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2014

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2014

CZECH NATIONAL BANK

WORKING PAPER SERIES

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9/2014

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The Czech Housing Market Through the Lens of a DSGE Model Containing Collateral-Constrained Households

Jaromír Tonner and Jan Brůha *

Abstract

We incorporate a housing market with liquidity-constrained households into the Czech National Bank's core forecasting model (g3) to analyze the relationship between housing market and aggregate fluctuations in a small open economy framework. We discuss the historical shock decomposition of house prices and interpret the results in the light of recent empirical work. For a wide range of model calibrations, the interaction between the housing market and the aggregate economy is weak and so the monetary policy implications of house price fluctuations for the Czech Republic are not strong. We interpret this – in line with recent empirical evidence – as an indication that the wealth effects stemming from house ownership are not significant in the Czech Republic. Nevertheless, we show that the collateral mechanism significantly improves the forecasting properties of the extended model, especially for private consumption. This indicates the importance of the collateral effect, which can be caused by assets other than houses.

Abstrakt

V příspěvku vkládáme trh nemovitostí s rozpočtově omezenými domácnostmi do základního modelu České národní banky (model g3), abychom mohli analyzovat vztahy mezi trhem nemovitostí a hospodářským cyklem v rámci modelu malé otevřené ekonomiky. Diskutujeme rozklad cen nemovitostí do šoků a interpretujeme výsledky ve světle aktuálních empirických prací. Zjišťujeme, že působení trhu nemovitostí na ekonomický cyklus je slabé, a tak ani měnověpolitické implikace kolísání cen nemovitostí nejsou významné. To platí pro širokou množinu modelových parametrizací. Výsledek interpretujeme - v souladu se současnými empirickými pracemi - tak, že efekty bohatství plynoucí z vlastnictví nemovitostí nejsou v České republice významné. Nicméně ukazujeme, že mechanismus zajištění významně vylepšuje predikční vlastnosti rozšířeného modelu, hlavně u predikce spotřeby domácností. To naznačuje důležitost efektu zajišťování, přičemž zástavu mohou představovat jiná aktiva než nemovitosti.

JEL Codes: E32, E37, R31.
Keywords: Aggregate consumption, DSGE models, housing market.

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This paper was prepared as part of the Czech National Bank research project B5/11. We are grateful for helpful comments and suggestions from Paul Corrigan, Michal Hlaváček and Martin Slanicay. The views expressed here are those of the authors and do not necessarily reflect the position of the Czech National Bank.

Nontechnical Summary

Since the outbreak of the Great Recession, house prices have started to be associated with economic fluctuations. Therefore, not only academia, but also policy institutions – including central banks – have started to pay attention to the dynamics of house prices. Various approaches have been proposed to explain the observed facts and to derive policy recommendations. One of the most popular approaches is based on the effect of house prices on the macroeconomy through the collateral constraint: households who want or need to borrow use houses as collateral, and during periods when house prices are high they borrow to boost their consumption, which is propagated to the rest of the economy. The paper by Iacoviello and Neri (2010) is the workhorse for this stream of DSGE models.

The aim of this paper is to use this framework to extend the Czech National Bank's core forecasting model accordingly. The paper does not search for the most suitable approach to house price modeling in general equilibrium. Instead, it takes the framework containing houses as collateral as given, aims at finding the most plausible calibration (in terms of the forecasting properties of the extended model) and looks at housing market developments in the Czech Republic through the lens of this extended model.

By doing so, the paper makes three contributions. First, we show how this mechanism can be implemented in a rich DSGE model of a small open economy and we assess the forecasting properties of the extended model. We find that for a wide range of model calibrations the interaction between the housing market and the aggregate economy in the Czech Republic has been weak and thus monetary policy need not react to house price movements. This is in line with recent microeconometric evidence for the Czech Republic. We also find that the forecasting properties of the model containing the collateral effect are somewhat improved, especially for consumption and investment. Importantly, if house prices are not observed, the model forecasts consumption much better. This suggests that the collateral effect may be important for consumption, but that in the Czech Republic the collateral takes the form of assets other than houses alone.

Second, we analyze two recent episodes of surges in house prices. The model attributes the house price increase around the years 2003 and 2004 to an exogenous preference shock, hence confirming the popular belief that the increase was unrelated to macroeconomic dynamics. The second increase in house prices – in 2007–2008 – was more related to the overall economic conditions and can be explained by demand effects to a larger degree, although not fully.

Third, we compare the stabilizing role of the inflation target MP rule with alternative policy rules containing the deviation of house prices from their equilibrium value. We find that the rule containing house prices does not stabilize the economy compared to pure inflation targeting.

1. Introduction

1.1 Motivation

An understanding of house price determinants seems to be important for central banks, especially in relation to the Great Recession. House price fluctuations are associated with business cycle dynamics and some economists even claim that house prices are the business cycle (Leamer, 2007). Various approaches to explaining and modeling the observed statistical association have been proposed, and structural macroeconomic models have been built to replicate the observed features, to shed light on house price dynamics, and to assess the role of policy in mitigating house price fluctuations. One of the most popular macroeconomic approaches is centered on the ground-breaking paper by Iacoviello and Neri (2010), who argue that house price fluctuations which are the result of preference shocks contribute in a significant way to economic fluctuations, i.e., that exogenous house prices are the source of business cycles.[1]

The aim of this paper is to use the Iacoviello and Neri (2010) (henceforth IN) framework and to extend the Czech National Bank's (CNB) core forecasting model, called g3, to include this framework.[2] The goal of this paper *is not* to assess the IN framework vis-à-vis alternative approaches to incorporating the housing market into the structural macroeconomic framework. This paper instead takes the IN framework as given, aims at finding the most plausible calibration (in terms of the forecasting properties of the extended model), and looks at house market developments in the Czech Republic through the lens of this extended model.

By doing so, the paper makes three contributions. First, we show how this mechanism can be implemented in a rich DSGE model of a small open economy and we assess the forecasting properties of the extended model. We find that for a wide range of model calibrations the interaction between the housing market and the aggregate economy is weak and thus monetary policy need not react to house price movements. The likely reason is that the wealth effects stemming from house ownership are not significant, which is in line with recent microeconometric evidence. We also find that the forecasting properties of the model containing the IN mechanism was somewhat improved, especially for consumption and investment. Importantly, if house prices are not observed, the forecasting properties for consumption improve much more. This suggests that the IN mechanism may be important for consumption, but that in the Czech Republic the collateral takes form of assets other than houses alone.

Second, we analyze two recent episodes of surges in house prices. The model attributes the house price increase around the years 2003 and 2004 to an exogenous preference shock, hence confirming the popular belief that the increase was unrelated to macroeconomic dynamics and is usually attributed to expected EU entry in May 2004 (Hlaváček and Komárek, 2009). The second increase in house prices – in 2007–2008 – was more related to the overall economic conditions and can be explained by demand effects to a larger degree, although not fully.

Third, we compare the stabilizing role of the inflation target MP rule (implemented in the g3 model) with alternative policy rules containing house prices. This comparison reflects actual policy discussions. Indeed, Holman (2010) suggested that a house price index should be explicitly part of the CNB's MP reaction function. We find that the rule containing the deviation of house prices from their equilibrium value does not stabilize the economy, in the sense that under such a rule the vari-

[1] Alternative explanations have been based on expectations about future growth (Kahn, 2008; Tomura, 2010) or on disagreements among agents about fundamentals, (Tomura, 2013; Piazzesi et al., 2007).
[2] See Andrle et al. (2009) for a description of the CNB's forecasting model g3.

ance and persistence of output, interest rates, and inflation would be higher than in the pure inflation targeting regime.

The rest of the paper is organized as follows. The rest of this section describes the data used and survey-related literature. Section 2 then briefly describes the model (the extended g3 model containing the IN mechanism) and its properties. Section 3 contains the empirical analysis, while Section 4 evaluates alternative MP rules. The last section concludes and the appendices contain additional material, mostly technicalities.

1.2 Data

The model is an extension of the g3 model and therefore we use the same dataset as the g3 model does. Since the g3 model does not contain a housing sector, we have to add two new observables. For house price data we use the real estate transfer price index constructed by the Czech Statistical Office, which is the same time series that has been used in recent empirical studies (e.g. Brůha et al., 2013). [3] We also use the construction production index (buildings[4]) as an observable for construction sector output.[5] Both time series are available at quarterly frequency.

Figure 1: Housing Market Data

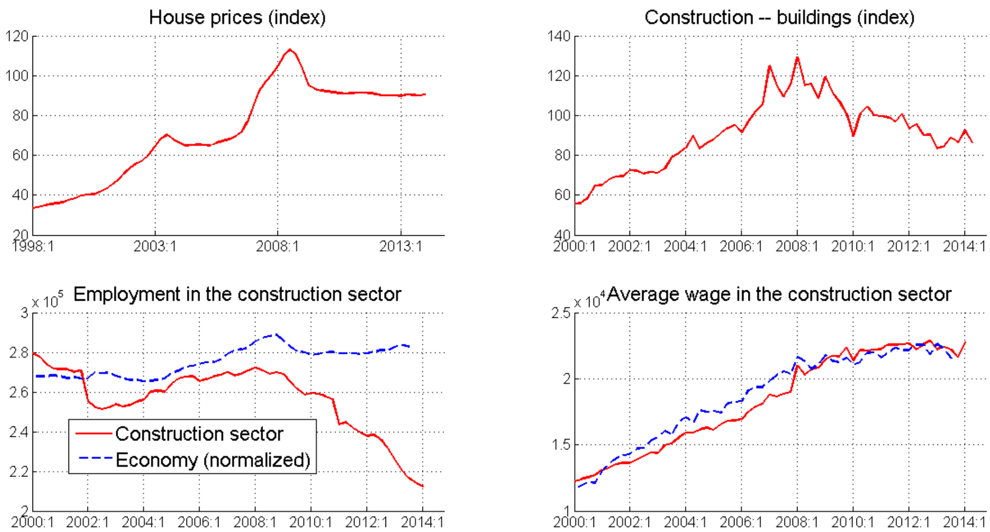


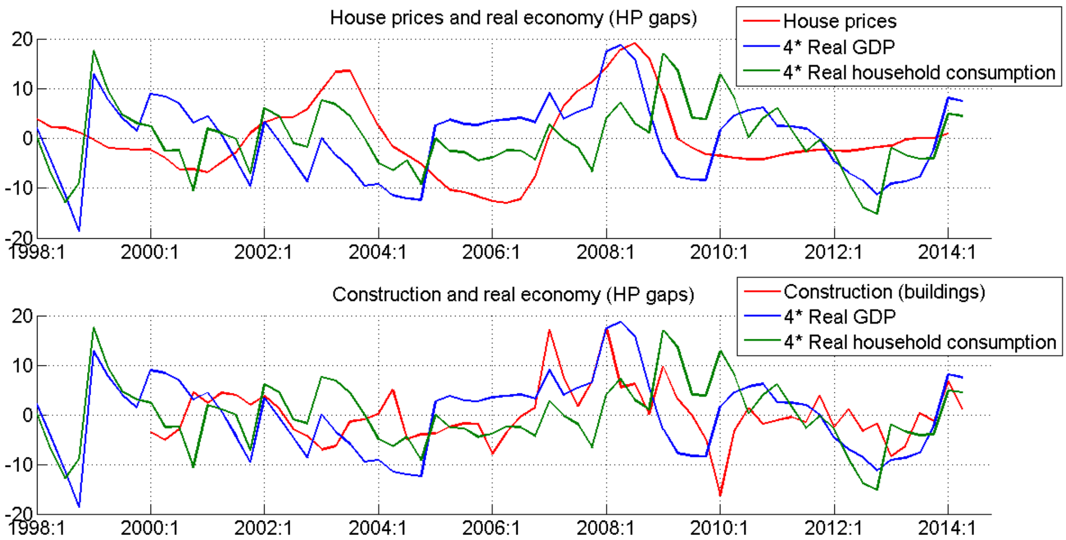
Figure 1 shows the levels of seasonally adjusted indicators of the housing market. The first subplot displays the house price index, with clear episodes of a surge in house prices. The second subplot shows the new buildings index, which peaks before the Great Recession. The third subplot shows employment in the construction sector, which dropped steadily after the crisis hit the Czech economy. This drop was more significant than that in economy-wide employment. The last sub-

[3] Hlaváček and Komárek (2009) discuss and assess in detail the various data sources available for house prices and the advantages and disadvantages of those sources.
[4] Hence we exclude civil engineering works, which are dominated by large infrastructure projects. Infrastructure construction is financed mainly by the public sector and hence its dynamics are not influenced by private decisions.
[5] See http://www.czso.cz/eng/redakce.nsf/i/sta_ ts for this data source.

plot displays the nominal average wage in the construction sector. The nominal wage in this sector shows a qualitatively similar pattern as in the rest of the economy, i.e., a stagnation after the crisis.[6]

Figure 2 shows a comparison of housing data gaps (construction and prices) with GDP and consumption gaps.[7] The figure apparently shows two episodes of surges in the house price gap. The first period occurred in 2002–2004 and is usually attributed to exogenous events not related to the then economic conditions.[8] The second rise, which occurred in 2006–2008, is more synchronized with the business cycle. The construction gap is significantly positive only during the second episode, with a significant drop after 2009. In general, the construction index gap seems to lag behind the price gap.

Figure 2: Comparison of Cyclical Dynamics of Housing Market Data with Real Economy



1.3 Related Literature

As stated above, Iacoviello and Neri (2010) is the workhorse of structural macroeconomic models containing a housing sector. The authors develop and estimate a DSGE model with a rich housing sector that contains two important features typical of the housing market. On the supply side, they capture the different trends and cyclical properties of house prices and investment relative to other prices and other components of aggregate demand. On the demand side, collateral constraints affect borrowing capacity and allow for spillovers from the housing market to consumer spending. This collateral effect works as follows. In the first phase a rise in house prices increases the value of property used as loan collateral, leading to credit expansion. This expansion increases aggregate demand, which, in turn, fosters a temporary rise in economic activity.

[6] The last two variables are related to the whole construction sector, i.e., including civil engineering. We were unfortunately unable to obtain separate data for the subset of the sector corresponding only to house construction.
[7] The gaps are constructed using the HP filter with the conventional value of the smoothing parameter $\lambda = 1600$. The GDP and consumption gaps are multiplied by 4.
[8] The popular story goes as follows: the surge in house prices is attributed to house owners' expectations that EU entry in May 2004 would cause a rise in housing demand. When these expectations proved to be wrong, house prices rapidly declined at the beginning of 2004. The story is corroborated by the fact that the surge was significant mainly in Prague, where the rise in demand would have been especially large.

The popularity of the Iacoviello and Neri (2010) framework has resulted in a number of authors using this framework to investigate important monetary policy issues. For example, Walentin and Sellin (2010) aim at quantifying the role that housing collateral plays in the monetary transmission mechanism, specifically the impact of the loan-to-value ratio, using an estimated model that closely follows Iacoviello and Neri (2010). The identified mechanism works through the effects of the interest rate on house prices as well as on inflation and thereby on the real value of nominal debt. The authors find that the component of the monetary transmission mechanism becomes stronger the higher the loan-to-value ratio is. A change in the maximum loan-to-value ratio from 85% to 95%, all else being equal, implies that the effect of a monetary policy shock is increased by 4% for inflation, 8% for GDP, and 24% for consumption. They conclude that to properly understand the monetary transmission mechanism and its changing nature over time, we need to take into account the effects of housing-related collateral constraints.

Lambertini et al. (2010) analyze housing market boom-bust cycles driven by changes in households' expectations. They investigate the role of expectations in productivity and also in several other shocks that originate in the housing market, the credit market, and the conduct of monetary policy. They find that, in the presence of nominal rigidities, expectations about both the conduct of monetary policy and future productivity can generate housing market boom-bust cycles that resemble data features. Increased access to credit generates a boom-bust cycle in most variables only if it is expected to be reversed in the near future.

Christensen et al. (2009) are close to our paper in that they take the IN framework, estimate it on Canadian data, and ask how much the framework can help explain economic dynamics, especially consumption dynamics. Contrary to us, they find on Canadian data that house prices indeed significantly help explain consumption dynamics. This finding from the model estimated on Canadian data is in line with a recent Canadian microeconomic study (Kartashova and Tomlin, 2013).

There has been some interesting research on the relation between the macroeconomy and the housing market in the Czech Republic, too. Hlaváček and Komárek (2009) use econometric analysis to inquire about the macroeconomic determinants of house prices. Brůha et al. (2013) use sophisticated microeconometric methods to estimate the effect of house price changes on the consumption, savings, and indebtedness of households, with an identification strategy that relies on house ownership and spatial patterns of house price changes as identification tools. They find little evidence for the consumption effect of house price changes. We will use the results of these two studies below to explain and confront our findings.

2. The Model

In this section we briefly describe the way we incorporate the housing market into the g3 model and discuss the transmission mechanism via impulse responses.

2.1 Model Structure

As said in the introduction, the aim of the paper is to extend g3 by introducing the IN framework. The equations describing the extensions are therefore standard and are shown fully in Appendix A.1. The derivation of the steady state (along with stationarization) is described in Appendix A.2.

Figure 3 describes the extension of the g3 model to include the housing market. The black arrows show the mechanisms in the original g3 model,[9] while the red arrows show the extension. The extensions are the following:

- There are two types of households (patient and impatient) as in Iacoviello and Neri (2010). The impatient households borrow against collateral, which takes the form of houses. Both types of households consume consumption goods and own houses. The housing stock provides utility for both types of households, and houses are additionally useful to impatient households for their collateral value.
- There is a new sector producing houses; the sector inputs are labor and capital. Capital is sector-specific.
- In the original g3 model investment is fully imported, whereas we allow a domestic component in the production of investment.[10] Investment can be used to create capital in both sectors (the housing sector and the intermediate sector).

2.2 Calibration

There are currently two popular ways of parametrizing a model:[11] Bayesian estimation, and calibration (Andrle et al., 2009). Calibration means that the model maker tries to find parameters that bring desired properties to the model, e.g. intuitive impulse responses, intuitive shock decomposition of endogenous variables, model moments corresponding to data moments, and good predictive power. The latter property is particularly important in institutions where models are used for forecasting.

The model was thus calibrated to improve its forecasting properties relative to the g3 model. The forecasting properties are measured by the root mean square error (RMSE) of the eight-quarter-ahead prediction assuming that external developments are correctly anticipated by agents.[12] We also evaluated the forecasting properties using the mean absolute error (MAE) to guard against outliers in the forecasted series and found that the ranking of the various calibrations is almost

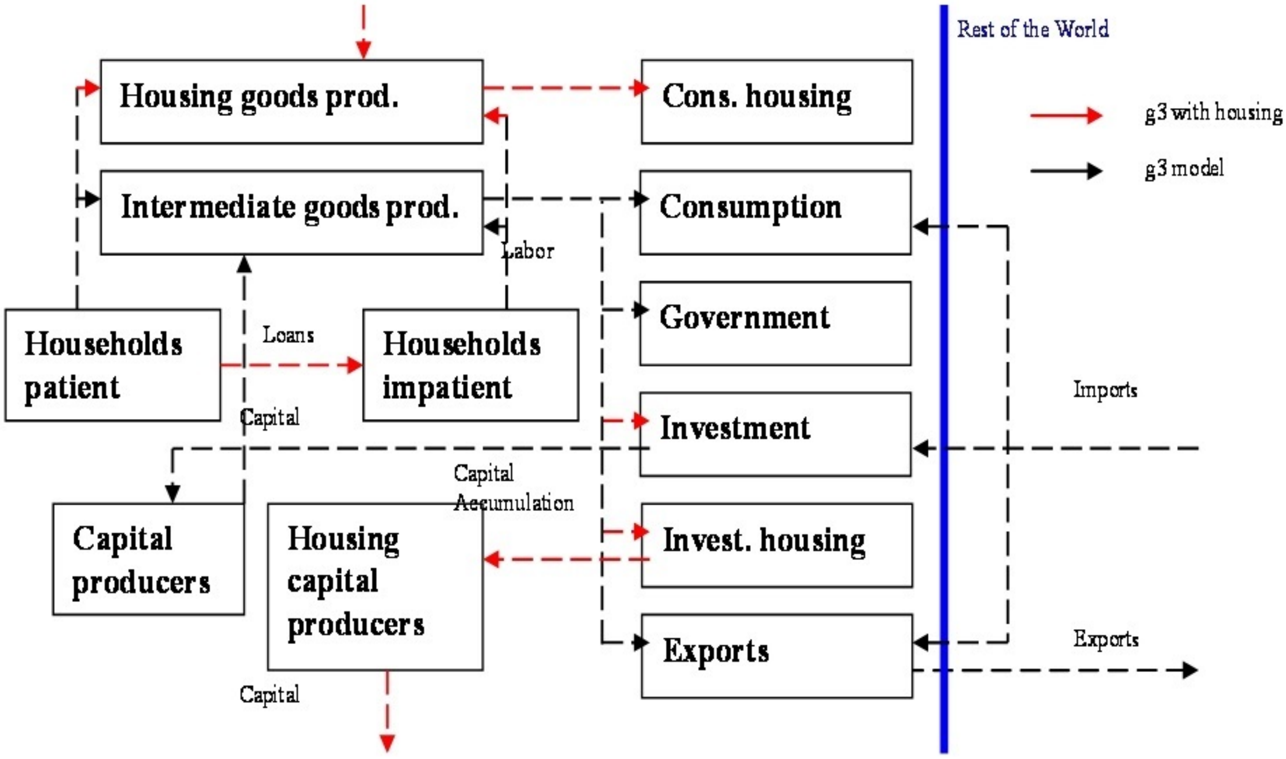
[9] See Andrle et al. (2009) for a more detailed description of the g3 model.

[10] Investment is therefore produced using Leontief technology from domestic and imported inputs, analogously to the consumption and export sectors in the original g3 model.

[11] A trivial requirement is to identify parameters that allow one to find and solve a model steady state. See Appendix A.2 for a discussion of the dependence of beta on the lambda ratio.

[12] This means, for example, that when one computes the RMSE for the final quarters of 2008, agents in both models know the drop in foreign demand caused by the Great Recession. This is important since if external developments were not available to the model agents, an inappropriate calibration could by chance 'forecast' the 2009 recession due to a crazy transmission mechanism and this would lead to a wrong conclusion.

Figure 3: g3 with Housing Market



invariant to the choice of criterion (RMSE versus MAE). Numerical results are available in Section 3.2.

There are two reasons why we prefer the eight-step-ahead prediction error criterion to the usual one-step-ahead criterion (or likelihood-based criteria, which are based on one-step-ahead criteria). The first reason is that the monetary policy horizon is longer than one quarter (roughly four quarters). The second reason is that the growing literature shows that the one-step-ahead criterion in misspecified models tends to put too much emphasis on high-frequency fluctuations (see e.g. McElroy and Wildi, 2013; Xia and Tong, 2011). For macroeconomic models this would mean too much emphasis being put on short-run fluctuations rather than on business cycle dynamics.

Table 1 surveys our preferred calibration. This calibration was used to generate all the figures in the paper.

Nevertheless, it should be stressed that most of the qualitative results in this paper are pretty robust to the calibration used. Unless we use a calibration that totally destroys the forecasting properties

Table 1: Housing Market Parameters

Par/Var	Name	g3	g3 with housing	
	Nominal consumption to GDP	0.510	0.330	
	Nominal housing to GDP	-	0.100	
	Nominal investment to GDP	0.270	0.250 - Nonhousing	0.100 - Housing
	Nominal government to GDP	0.220	0.220	
	Nominal exports to GDP	0.780	0.780	
	Nominal imports to GDP	0.780	0.780	
χ	External habit parameter	0.750	0.750 - Patient	0.850 - Impatient
β	Discount factor	0.997	0.951 - Patient	0.946 - Impatient
γ	Labor share in production	0.665	0.651 - Nonhousing	0.007 - Housing
υ^H	Ratio of patient/impatient labor	-	0.900 - Nonhousing	0.900 - Housing
$L2V$	Loan-to-Value ratio	-	0.800	
$\delta_{housing}$	Depreciation of houses	-	0.010	
$markup$	Markups	1.200	1.200 - Nonhousing	1.260 - Housing

of the extended model and yields implausible impulse responses, our conclusions about the weak transmission between house prices and the macroeconomy still hold.

The final note is about the calibration of the discount factors β (see Appendix A.2 for a discussion). First, the difference between the discount factors of patient and impatient households may seem small – an order of magnitude lower than in Iacoviello and Neri (2010). The difference is that a small open economy can in principle borrow any amount of money from abroad and it would be possible for patient agents to borrow abroad and lend these funds to impatient agents. Although this perverse effect is somewhat mitigated by the presence of a debt-elastic premium, the difference between the two discount factors still should not be too high. Second, the relatively low values of these parameters do not translate to high steady-state interest rates – because the g3 model features a wedge in the Euler equation to replicate the interest rates observed during the convergence process, the lower values of the discount factors merely increase the value of this wedge and this leaves the steady-state interest rate unchanged.

2.3 Impulse Response Analysis

In this section, we describe the shocks newly added to the model, i.e., the housing preference shock and the housing technology shock. We report both anticipated and unanticipated shocks. The logic behind unanticipated shocks is similar to the original paper Iacoviello and Neri (2010).

An unanticipated housing preference shock (Figure 4) increases both the housing stock and house prices (since the supply side cannot react so fast). This, in turn, increases the collateral value of impatient households, whose consumption therefore rises as well. The consumption of patient households declines (they become net lenders), but the effect on aggregate consumption is positive, which is transmitted to investment and inflation as well. Because of the rise in inflation, the monetary authority increases its policy rate, which leads to exchange rate appreciation. The impact of an anticipated shock, however, is different: the increase in the consumption of impatient households is weaker and the total effect on aggregate consumption is therefore negative. Impatient households accumulate their housing stock in advance (the total housing stock increases), which increases house prices even before the shock hits (and therefore the collateral channel still works), but the high expected future interest rates make borrowing less desirable for impatient households and so they increase their consumption less than in the case of unanticipated shocks. Moreover, patient households reduce their consumption substantially after the announcement of the shock (total consumption decreases) as they switch their expenditure to houses.

Figure 4: Housing Preference Shock

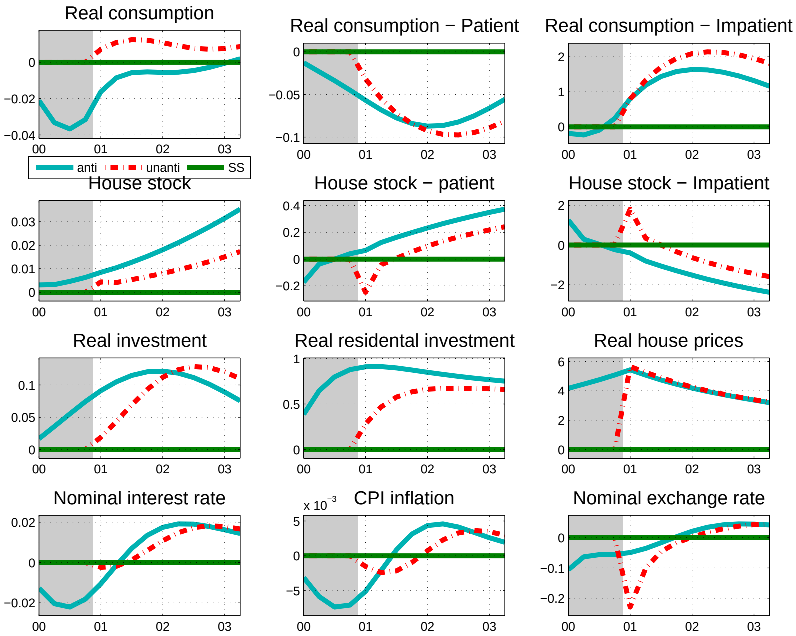


Figure 5 shows the impulse responses for the anticipated and unanticipated shocks to housing technology. Here, the responses to both kinds of this shock are qualitatively similar. This shock reduces house prices (as it is less costly to build houses) and therefore increases house purchases. Only patient households start to own more houses (impatient households experience a negative wealth shock) and the real net value of the housing stock declines as the price effect outweighs the quantity effect. Therefore, impatient households must reduce their debts and hence also consumption, which increases the consumption of patient households. The net effect on aggregate consumption is thus small. The switch from normal consumption to houses slightly increases consumption prices (CPI) and therefore also the policy rate.

The reaction of the extended model to a monetary policy shock (Figure 6) is similar to the standard new Keynesian model. The monetary policy shock reduces aggregate demand and therefore also inflation (in an open economy model this effect is strengthened by exchange rate appreciation). Besides this effect, the extended model has one additional channel: the increase in the interest rate leads to a fall in house prices and hence in collateral value for impatient households, who have to decrease their consumption even more.

We then compare the impulse responses of the extended and original model. The behavior of the models is similar for most important shocks (see the Appendix).

Figure 5: Housing Technology Shock

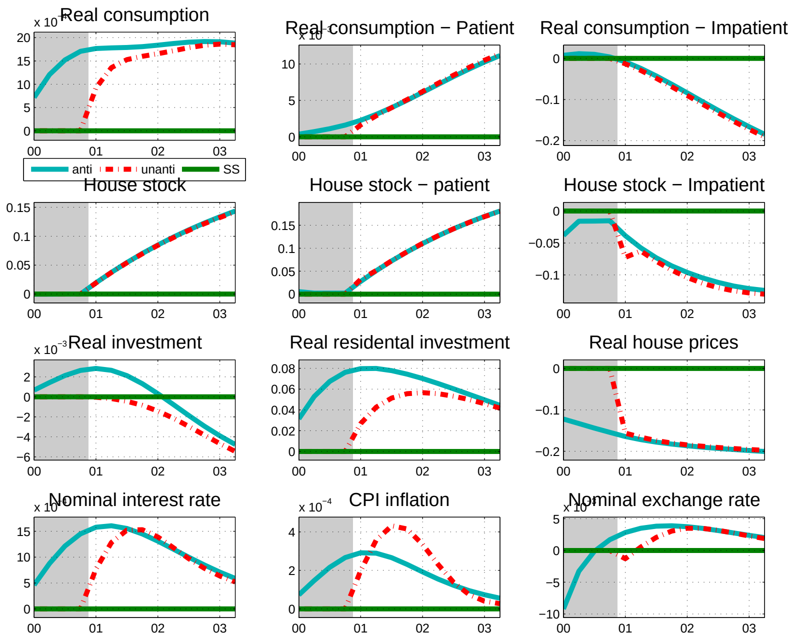
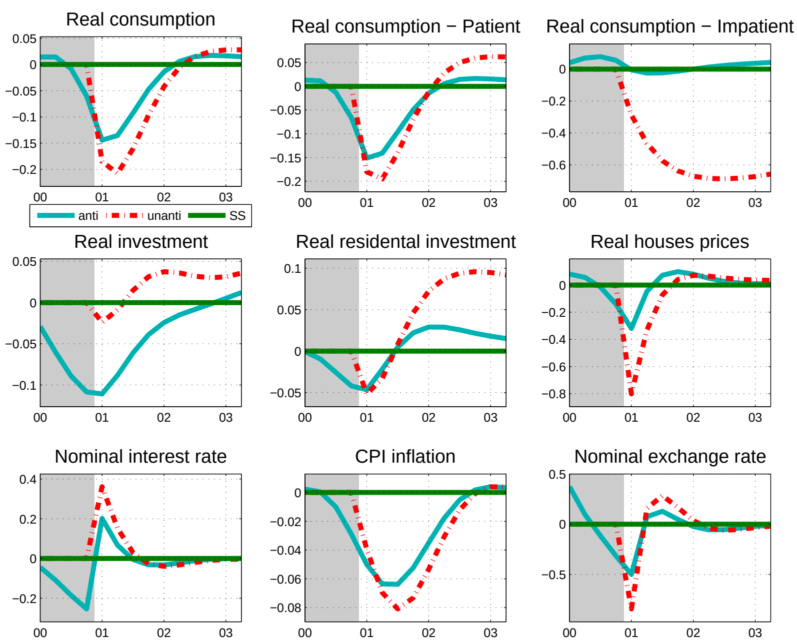


Figure 6: Monetary Policy Shock



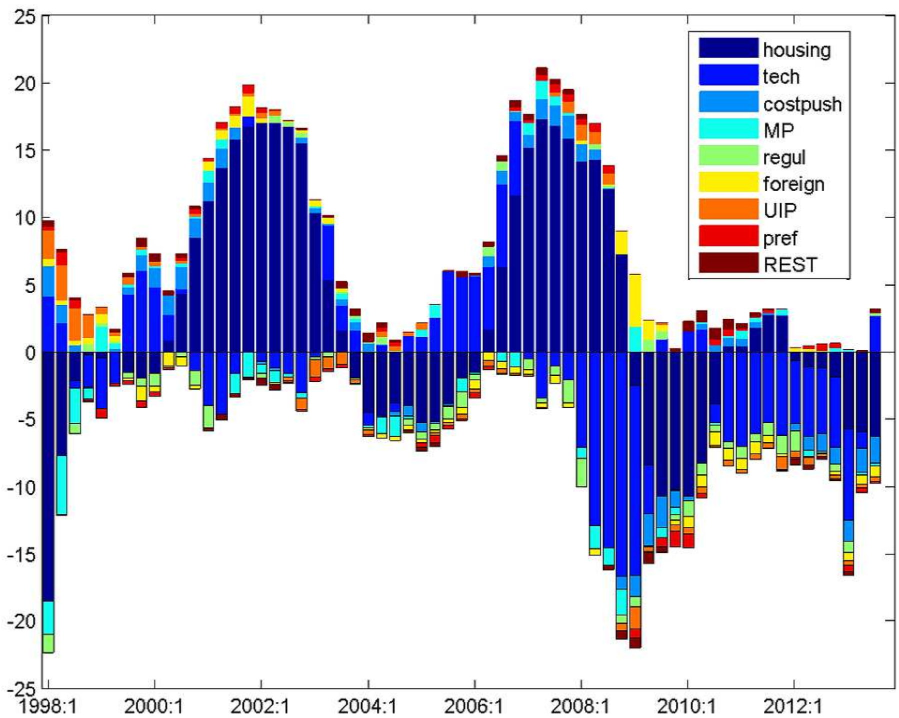
3. Empirical Results

This section provides an overview of the empirical results using our preferred calibration given in Table 1.

3.1 Shock Decompositions

Figures 7 and 8 display the shock decompositions[13] of house price inflation and the growth rate in housing construction. The increase in house prices in 2003 is explained mainly by the housing preference shock, which supports the notion that the increase was caused by external factors: the expected, but ex-post not fulfilled increase in housing demand associated with EU entry (see Hlaváček and Komárek (2009)). The house price rise before the Great Recession is also dominated by the house preference shock, but the usual business cycle shocks play a rather more important role[14].

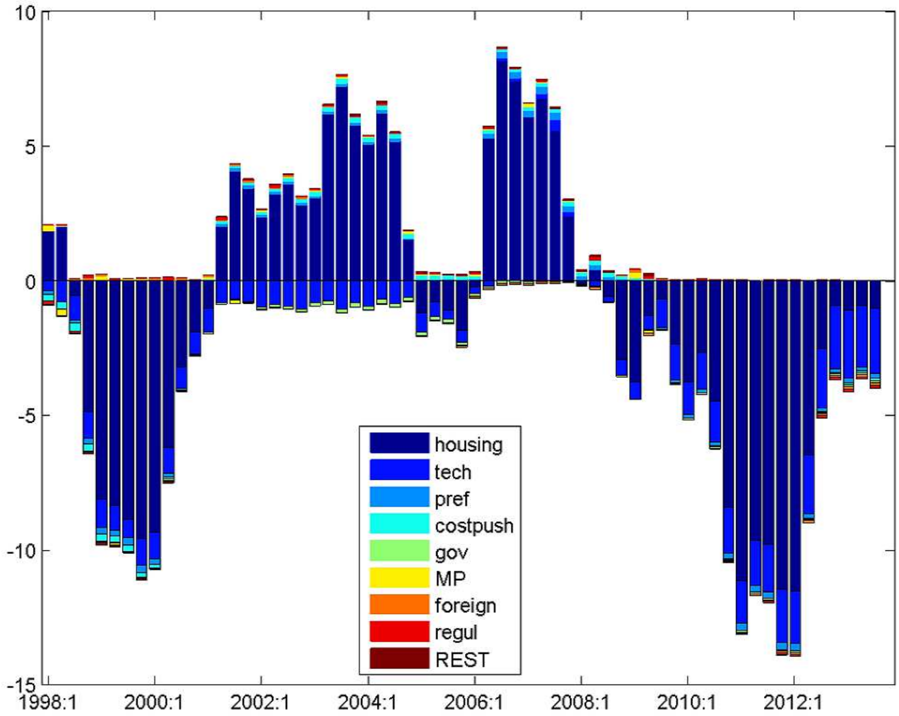
Figure 7: Shock Decomposition of House Price Inflation (q-o-q, annualized)



[13] A shock decomposition is used to fully understand a story behind the observed data. It shows which shocks explains a deviation of a given Kalman-filtered observable from its steady state. See Andrle et al. (2009).

[14] The *housing* label in the figures denotes housing preference shock and housing technology shock. The *tech* label denotes technology shocks as labour-augmented technology shocks and TFP shocks. The *costpush* label denotes costpush shocks in consumption, investment, government, export, import and intermediate sectors. The *foreign* label denotes shocks to foreign variables, i.e. foreign demand, foreign interest rates and foreign prices. *gov* label denotes government shocks. The *pref, UIP, MP, regul* labels denote habit, uncovered interest rate parity, monetary policy and regulated prices shocks.

Figure 8: Shock Decomposition of Housing Construction (q-o-q, annualized)



The effect of house price dynamics on consumption is almost nil, as shown in Figure 9 where a contribution of housing shocks is missing. The figure shows this for our preferred calibration, but it would continue to hold for almost any reasonable calibration. Hence, we conclude that the dynamics of the housing market do not help significantly predict Czech consumption and the rest of the variables.

Given that the MP rule in the model does not explicitly contain house prices and that our calibration did not find strong transmission from house prices to the aggregate economy, it is not surprising to find that house prices do not have a significant role in the shock decomposition of the policy rate (see Figure 10). Again, this result is robust to reasonable calibrations.

Figure 9: Shock Decomposition of Real Consumption Growth (q-o-q, annualized)

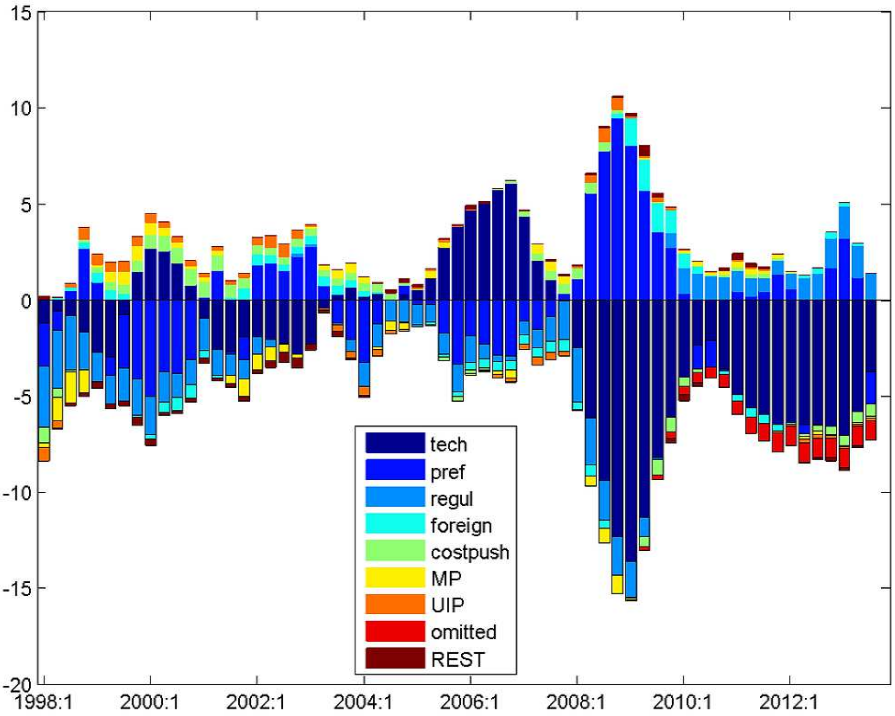
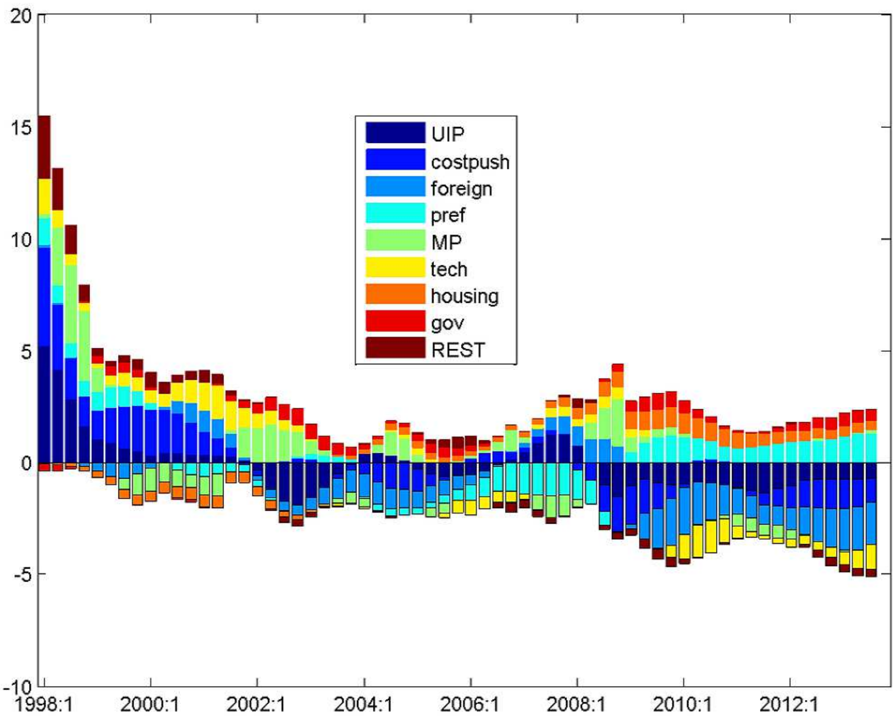


Figure 10: Shock Decomposition of Nominal Interest Rates (%, annualized)



3.2 In-sample Simulations

In this part of the paper, we comment on the root mean square error (RMSE) of the extended model relative to the g3 model. As a benchmark, the RMSE is computed for the eight-quarter-ahead prediction given the ex-post known external information (we explained above why we think that this horizon is the right benchmark).

Table 2 reports the RMSEs of the predictions of the main variables, such as the policy rate (I), CPI inflation (CPI), the nominal exchange rate (S), real GDP (GDP), nominal wage growth (W), real consumption (C), real investment (I), real exports (X), real imports (M), and their deflators (PC, PJ, PX, and PN). The numbers in the table correspond to the increase (-) or decrease (+) in prediction ability in percentage points of the prediction ability of the original model. Graphically, the results are available in Figure A.4.

The evaluation was done for two cases: observed house prices and unobserved house prices. It is apparent that for some variables, such as consumption and GDP, the model containing collateral-constrained households gives much more accurate predictions if house prices are not observed. We interpret this as evidence that collateral effects may be important for consumption in the Czech Republic, but that the collateral can take the form of assets other than houses. We also looked at the mean absolute errors and found that the increase in forecasting power for consumption and GDP remains valid if the forecasting power is measured by the MAE instead of the RMSE.

Table 2: Eight-step-ahead Prediction: RMSE (In-sample Simulations)

var/model	**I**	**CPI**	**S**	**GDP**	**W**	**C**	**J**	**X**	**N**	**PC**	**PJ**	**PX**	**PN**
housing/g3 - housing observed	-21	1	-13	-16	17	3	2	2	16	-1	-5	-1	-3
housing/g3 - housing unobserved	-22	0	-15	-20	11	-8	-0	1	15	-1	-13	-2	-9

Nevertheless, a referee of this paper asked us to provide the one-step-ahead predictions as well, so we present them in Table 3. The predictions of almost all the variables now worsen if house prices are observed. However, if these prices are not observed, the RMSE is only marginally worse. We interpret this as evidence that the collateral effect (not necessarily caused by houses) operates at medium frequency rather than in the very short run. Moreover, it shows us the importance of choosing the right criterion for model calibration, i.e., the one-step-ahead criteria puts too much weight on high-frequency features of the data and this is detrimental for misspecified models.

Table 3: One-step-ahead Prediction Error – RMSE (In-sample Simulations)

var/model	**I**	**CPI**	**S**	**GDP**	**W**	**C**	**J**	**X**	**N**	**PC**	**PJ**	**PX**	**PN**
housing/g3 - housing observed	12	-0	3	9	-5	2	18	9	18	-3	-4	1	1
housing/g3 - housing unobserved	3	-0	4	1	-2	5	6	8	16	-1	-8	0	2

4. Implications for Monetary Policy

In this part of the paper, we investigate the implications of alternative policy rules for the volatility of selected variables.

Therefore, we consider the following policy rule:

$$i_t = i_{t-1}^{\rho_i} \left\{ \left(\frac{\mathbf{E}_t \pi_{t+4}}{\overline{\pi}} \right)^{\psi} \left(\frac{\mathbf{E}_t \pi_{t+F}^H}{\overline{\pi^H}} \right)^{\psi_H} \right\}^{1-\rho_i} \exp(\varepsilon_t^{MP}),$$

where i_t is the policy rate, $\mathbf{E}_t \pi_{t+4}$ is expected inflation four quarters ahead, $\overline{\pi}$ is the inflation target, $\mathbf{E}_t \pi_{t+k}^H$ are expected house prices k periods ahead, $\overline{\pi^H}$ is the steady-state growth rate of house prices, ε_t^{MP} is the monetary-policy shock, and ρ_i, ψ, and ψ_H are parameters. The case $\psi_H = 0$ corresponds to the pure inflation targeting regime (and is the g3 policy rule).

For the model, we computed the autocovariance function (ACF) for the growth rate and HP gaps of selected variables.[15] Note that the ACF at zero is equal to the variance. Moreover, high values of the ACF signal an increase in the persistence of the process. Hence, if the ACF is higher for one policy regime, one can conclude that such a policy would be more destabilizing in the sense that it increases the variance and the persistence of the variables.

Figure 11 displays the ACF for the HP gaps for the case where monetary policy (MP) reacts to contemporaneous movements ($F = 0$) in house price growth for three different values of parameter $\psi_H = 0, 0.2, 1.0$. As mentioned above, the case $\psi_H = 0$ corresponds to pure inflation targeting, and we chose two values of ψ_H corresponding to moderate and aggressive MP responses to house price growth. Apparently, if MP reacts aggressively to house price growth, it can stabilize house prices, but destabilizes inflation and real variables such as consumption and investment. If the MP reaction to house prices is moderate, then it destabilizes the real economy slightly, but fails to stabilize the housing market.

The reader may be interested in the effect of the forward-lookingness of policy. Therefore, we did the same computation for the case of ($F = 4$), i.e., MP reacts to expected movements four periods ahead. The results are shown in Figure 12. In this case, the inclusion of house prices in the rule is destabilizing for both moderate and strong MP reactions, and it is monotone with parameter ψ_H. Our explanation of why the forward-lookingness of the rule with respect to house price growth is destabilizing is that the calibration of the model implies a relatively weak effect of shocks other than house preference shocks on house prices and therefore the current cyclical position can tell us little about future house price growth.

Our model would therefore not support the inclusion of house prices in the rule.

[15] Since the model is linear and its reduced form can thus be represented as the linear state space, the autocovariance functions can be computed easily without the need for simulation. The IRIS function `acf` implements this.

Figure 11: ACF of HP Gaps of Selected Variables ($F = 0$)

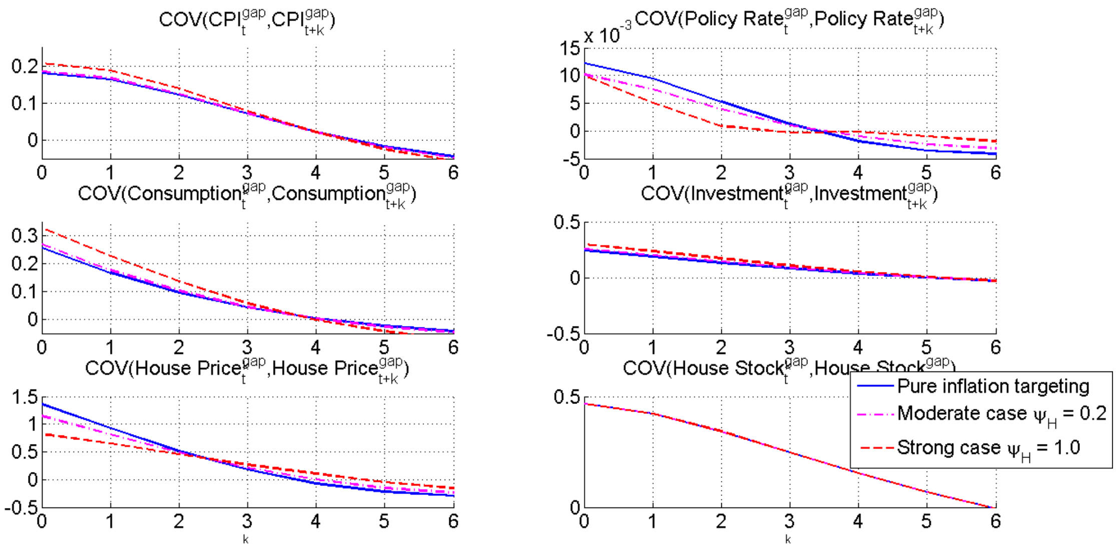
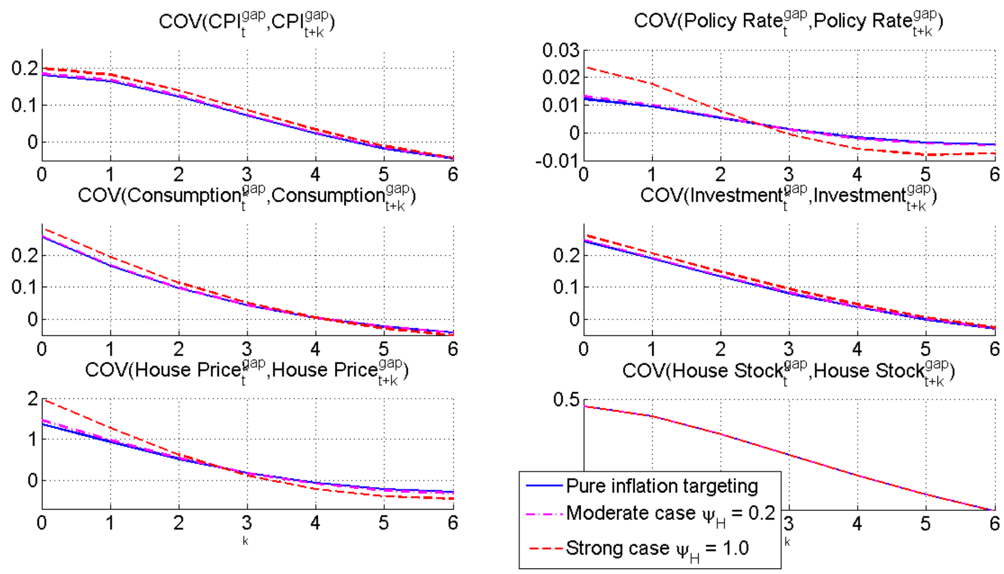


Figure 12: ACF of HP Gaps of Selected Variables ($F = 4$)



5. Summary

This paper describes an extension of the CNB's core model, called g3, incorporating the housing market à la Iacoviello and Neri (2010), in which houses can serve as collateral for financially constrained households. The calibration of the extension aims at enhancing the forecasting properties of the model. We find that if house prices are observed, the forecasting properties improve little. On the other hand, if housing market data are not observed, the extended model significantly improves the forecast, especially for consumption. We interpret this finding as evidence that financial channels play an important role in Czech consumption, but that the collateral probably also takes forms other than houses and apartments.

The shock decomposition under our preferred calibration shows little impact of house prices on inflation, interest rates or real variables. This finding is robust to a wide range of parameter calibrations. It is also consistent with a recent empirical study (cf. Brůha et al. (2013)) which finds that house prices have little effect on household consumption.

Finally, we ask how the volatility and persistence of macroeconomic variables would change if the monetary policy rule also contained house prices, as recently suggested by some economists. We find that under some circumstances, such a modified policy would stabilize house prices, but would increase the volatility and persistence of real macroeconomic variables.

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Appendix A: Technical Appendix

A.1 Model Equations of the g3 Model with the Housing Market

The **patient** households solve a maximization problem of the form:

$$\max_{\mathfrak{H}_t^P(h),B_t(h)\dots} \mathscr{L}_s(h) = E_t \sum_{s=t}^{\infty} \beta^{s-t} \{\exp(\varepsilon_t^{\mathfrak{H}}) \log(\mathfrak{H}_s^P(h)) + \mathscr{U}(C_s^P(h) - \chi H_s^P(h)) + \mathscr{V}(1 - L_s^P(h))$$
$$- \lambda_s^P [P_s^H \mathfrak{H}_s^P(h) + B_s(h) \dots - (1-\delta^{\text{housing}}) P_s^H \mathfrak{H}_{s-1}^P(h) - i_{s-1} B_{s-1}(h) \dots]$$
$$- \mu_s \left[K_s - K_{s-1}^{1-\delta} \left(\frac{J_s}{\delta}\right)^{\delta} + \frac{\eta}{2} \left(\frac{J_s}{J_{s-1}} \frac{1}{\alpha\alpha^J} - 1 \right)^2 K_{s-1} \right] \},$$

where $\mathscr{U}$ is the utility of consumption, $\mathscr{V}(1 - L_s^P(h))$ is the disutility of working (see Andrle et al., 2009) for more details, $\mathfrak{H}_s^P(h)$ is the stock of houses owned by the patient household (h), and $\exp(\varepsilon_t^{\mathfrak{H}})$ is the corresponding preference shock. The other terms (such as capital adjustment costs) are taken from the g3 model (and are almost self-explanatory).

The patient households' budget constraint is given by

$$P_t^H \mathfrak{H}_t^P(h) + B_t(h) + B_t^{P->IMP}(h) + P_t^C C_t^P(h) + P_t^J J_t(h)$$
$$= (1-\delta^{\text{housing}}) P_t^H \mathfrak{H}_{t-1}^P(h) + i_{t-1} B_{t-1}(h) + i_{t-1} B_{t-1}^{P->IMP}(h)$$
$$+ P_t^K K_{t-1}(h) + P_t^C F_t(h) + \Psi_t(h) + \Phi_t(h),$$

where $P_t^H ho_t(h) = P_t^H \mathfrak{H}_t(h) - (1-\delta^{\text{housing}}) P_t^H \mathfrak{H}_{t-1}(h)$ is the nominal value of new houses *ho* bought by patient households and $B^{P->IMP}$ is the debt of impatient households to patient households.

We can unpack the infinite sum of the Lagrangian so that periods $s=t$ and $s=t+1$ appear explicitly

$$\mathscr{L}_{t,t+1}(h) = \log(\mathfrak{H}_t^P(h)) + \dots$$
$$- \lambda_t^P [P_t^H \mathfrak{H}_t^P(h) + B_t(h) \dots - (1-\delta^{\text{housing}}) P_t^H \mathfrak{H}_{t-1}^P(h) - i_{t-1} B_{t-1}(h) \dots]$$
$$- \mu_t \left[K_t - K_{t-1}^{1-\delta} \left(\frac{J_t}{\delta}\right)^{\delta} + \frac{\eta}{2} \left(\frac{J_t}{J_{t-1}} \frac{1}{\alpha\alpha^J} - 1 \right)^2 K_{t-1} \right]$$
$$+ \beta \{ \log(\mathfrak{H}_{t+1}^P(h)) + \dots$$
$$- \lambda_{t+1}^P [P_{t+1}^H \mathfrak{H}_{t+1}^P(h) + B_{t+1}(h) \dots - (1-\delta^{\text{housing}}) P_{t+1}^H \mathfrak{H}_t^P(h) - i_t B_t(h) \dots]$$
$$- \mu_{t+1} \left[K_{t+1} - K_t^{1-\delta} \left(\frac{J_{t+1}}{\delta}\right)^{\delta} + \frac{\eta}{2} \left(\frac{J_{t+1}}{J_t} \frac{1}{\alpha\alpha^J} - 1 \right)^2 K_t \right] \} \dots$$

The problem of impatient households can be stated analogously. The first-order condition (FOC) of impatient households w.r.t. $\mathfrak{H}_t^P$, e.g. w.r.t. the utility of housing, is

$$\frac{1}{\mathfrak{H}_t^P(h)} - \lambda_t^P P_t^H + \beta(-\lambda_{t+1}^P)(-(1-\delta^{\text{housing}})P_{t+1}^H) = 0$$

Rearranging terms, we get:

$$\lambda_t^P P_t^H = \frac{1}{\mathfrak{H}_t^P(h)} + \beta\lambda_{t+1}^P(1-\delta^{\text{housing}})P_{t+1}^H$$

stationarized by $Z_t h\_tech_t$

$$\lambda_t^P P_t^H Z_t h\_tech_t \frac{P_t^Y}{P_t^Y} = \frac{Z_t h\_tech_t}{\mathfrak{H}_t^P(h)} + \beta\lambda_{t+1}^P(1-\delta^{\text{housing}})P_{t+1}^H Z_t h\_tech_t \frac{P_{t+1}^Y Z_{t+1} h\_tech_{t+1}}{P_{t+1}^Y Z_{t+1} h\_tech_{t+1}}$$

and again rearranged

$$\lambda_t^P P_t^Y Z_t \frac{P_t^H h\_tech_t}{P_t^Y} = \frac{Z_t h\_tech_t}{\mathfrak{H}_t^P(h)} + \beta\lambda_{t+1}^P P_{t+1}^Y Z_{t+1}(1-\delta^{\text{housing}})\frac{P_{t+1}^H h\_tech_{t+1}}{P_{t+1}^Y}\frac{Z_t h\_tech_t}{Z_{t+1} h\_tech_{t+1}}$$

finally

$$\tilde{\lambda^P}_t \tilde{P}_t^H = \frac{1}{\tilde{\mathfrak{H}^P}_t(h)} + \frac{\beta\tilde{\lambda^P}_{t+1}(1-\delta^{\text{housing}})\tilde{P}_{t+1}^H}{\dot{Z}_{t+1}\dot{tech}_{t+1}}$$

because $\tilde{\lambda^P}_t = \lambda_t^P P_t^Y Z_t$, $\tilde{P}_t^H = \frac{P_t^H h\_tech_t}{P_t^Y}$ and $\frac{Z_{t+1} h\_tech_{t+1}}{Z_t h\_tech_t} = \dot{Z}_{t+1}\dot{tech}_{t+1}$.

The FOC of patient households w.r.t. B_t, e.g. w.r.t. the utility of investing in bonds, is

$$-\lambda_t^P + \beta(-\lambda_{t+1}^P(-i_t)) = 0$$

rearranged and stationarized

$$\frac{1}{i_t} = \beta\frac{\lambda_{t+1}^P P_{t+1}^Y Z_{t+1}}{\lambda_t^P P_t^Y Z_t}\frac{P_t^Y Z_t}{P_{t+1}^Y Z_{t+1}}$$

finally

$$\frac{1}{i_t} = \beta\frac{\tilde{\lambda}_{t+1}^P}{\tilde{\lambda}_t^P}\frac{1}{\dot{P}_{t+1}^Y \dot{Z}_{t+1}}$$

The **impatient** households solve a maximization problem of the form:

$$\max_{\mathfrak{H}_t^{IMP}(h),B_t^{P->IMP}\dots} \mathscr{L}_s(h) = E_t \sum_{s=t}^{\infty} \beta^{s-t}\{\log(\mathfrak{H}_s^{IMP}(h)) + \mathscr{U}(C_s^{IMP}(h) - \chi H_s^{IMP}(h))\dots$$
$$-\lambda_s^{IMP}[P_s^H \mathfrak{H}_s^{IMP}(h) + i_{t-1}B_{t-1}^{P->IMP}(h)\dots$$
$$-(1-\delta^{\text{housing}})P_s^H \mathfrak{H}_{s-1}^{IMP}(h) - B_t^{P->IMP}(h)\dots]$$
$$-\lambda_s^B[B_t^{P->IMP} - L2V\frac{P_{t+1}^H \mathfrak{H}_t^{IMP}(h)}{i_t}]\},$$

and their budget constraint is given by

$$P_t^H \mathfrak{H}_t^{IMP}(h) + i_{t-1}B_{t-1}^{P->IMP}(h) + P_t^C C_t^{IMP}(h)$$
$$= (1-\delta^{\text{housing}})P_t^H \mathfrak{H}_{t-1}^{IMP}(h) + B_t^{P->IMP}(h) + P_t^C F_t(h) + \Psi_t(h) + \Phi_t(h)$$

where $P_t^H ho_t(h) = P_t^H \mathfrak{H}_t(h) - (1-\delta^{\text{housing}})P_t^H \mathfrak{H}_{t-1}(h)$ is the nominal value of new houses bought by patient households, and by

$$B_t^{P->IMP} = L2V\frac{P_{t+1}^H \mathfrak{H}_t^{IMP}(h)}{i_t}$$

We can unpack the infinite sum of the Lagrangian so that periods $s=t$ and $s=t+1$ appear explicitly

$$\mathscr{L}_{t,t+1}(h) = \log(\mathfrak{H}_t^{IMP}(h)) + \dots - \lambda_t^{IMP}[P_t^H \mathfrak{H}_t^{IMP}(h) + i_{t-1}B_{t-1}^{P->IMP}(h) - \dots$$
$$(1-\delta^{\text{housing}})P_t^H \mathfrak{H}_{t-1}^{IMP}(h) - B_t^{P->IMP}(h)\dots]$$
$$-\lambda_s^B[B_t^{P->IMP} - L2V\frac{P_{t+1}^H \mathfrak{H}_t^{IMP}(h)}{i_t}]$$
$$+\beta\{\log(\mathfrak{H}_{t+1}^{IMP}(h)) + \dots - \lambda_{t+1}^{IMP}[P_{t+1}^H \mathfrak{H}_{t+1}^{IMP}(h) + i_t B_t^{P->IMP}(h)\dots -$$
$$(1-\delta^{\text{housing}})P_{t+1}^H \mathfrak{H}_t^{IMP}(h) - B_{t+1}^{P->IMP}(h)\dots]$$
$$-\lambda_{t+1}^B[B_{t+1}^{P->IMP} - L2V\frac{P_{t+2}^H \mathfrak{H}_{t+1}^{IMP}(h)}{i_{t+1}}]\}\dots$$

The FOC of impatient households w.r.t. $\mathfrak{H}_t^{IMP}$, e.g. w.r.t. the utility of housing, is

$$\frac{1}{\mathfrak{H}_t^{IMP}(h)} - \lambda_t^{IMP} P_t^H - \lambda_t^B(-L2V\frac{P_{t+1}^H}{i_t}) + \beta(-\lambda_{t+1}^{IMP})(-(1-\delta^{\text{housing}})P_{t+1}^H) = 0$$

rearranged

$$\lambda_t^{IMP} P_t^H = \frac{1}{\mathfrak{H}_t^{IMP}(h)} + \beta\lambda_{t+1}^{IMP}(1-\delta^{\text{housing}})P_{t+1}^H + L2V\lambda_t^B\frac{P_{t+1}^H}{i_t}$$

stationarized by $Z_t h\_tech_t$

$$\lambda_t^{IMP} P_t^H Z_t h\_tech_t \frac{P_t^Y}{P_t^Y} = \frac{Z_t h\_tech_t}{\mathfrak{H}_t^{IMP}(h)} + \beta\lambda_{t+1}^{IMP}(1-\delta^{\text{housing}})P_{t+1}^H Z_t h\_tech_t \frac{P_{t+1}^Y Z_{t+1} h\_tech_{t+1}}{P_{t+1}^Y Z_{t+1} h\_tech_{t+1}}$$
$$+ L2V\lambda_t^B\frac{P_{t+1}^H}{i_t} Z_t h\_tech_t \frac{P_{t+1}^Y P_t^Y h\_tech_{t+1}}{P_{t+1}^Y P_t^Y h\_tech_{t+1}}$$

and again rearranged

$$\lambda_t^{IMP} P_t^Y Z_t \frac{P_t^H h\_tech_t}{P_t^Y} = \frac{Z_t h\_tech_t}{\mathfrak{H}_t^{IMP}(h)} + \beta\lambda_{t+1}^{IMP} P_{t+1}^Y Z_{t+1}(1-\delta^{\text{housing}})\frac{P_{t+1}^H h\_tech_{t+1}}{P_{t+1}^Y}\frac{Z_t h\_tech_t}{Z_{t+1} h\_tech_{t+1}}$$
$$+ L2V\lambda_t^B P_t^Y Z_t \frac{P_{t+1}^H h\_tech_{t+1}}{P_{t+1}^Y i_t} h\_tech_t \frac{P_{t+1}^Y}{P_t^Y h\_tech_{t+1}}$$

finally

$$\lambda^{\tilde{IMP}}{}_t \tilde{P}_t^H = \frac{1}{\tilde{\mathfrak{H}}^{\tilde{IMP}}{}_t(h)} + \frac{\beta\lambda^{\tilde{IMP}}{}_{t+1}(1-\delta^{\text{housing}})\tilde{P}_{t+1}^H}{\dot{Z}_{t+1} t\dot{e}ch_{t+1}} + L2V\tilde{\lambda}_t^B\frac{\tilde{P}_{t+1}^H}{i_t}\frac{\dot{P}_{t+1}^Y}{\dot{h}\_tech_{t+1}}$$

because $\tilde{\lambda}_t^B = \lambda_t^B P_t^Y Z_t$, $\tilde{P}_t^H = \frac{P_t^H h\_tech_t}{P_t^Y}$ and $\frac{P_{t+1}^Y h\_tech_{t+1}}{P_t^Y h\_tech_t} = \dot{P}_{t+1}^Y t\dot{e}ch_{t+1}$.

The FOC of impatient households w.r.t. $B_t^{P->IMP}$, e.g. w.r.t. the utility of borrowing from patient households, is

$$\lambda_t^{IMP} - \lambda_t^B + \beta(-\lambda_{t+1}^{IMP}(i_t)) = 0$$

rearranged and stationarized

$$\frac{1}{i_t} = \beta\frac{\lambda_{t+1}^{IMP} P_{t+1}^Y Z_{t+1}}{(\lambda_t^{IMP} - \lambda_t^B)P_t^Y Z_t}\frac{P_t^Y Z_t}{P_{t+1}^Y Z_{t+1}}$$

finally

$$\frac{1}{i_t} = \beta\frac{\tilde{\lambda}_{t+1}^{IMP}}{\tilde{\lambda}_t^{IMP} - \tilde{\lambda}_t^B}\frac{1}{\dot{P}_{t+1}^Y \dot{Z}_{t+1}}$$

The impatient debt

$$B_t^{P->IMP} = L2V \frac{P_{t+1}^H \mathfrak{H}_t^{IMP}(h)}{i_t}$$

is stationarized

$$\frac{B_t^{P->IMP}}{Z_t P_t^Y} = L2V \frac{P_{t+1}^H \mathfrak{H}_t^{IMP}(h)}{i_t Z_t P_t^Y} \frac{tech\_h_{t+1}}{P_{t+1}^Y tech\_h_t} \frac{P_{t+1}^Y tech\_h_t}{tech\_h_{t+1}}$$

rearranged

$$\frac{B_t^{P->IMP}}{Z_t P_t^Y} = L2V \frac{P_{t+1}^H tech\_h_{t+1} \mathfrak{H}_t^{IMP}(h)}{P_{t+1}^Y Z_t tech\_h_t i_t} \frac{P_{t+1}^Y tech\_h_t}{P_t^Y tech\_h_{t+1}}$$

finally

$$\tilde{B}_t^{P->IMP} = L2V \frac{\tilde{P}_{t+1}^H \tilde{\mathfrak{H}}_t^{IMP}(h) \dot{P}_t^Y}{i_t \dot{tech\_h}_{t+1}}.$$

The new houses evolve as

$$ho_t(h) = \mathfrak{H}_t(h) - (1-\delta^{\text{housing}})\mathfrak{H}_{t-1}(h)$$

when stationarized

$$\frac{ho_t(h)}{Z_t tech\_h_t} = \frac{\mathfrak{H}_t(h)}{Z_t tech\_h_t} - (1-\delta^{\text{housing}}) \frac{\mathfrak{H}_{t-1}(h)}{Z_t tech\_h_t} \frac{Z_{t-1} tech\_h_{t-1}}{Z_{t-1} tech\_h_{t-1}}$$

finally

$$\tilde{ho}_t(h) = \tilde{\mathfrak{H}}_t(h) - (1-\delta^{\text{housing}}) \frac{\tilde{\mathfrak{H}}_{t-1}(h)}{\dot{Z}_t \dot{tech\_h}_t}$$

The borrowing by impatient households from patient households enters the patient households' budget constraint

$$\begin{aligned} &P_t^H \mathfrak{H}_t^P(h) + B_t(h) + B_t^{P->IMP}(h) + \ldots = \\ &(1-\delta^{\text{housing}}) P_t^H \mathfrak{H}_{t-1}^P(h) + i_{t-1} B_{t-1}(h) + i_{t-1} B_{t-1}^{P->IMP}(h) \ldots \end{aligned}$$

when stationarized

$$\begin{aligned} &P_t^H \mathfrak{H}_t^P(h) \frac{tech\_h_t}{P_t^Y} \frac{1}{Z_t tech\_h_t} P_t^Y Z_t + B_t(h) \frac{P_t^Y Z_t}{P_t^Y Z_t} + B_t^{P->IMP}(h) \frac{P_t^Y Z_t}{P_t^Y Z_t} + \ldots = \\ &(1-\delta^{\text{housing}}) P_t^H \mathfrak{H}_{t-1}^P(h) + i_{t-1} B_{t-1}(h) \frac{P_{t-1}^Y Z_{t-1}}{P_{t-1}^Y Z_{t-1}} \frac{P_t^Y Z_t}{P_t^Y Z_t} + i_{t-1} B_{t-1}^{P->IMP}(h) \frac{P_{t-1}^Y Z_{t-1}}{P_{t-1}^Y Z_{t-1}} \frac{P_t^Y Z_t}{P_t^Y Z_t} \ldots \end{aligned}$$

when divided by $P_t^Y Z_t$ finally

$$\begin{aligned} &\tilde{P}_t^H \tilde{\mathfrak{H}^P}_t(h) + \tilde{B}_t(h) + \tilde{B}_t^{P->IMP}(h) + \ldots = \\ &(1-\delta^{\text{housing}}) \frac{\tilde{P}_t^H \tilde{\mathfrak{H}^P}_{t-1}(h)}{\dot{Z}_t \dot{tech\_h}_t} + i_{t-1} \frac{\tilde{B}_{t-1}(h)}{\dot{Z}_t \dot{P}_t^Y} + i_{t-1} \frac{\tilde{B}_{t-1}^{P->IMP}(h)}{\dot{Z}_t \dot{P}_t^Y} \ldots \end{aligned}$$

A.2 Steady State

We have a new nominal ratio of nominal consumption to nominal housing, labeled $\frac{P^C C}{P^H ho}$. Let us look at how this ratio influences the ratio of the shadow price of wealth (for patient and impatient households) and the shadow price of wealth for borrowing by patient households.

When we use the FOCs of households w.r.t. consumption and housing, the capital accumulation equation, and the FOC of impatient households w.r.t. borrowing and substitute them into $\frac{P^C C}{P^H ho}$ we get

$$\frac{P^C C}{P^H ho} = \frac{P^C (C^P + C^{IMP})}{P^H \frac{ho}{\mathfrak{H}} (\mathfrak{H}^P + \mathfrak{H}^{IMP})} =$$

$$= \frac{\frac{1}{\lambda^P} P^C C^P \lambda^P + \frac{1}{\lambda^{IMP}} P^C C^{IMP} \lambda^{IMP}}{P^H \frac{ho}{\mathfrak{H}} \left(\frac{1}{\lambda^P P^H \left(1 - \beta^P \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}}\right)} + \frac{1}{\lambda^{IMP} P^H \left(1 - \beta^{IMP} \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}} - L2V \frac{1 - \frac{\beta^{IMP} iwedge\_eulerIMP}{\dot{Z}\dot{P}^Y}}{\dot{Z}\dot{tech\_h}}\right)} \right)}$$

$$= \frac{\frac{\lambda^{IMP}}{\lambda^P} \frac{1-\chi^P}{1-\frac{\chi^P}{\dot{Z}}} + \frac{1-\chi^{IMP}}{1-\frac{\chi^{IMP}}{\dot{Z}}}}{\frac{ho}{\mathfrak{H}} \left(\frac{\lambda^{IMP}}{\lambda^P} \frac{1}{\left(1 - \beta^P \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}}\right)} + \frac{1}{\left(1 - \beta^{IMP} \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}} - L2V \frac{1 - \frac{\beta^{IMP} iwedge\_eulerIMP}{\dot{Z}\dot{P}^Y}}{\dot{Z}\dot{tech\_h}}\right)} \right)}.$$

From the above equation we can see that the shadow price of wealth ratio $\frac{\lambda^{IMP}}{\lambda^P}$ depends on parameters only. We can derive it explicitly.

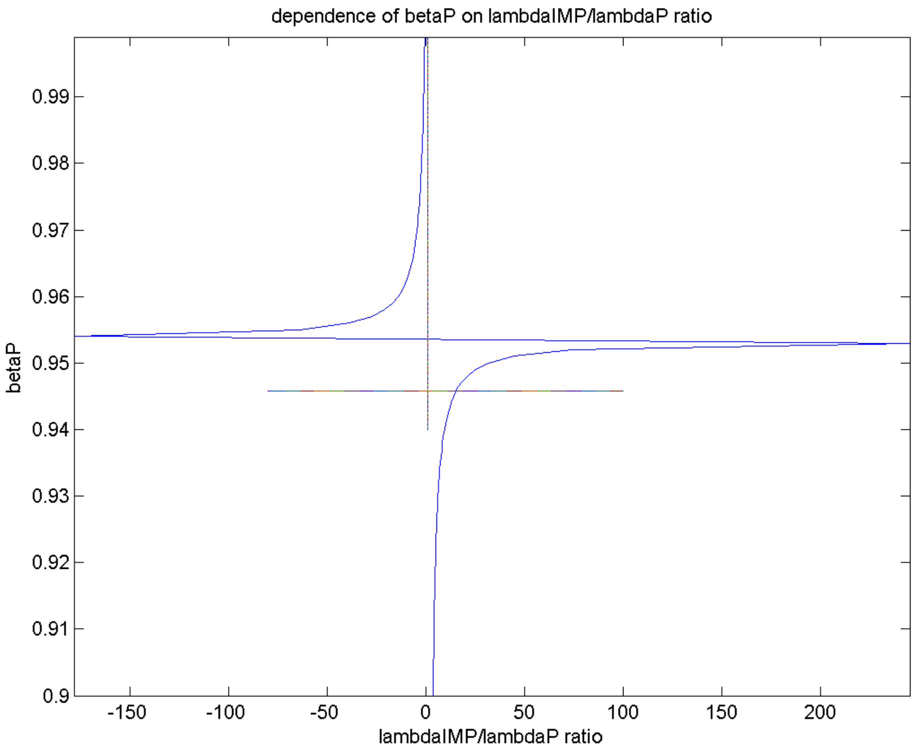
$$\frac{\lambda^{IMP}}{\lambda^P} = \frac{\frac{ho}{\mathfrak{H}} \frac{1}{\left(1 - \beta^{IMP} \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}} - L2V \frac{1 - \frac{\beta^{IMP} iwedge\_eulerIMP}{\dot{Z}\dot{P}^Y}}{\dot{Z}\dot{tech\_h}}\right)} \frac{P^C C}{P^H ho} - \frac{1-\chi^{IMP}}{1-\frac{\chi^{IMP}}{\dot{Z}}}}{\frac{1-\chi^P}{1-\frac{\chi^P}{\dot{Z}}} - \frac{ho}{\mathfrak{H}} \frac{1}{\left(1 - \beta^P \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}}\right)} \frac{P^C C}{P^H ho}}$$

This result is important, because not all parameter settings guarantee a ratio $\frac{\lambda^{IMP}}{\lambda^P} > 1$ which guarantees the crucial effects of a housing preference shock on consumption. Recall that $\beta^P > \beta^{IMP}$. Figure A1 shows the dependence of the lambda ratio on β^P when $\beta^{IMP} = 0.974$, $\dot{Z} = 1.0099 = 4\%yoy$, $\dot{P}^Y = 1.0050 = 2\%yoy$, $i = 1.0074 = 3\%p.a.$, $\chi^P = 0.75$, $\chi^{IMP} = 0.85$, $L2V = 0.9$, $\dot{tech\_h} = 1.005 = 2\%yoy$, $wedge\_eulerIMP = 1$, $\delta_{housing} = 0.0100$, and $\frac{P^C C}{P^H ho} = 1.5333$. We can see that β^P must be between 0.974 and 0.986.

Proof: $\frac{ho}{house_s tock} = \frac{1-(1-\delta^{housing})}{\dot{Z}\dot{tech\_h}}$ comes from the housing stock accumulation equation. $P^C C^P \lambda^P = \frac{1-\chi^P}{1-\frac{\chi^P}{\dot{Z}}}$ and $P^C C^{IMP} \lambda^{IMP} = \frac{1-\chi^{IMP}}{1-\frac{\chi^{IMP}}{\dot{Z}}}$ are the FOCs w.r.t. consumption (patient and impatient). $\mathfrak{H}^{IMP} = \frac{1}{\lambda^{IMP} P^H \left(1 - \beta^{IMP} \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}} - L2V \frac{1 - \frac{\beta^{IMP} iwedge\_eulerIMP}{\dot{Z}\dot{P}^Y}}{\dot{Z}\dot{tech\_h}}\right)}$ and $\mathfrak{H}^P = \frac{1}{\lambda^P P^H \left(1 - \beta^P \frac{1-\delta^{housing}}{\dot{Z}\dot{tech\_h}}\right)}$ are the

FOCs w.r.t housing (impatient and patient). The link between λ^{IMP} and λ^{B}, namely, $\lambda^{B} = (1 - \frac{\beta^{IMP} iwedge\_eulerIMP}{\dot{Z}\dot{P}^{Y}})\lambda^{IMP}$, was used.

Figure A1: Dependence of Beta on Lambda Ratio



A.3 Impulse Responses Compared to g3

Figure A2: Monetary Policy Shock

1

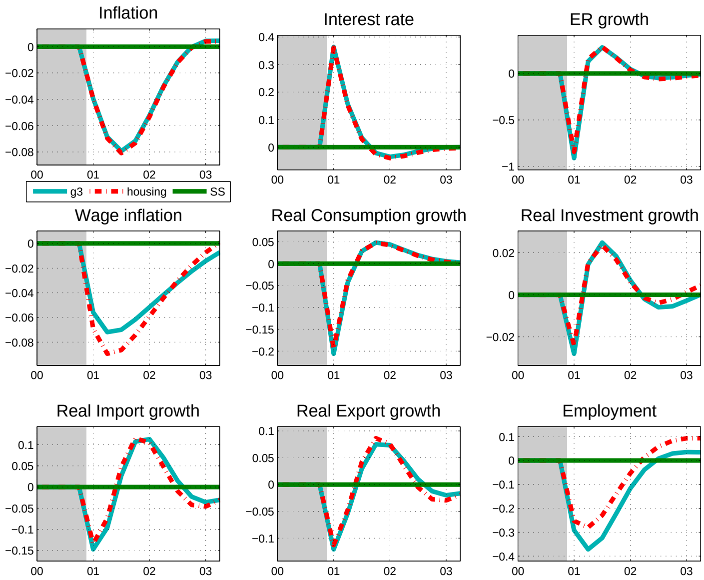
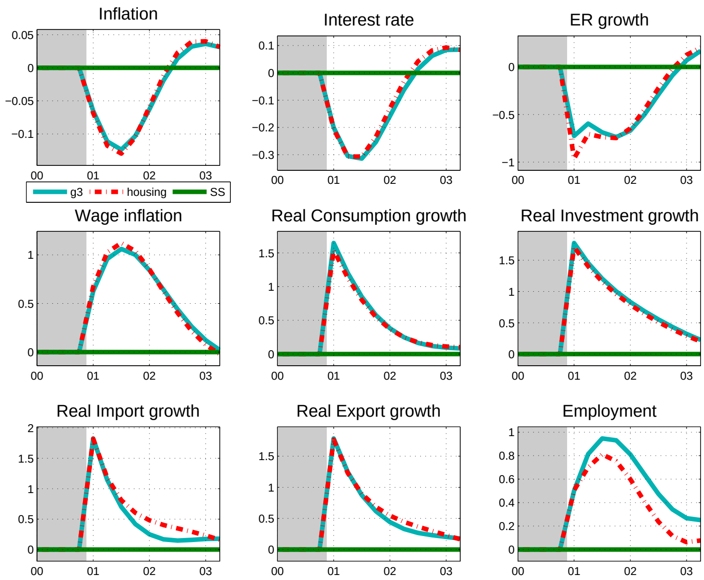


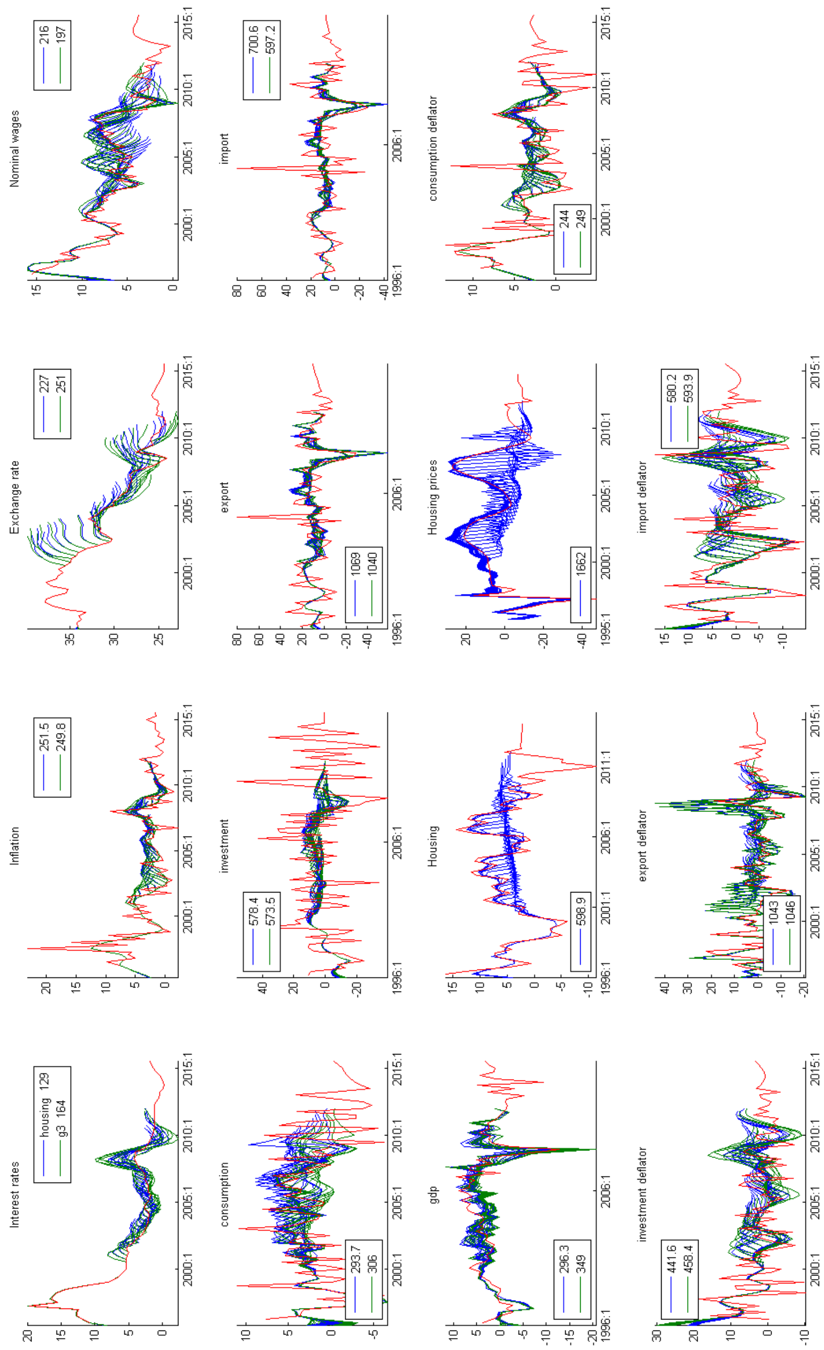
Figure A3: Labour-augmented Technology Shock

1



A.4 In-sample Simulations of g3 Model with and without Housing

Figure A4: Sum of RMSE of Prediction of g3 Model with and without Housing in Legends



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ISSN 1803-7070