theta_{w,h}$	beta	0.67	0.05	0.69	0.62	0.75
Technology growth rates						
$100\,\gamma_{AC}$	normal	0.50	1	0.41	0.37	0.46
$100\,\gamma_{AH}$	normal	0.50	1	– 0.53	– 0.95	–0.09
$100\,\gamma_{AK}$	normal	0.50	1	0.10	0.05	0.14

Source: Author's calculations

The estimated parameters of technology growth rates (γs) can be used to compute trends of the model variables.[10] The quarterly growth rates for consumption (G_C), business investment (G_{IK}), residential investment (G_{IH}) and real house prices (G_Q) are 0.46, 0.56, –0.28 and 0.74, respectively. The simple univariate trend calculated on data delivers the following slopes: 0.63, 0.78, –0.38 and 1.44. The model captures a relative relation between growth rates of the variables ($G_{IH} < G_C < G_{IK} < G_Q$) but fails to capture its magnitude. The model under-predicts growth in consumption, business investment and especially house prices. The reason for this is that the growth rates in the model are mutually connected because of the existence of a balanced growth path, but the growth rate in the data may be influenced by structural changes. To return to the model, the steep trend in house prices was mainly caused by negative technological progress in the housing sector.

[10] Equations (13) to (16).

The model fit on the data was evaluated by comparison of moments calculated from the data, and moments obtained from model simulations. One can argue that the empirical performance of the model is acceptable.[11]

To provide answers to the research questions various methods are used. Comparison of impulse responses for different model specifications is a key tool for examining the effects of housing collateral in the monetary policy transmission mechanism. The relationship between the housing sector and the rest of the economy is studied by variance decomposition of forecast errors, while historical shock decomposition is used to identify the shocks behind developments in real house prices.

4.1 Impulse Response Analysis

This section examines the behaviour of the model in reaction to shocks under different loan-to-value ratio assumptions. First, we will focus on an interpretation of impulse responses, and then we will carry out a quantitative assessment of the transmission mechanism.

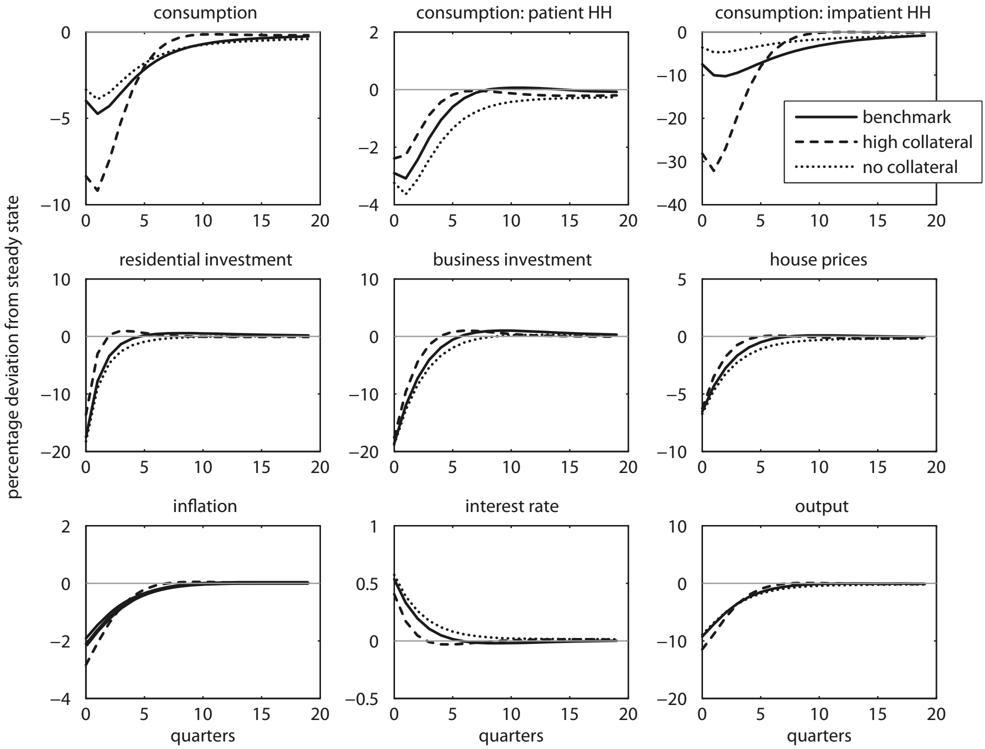
Figure 2 shows the reaction of the model variables to a monetary policy shock – the increase of nominal interest rate by one percentage point. The y-axis measures percentage deviation from the steady state; the reaction of the benchmark model is depicted by a solid line. A temporary increase in the nominal interest rate causes a drop in inflation by 2%; output decreases by as much as 9%, and house prices by 6%. Both types of investment decrease by roughly the same amount; however, residential investment returns faster. The decrease in investment is larger than that in output, which is, in turn, larger than in consumption. The reaction in consumption is hump-shaped, with a trough in the second period following the shock, and is long-lasting, with return after fifteen quarters. The consumption drop is driven primarily by the consumption of impatient (credit constrained) households: the fall in consumption is three times larger for impatient households than for patient households. This is for two reasons: first, collateral constraint becomes tighter because of the fall in house prices; second, there is the Fisher debt-deflation effect – an unexpected fall in inflation increases ex--post real interest rate, and thus results in an increased real debt burden. Therefore, wealth is transferred from borrowers to savers.

Figure 2 also shows the reaction of variables for other versions of the model. In all three specifications the estimated parameters are kept at their posterior means. In the benchmark model the loan-to-value ratio (parameter) is calibrated to 0.75, in the "high collateral" model it is 0.95, which means that constrained households are in a better position to obtain a loan; in the "no collateral" specification, the LTV is set to 0.0001, which means that houses are not collateralizable and impatient households are excluded from the financial market.

The reactions of the model variables for all three specifications are qualitatively identical but differ in magnitude, especially for consumption and output. Table 2 summarizes these findings. Each row shows the difference at trough of impulse responses for the corresponding variable between the specifications. The presence of collateral constraint (first row) does not produce much difference. However, an increase of LTV ratio from 0.75 to 0.95 (second row) causes a bigger drop in consumption by 4.5 and in output by 2.2 percentage points. On the other hand, the impact for inflation is quantitatively small (0.68 p.p.). Figure 3 shows the amplitude of the impulse responses in reaction to the LTV ratio (up to =0.95). This figure documents the fact that effect of LTV ratio is non-linear: a marginal increase at high values of LTV causes a much higher drop in all variables than a marginal increase at lower values of LTV. The results of this exercise lead to two conclusions: (i) monetary policy shocks are amplified when collateral effect is present and LTV ratio is high, and (ii) the impact for real variables such as consumption and output is much larger than the impact for inflation. Thus, restrictive monetary policy aimed at reducing inflation may result in large drops in real variables, when the LTV ratio is high. These results are in line with the findings of Walentin (2014) for the Swedish economy.

[11] For details see the online Appendix (available at the website of this journal, see the online version of the *Statistika: Statistics and Economy Journal* No. 4/2016 at: <*http://www.czso.cz/statistika_journal*>).

Figure 2 Impulse responses to monetary policy shock



Source: Author's construction

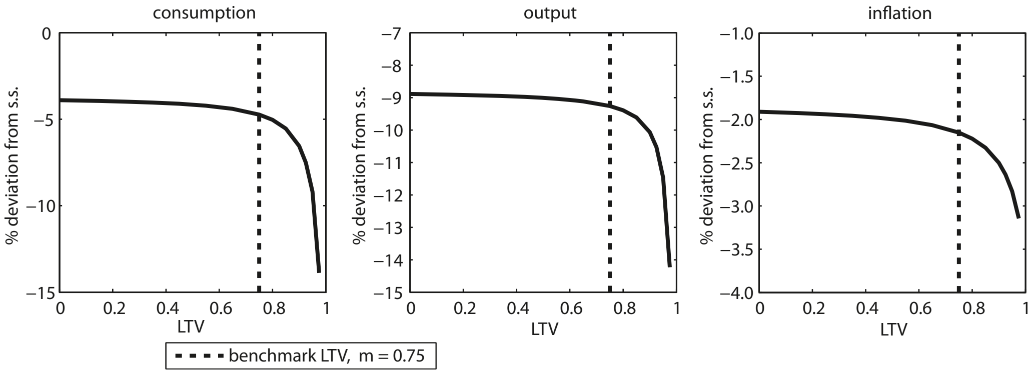
Figure 4 shows a reaction to housing preference shocks that can be interpreted as an increase in demand for housing. This shock causes a very persistent increase in house prices. Since houses serve as collateral for constrained households, any raise in their price increases the households' borrowing capacity and thus their spending. Given the higher propensity of borrowers to consume, the overall impact on aggregate consumption is positive, even if consumption of unconstrained households (savers) falls. Both residential and business investment increase and so does output. Inflation also increases, and the central bank raises the interest rate in order to bring the economy back to steady state. Subsequently, the reaction of the economy to this shock is in line with the results of Walentin (2014) for the Swedish economy, where business investment also rises while it was found to decline for the U.S., as reported by Iacoviello and Neri (2010). Looking at other model specifications, the model with high LTV ratio ($m = 0.95$) produces qualitatively similar results but much larger deviations e.g. for consumption and inflation. On the other hand, when collateral constraint is switched off,

Table 2 Effect of collateral constraint on amplitude of impulse response to monetary policy shock (difference between IRFs at trough in percentage points)

	Consumption	Output	Inflation
IRF no collateral ($m = 0$) – IRF benchmark ($m = 0.75$)	0.84	0.37	0.24
IRF benchmark ($m = 0.75$) IRF high LTV ($m = 0.95$)	4.45	2.20	0.68

Source: Author's calculations

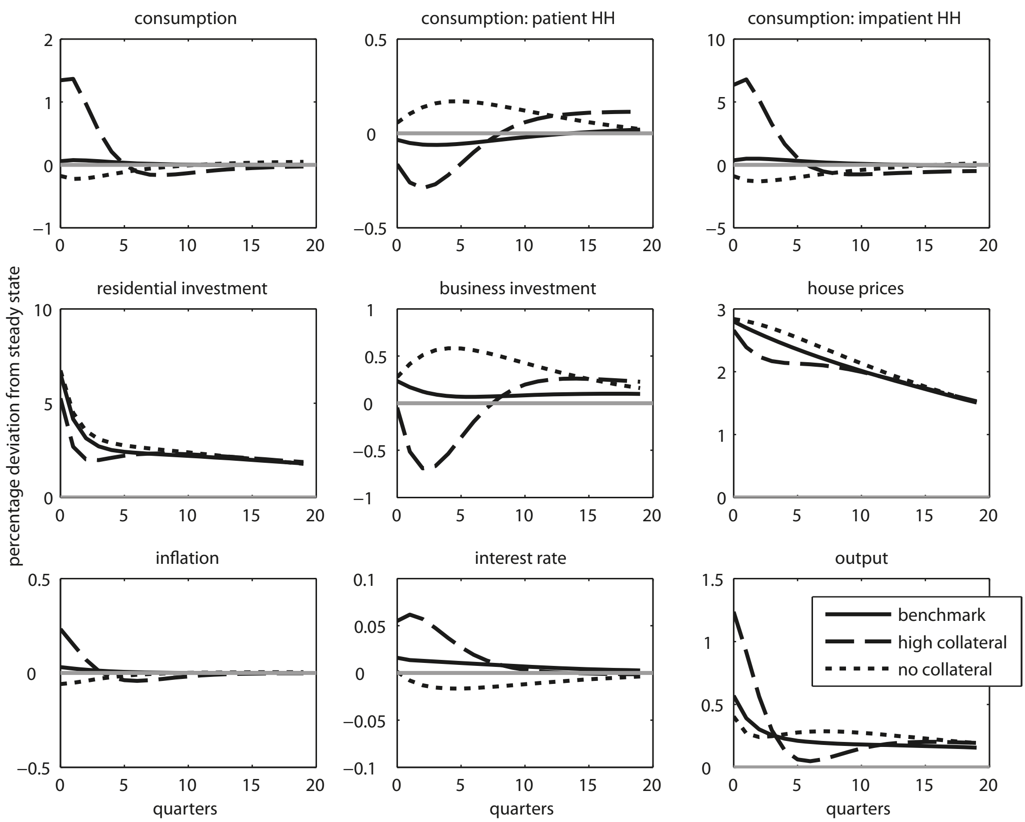
Figure 3 Effect of different LTV on amplitude of impulse responses to monetary policy shock



Source: Author's construction

the reaction of consumption, inflation and interest rate is the very opposite. However, this last model prediction contradicts the empirical evidence. Using the VAR model estimated on Czech data, Hloušek (2012) found that there is a positive co-movement of consumption and house price in response to house price shock.

Figure 4 Impulse responses to housing preference shock

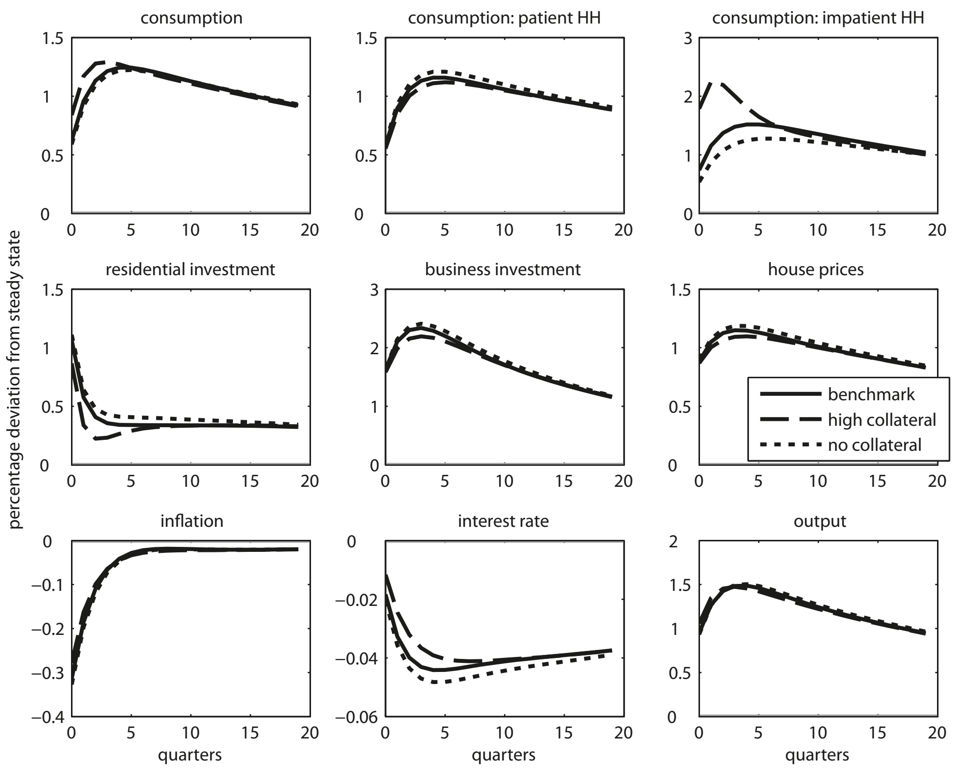


Source: Author's construction

Iacoviello (2005) obtained similar results for the United States. Therefore, the collateral effect is a necessary feature of the model for it to show a positive response in consumption to the house price shock, as is evident in the data.

Figure 5 shows the reaction of the variables to consumption goods technology shock. This shock results in cheaper production of consumption goods; therefore, inflation decreases, whilst consumption increases. Both types of investment increase, and thus output also increases. However, the drop in inflation is more significant than the rise in output and so the central bank lowers the interest rate. This shock is quite persistent and the deviation of the variables from steady state is thus long-lasting. There are only slight differences across the specifications. Collateral effect is not important here because this shock causes opposite reactions in house prices and inflation, and the amplification mechanism is dampened. The rise in house prices increases impatient households' borrowing capacity, while the decrease in inflation increases the real interest rate and causes a negative income effect for borrowers.

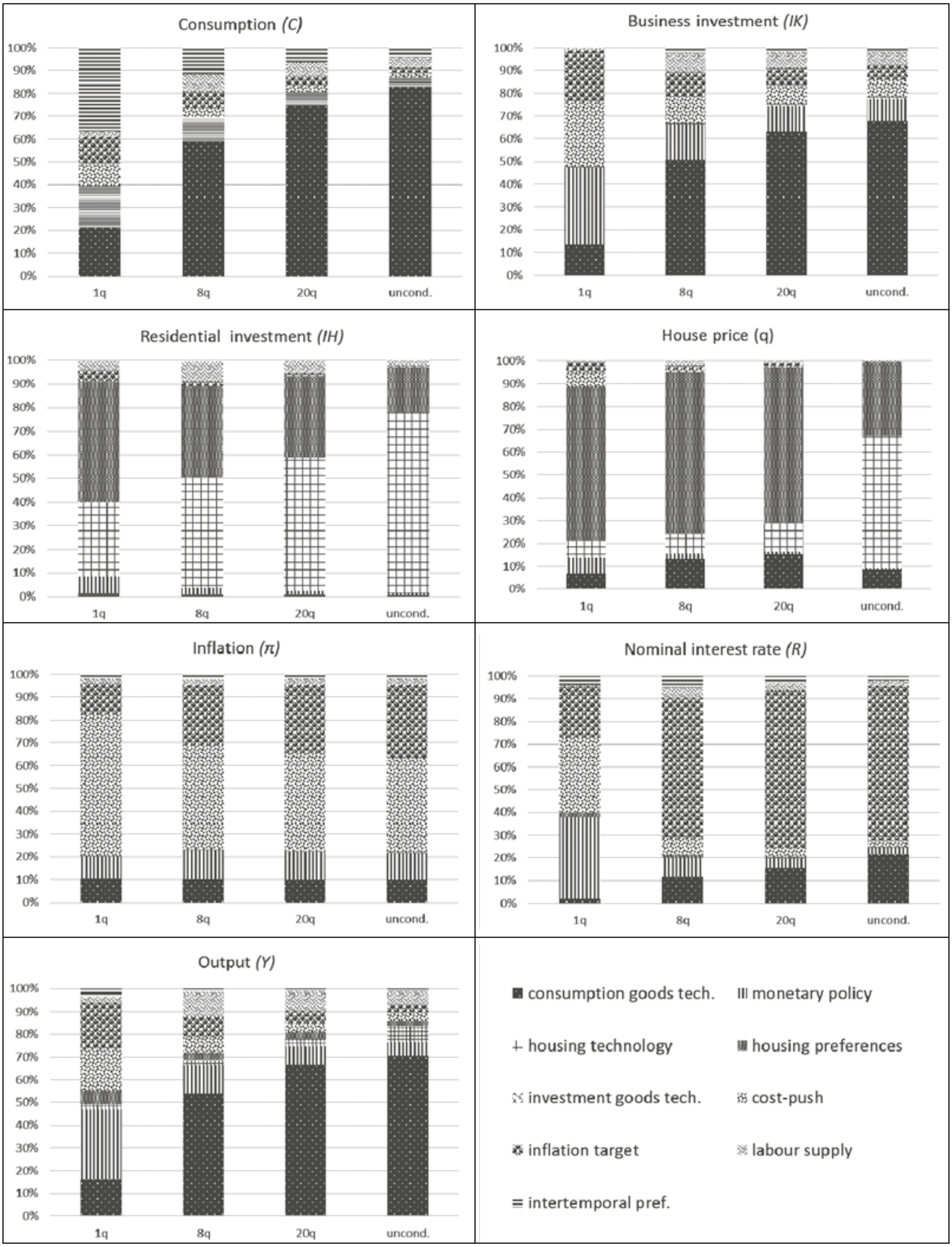
Figure 5 Impulse responses to consumption good technology shock



Source: Author's construction

The collateral effect is important only for some kind of shocks: those that move house prices and inflation in the same direction. These are, specifically, monetary policy shock, housing demand shock, housing technology shock and inflation target shock (the last two are not shown here). The increase of LTV to higher values against the benchmark amplifies short run responses in consumption, output or inflation, whose magnitudes vary according to the type of shock. These effects are quantitatively substantial and support a policy of setting maximum limits on LTV ratios, with the aim of reducing the volatility of the variables.

Figure 6 Variance decomposition



Source: Author's construction

4.2 Variance Decomposition

Figure 6 shows a conditional variance of the model variables explained by each shock for a one-, eight- and twenty-quarter forecast horizon, and an unconditional forecast error variance decomposition. There is an interesting pattern to be observed: monetary policy shock, cost-push shocks and inflation target shocks are quite important in the short term, not only for the nominal variables but also the real variables. However, their influence on the real variables fades over time. The opposite is true for technology shocks, whose influence increases with time. Housing preference shocks are more or less stable in explaining the variance of residential investment and real house prices.

The last columns of the Figure 6 show an unconditional variance decomposition and deserves bigger attention. Productivity shocks in the non-housing sector for consumption goods explain most of the volatility in consumption, business investment and output. On the other hand, investment-specific technology shocks are unimportant even for business investment. Housing technology and preference shocks are important for the behaviour of residential investment (IH) and house prices (q), while the latter is more significant in the shorter term (compare with the previous part). Inflation target shocks are mainly responsible for variance in interest rate (R) and together with cost-push shocks also for variance in inflation (π). Labour supply shocks and intertemporal shocks are relatively unimportant.

The central objective of this paper is to assess the relationship between the housing market and the rest of the economy. One can see that there is a large degree of disconnection. Both housing market shocks (technology and preferences) explain in sum 96% of variance in housing investment and 90% of variance in housing prices.[12] As regards non-housing shocks, only consumption good technology shocks play some role in the variance in housing prices. The opposite also holds: housing market shocks explain about ten percent of output variance (mostly through housing investment) but almost zero variance in inflation. Therefore spill-overs of housing specific shocks into the broader macroeconomy can be considered negligible. Potential problems in the housing sector do not therefore represent any threat for the economy in this benchmark setting.

The effects of LTV ratio on the monetary transmission mechanism that were analysed by impulse responses in the previous section can be further illustrated by looking at the unconditional forecast error variance decomposition. Table 3 shows the variance of consumption, output and inflation accounted for by monetary policy shock for different values of LTV ratio. When the LTV is increased from 0.75 to 0.95, monetary policy shocks have a larger effect, especially on consumption (more than twofold) followed by inflation and output (by 32%). When the collateral effect is switched off ($m = 0$), monetary policy shocks explain a smaller fraction of the variability, but the difference from the benchmark is intangible. These results repeatedly confirm the fact that increasing LTV amplifies the ability of monetary policy to influence consumption, output and inflation, with its largest effect being on consumption. Contrary to the results obtained from impulse responses,

Table 3 Unconditional variance decomposition: effect of monetary policy shock (in %)

	Consumption	Output	Inflation
High LTV (m =0.95)	8.4	7.5	15.6
Benchmark (m =0.75)	3.8	5.7	11.8
No collateral (m = 0)	2.8	5.5	9.6

Source: Author's calculations

[12] See Table 5 in the online Appendix for exact numbers (available at the website of this journal, see the online version of the *Statistika: Statistics and Economy Journal* No. 4/2016 at: <*http://www.czso.cz/statistika_journal*>).

the impact of higher LTV for output and inflation here is quantitatively similar. This is due to the fact that in IRF analysis we considered the very short term impacts, while the forecast error variance decomposition is calculated for the long-term and, as was documented in Figure 6, the effect of monetary policy shock for output strongly decreases with time.

Finally, Table 4 shows the effect of different values of LTV ratio on the variance decomposition of selected variables following housing preference shock. Again, high values of LTV amplify the impacts of the shock, especially for consumption and inflation. In this case, the spill-overs to the broader macroeconomy can be considered nontrivial, and may justify setting caps on the loan-to-value ratio. Regarding housing technology shock (not shown here), the impacts on macroeconomic variables increase only slightly with increasing LTV ratio.

Table 4 Unconditional variance decomposition: effect of housing preference shock (in %)

	Consumption	Output	Inflation
High LTV (m =0.95)	8.6	5.7	4.7
Benchmark (m =0.75)	0.1	2.5	0.1
No collateral (m = 0)	0.6	2.7	0.6

Source: Author's calculations

4.3 Historical Shock Decomposition

While variance decomposition relates to forecast error of exogenous shocks to particular variables, historical shock decomposition performs an error decomposition on historical data. Figure 7 depicts the historical decomposition of real house prices into shocks during the estimated period. It shows that housing preference shocks became more significant from the end of 2001; from this moment onwards, they were the main determinant of rising house prices. The same shocks were responsible for the subsequent house price decline during and after the crisis. Housing technology shocks also contributed to the development of house prices, but in a more stable way. Consumption goods technology shocks also increased their influence on the behaviour of house prices, mainly from 2002. After the peak in 2008, these non-housing technology shocks diminished, just as house prices declined. This analysis shows that both the demand and supply shocks played important roles; however, demand shocks were overall responsible for the fluctuation of house prices.

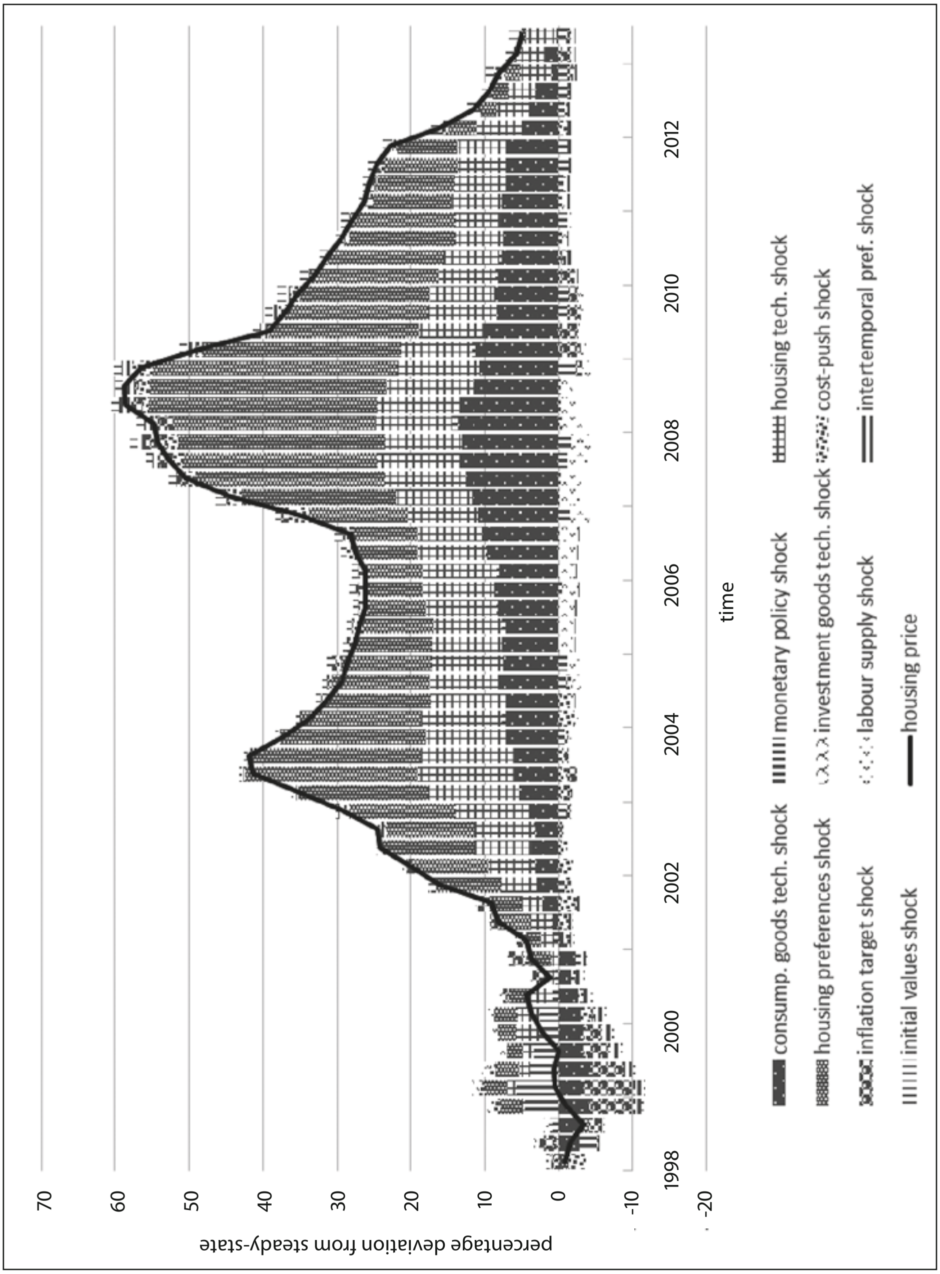
CONCLUSION

This paper presents the results of an estimation of a medium-scale DSGE model with housing sector using Czech data. The answer to the research question, regarding a possible connection between the housing sector and the rest of the economy, is rather complex. According to the forecast error variance decomposition, there is no significant link between these sectors. Housing sector shocks do not transfer to the broader economy, and only consumption good technology shocks explain some of the variability in real house prices.

If we look at the historical behaviour of house prices, shocks to housing preferences were their main driving force, especially during the turbulent past ten years. Technology shocks in the consumption goods sector and housing sector also contributed to raising house prices, but in a more stable manner.

In spite of the high degree of disconnection between the sectors, there is an important channel at work – a collateral constraint mechanism with houses serving as collateral. This mechanism influences transmission of monetary policy shocks to the real variables and crucially depends on loan-to-value ratio. If loans to constrained households are more accessible (high LTV), the reaction of both consumption and output to monetary policy shocks is much more pronounced, especially in the short term. On the other hand, the impact on inflation

Figure 7 Shock decomposition of housing prices



Source: Author's construction

is not so distinctive. Moreover, the value of LTV amplifies these responses in a non-linear way. A marginal increase in LTV at high values of this variable causes a larger impact, especially for consumption and output, than a marginal increase at lower values of LTV.

Similar amplification is also observed for housing preference shock and its impacts on macroeconomic variables. High values of LTV ratio magnify the impacts of this shock, especially for consumption and inflation. This outcome partly modifies the previous results that suggested disconnection between the sectors, instead indicating potential threats from the housing sector. There is also another potential cost connected with high LTV, which was not considered in the model, and that is that high LTV increases the probability of households defaulting on their loans, which can have impacts on the stability of the financial system and consequently on the whole macroeconomy.[13] These results should be taken into consideration in the formation of macroeconomic policy that will set limits on loan-to-value ratio. Such a practice has already been introduced in Sweden where LTV is limited to a maximum 85% (Swedish Financial Supervisory Authority, 2010). The aim of this policy was to decrease risk in the credit market that stems from the inability of heavily indebted borrowers to repay their debts.

The impacts of LTV ratio were illustrated in this paper in reaction to disinflationary (restrictive) monetary policy, which caused welfare losses in terms of consumption or output. As the model assumes symmetry, we would obtain equivalent but opposite effects for the case of a decrease in interest rate by the monetary authority. However, we might see asymmetric behaviour in consumption and output: a lower interest rate increases house prices and housing wealth, but the collateral constraint does not need to be binding. Credit constrained households become unconstrained following such a move, and change their consumption only a little compared with the case of restrictive monetary policy and low house prices. Another related issue is the zero lower bound on interest rate, which prevents the central bank from decreasing the interest rate, and may also contribute to the asymmetric behaviour of consumption and output. Guerrieri and Iacoviello (2014) explore these asymmetries, but focus mainly on house price shocks. This could therefore be an appropriate topic for further research.

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APPENDIX

See the separate PDF file in the online version of the *Statistika: Statistics and Economy Journal* No. 4/2016 at: <*http://www.czso.cz/statistika_journal*>.