The Housing Sector over Business Cycles

Brůha, Jan ; Polanský, Jiří
2014

WORKING PAPER SERIES 12

2014

Jan Brůha, Jiří Polanský:

The Housing Sector over Business Cycles: Empirical Analysis and DSGE Modelling

CZECH NATIONAL BANK

WORKING PAPER SERIES

The Housing Sector over Business Cycles: Empirical Analysis and DSGE Modelling

Jan Brůha
Jiří Polanský

12/2014

CNB WORKING PAPER SERIES

Reviewed by: Viktors Ajevskis (Bank of Latvia)
Andrew Benito (Goldman Sachs)
Daniel Duffy (Economic and Social Research Institute)
František Brázdik (Czech National Bank)

Project Coordinator: Jan Babecký

The Housing Sector over Business Cycles: Empirical Analysis and DSGE Modelling

Jan Brůha and Jiří Polanský *

Abstract

In this paper, we analyse the dynamics of the housing sector over business cycles. First, we provide an empirical analysis of the relationships between housing sector data and the main macroeconomic variables both on Czech data and on a sample of advanced economies. We document that in most countries the housing sector co-moves with the rest of the economy. In the past, the Czech housing market showed temporary episodes during which the housing sector was seemingly disconnected, but since 2005 the housing sector has become more cyclical. Second, we develop a cascade of increasingly complex DSGE models to assess the relative merits of each additional mechanism. Contrary to the popular framework with collateral constraints, we concentrate on the housing sector as an additional production sector via the *standard supply and demand mechanisms*. Our results confirm that these standard mechanisms are sufficient to replicate the observed comovements of housing market variables.

Abstrakt

V tomto článku analyzujeme dynamiku cen nemovitostí určených k bydlení v rámci hospodářských cyklů. Nejprve se zabýváme empirickou analýzou vztahu mezi sektorem nemovitostí určených k bydlení a hlavními makroekonomickými proměnnými v ČR a na vzorku vyspělých ekonomik. Ukazujeme, že ve většině zemí se tento sektor pohybuje souběžně se zbytkem ekonomiky. Česká data ukazují existenci období, v nichž se tento sektor choval nezávisle na zbytku ekonomiky, ale od roku 2005 je více sladěn s hospodářským cyklem. Dále konstruujeme kaskádu dynamických stochastických modelů všeobecné rovnováhy s rostoucí mírou složitosti a posuzujeme relativní význam každého přidávaného mechanismu. Na rozdíl od studií, které se zakládají na finančním omezení, modelujeme sektor nemovitostí určených k bydlení jako další produkční sektor pomocí standardních nabídkových a poptávkových mechanismů. Naše výsledky ukazují, že tento přístup je schopen vysvětlit pozorovaný souběžný vývoj ukazatelů trhu s bydlením.

JEL Codes: E32; R21; R31.
Keywords: Business cycles; DSGE; housing sector.

* Jan Brůha, Czech National Bank; jan.bruha@cnb.cz

Jiří Polanský, Česká spořitelna, a.s.; jpolansky@csas.cz

This paper was prepared as part of Czech National Bank Research Project B5/11. The support is gratefully acknowledged. We are grateful to Viktors Ajevskis, Michal Andrle, Andrew Benito, František Brázdik, Daniel Duffy and David Navrátil for discussions. We also appreciate the *Macro-financial linkages and macro-prudential policy* workshop held at the CNB in 2010 by Jaromír Beneš. The views expressed here are those of the authors and do not necessarily reflect the position of the Czech National Bank or of Česká spořitelna, a.s.

Nontechnical Summary

The housing sector has become one of the most widely discussed topics in contemporary macroeconomics. Economists are interested in understanding the links between the housing sector and the rest of the macroeconomy and explaining the observed comovements between house prices and macroeconomic aggregates. This paper contributes to this discussion and is composed of two parts.

First, we provide an empirical analysis of the relationships between housing data (house prices, housing production and inputs into the construction sector) and the main macroeconomic variables both on Czech data and on a sample of advanced economies. We document that in most advanced countries the housing sector strongly co-moves with the rest of the economy. In the past, the Czech housing market showed temporary episodes during which the housing sector was seemingly disconnected. Based on the literature, we describe these episodes and argue that one can expect the cyclical properties of the Czech housing market to more closely resemble those of advanced economies in future.

Second, we develop an increasingly complex cascade of DSGE models that incorporate the housing sector. These models are used to assess what is needed to model the housing market. Contrary to the popular framework with collateral constraints, we concentrate on the housing sector as an additional production sector via *standard supply and demand mechanisms*. Our results confirm that these standard mechanisms are sufficient to replicate the observed comovements of housing market variables and we conclude that special features such as collateral-constrained households are not needed to get the model to fit the data. The paper also discusses the relevance of various modelling approaches to fitting and explaining the data, especially the role of the utility function.

1. Introduction

Macroeconomic issues associated with the housing sector are among the most widely discussed topics in current macroeconomic analysis. The Great Recession and the associated fall in house prices have intensified this interest. Both academics and policymakers have started to enquire about the links between the housing sector and the rest of the macroeconomy and the underlying causes of the observed comovements between house prices and macroeconomic aggregates. An understanding of these issues will help answer important policy questions such as ‘Do house prices amplify business cycles and should we care strongly about them?’ and ‘Should monetary policy react strongly to booms and busts in house prices?’. The answers to these questions depend on our understanding of the channels between the housing market and the macroeconomy, which means that the macroeconomic linkages of the housing market are of utmost importance.

The objective of this paper is contribute to this important debate. The paper focuses one particular aspect, namely the dynamics of the housing market over the business cycle. There are two main contributions.

The paper starts with an empirical analysis of the comovements between housing sector data and economic activity. We collect data on a sample of advanced countries from two main sources (Eurostat and the Bank for International Settlements) and analyse how various housing sector indicators are related to economic activity over the business cycle. We find that for a typical country, house prices, housing and construction production and inputs into the housing sector are cyclical and slightly more volatile than the output cycle.

We then analyse the Czech housing market data in more detail. We find that some, but not all, housing sector data were disconnected from output dynamics over the business cycle and we identify and discuss specific episodes where this disconnect was most spectacular. Nevertheless, we argue that the alignment of the Czech housing sector with the business cycle has increased over time and we conjecture that the disconnect observed in the earlier period was due to the initial transition conditions and to a specific episode related to EU entry. In that respect, the Czech housing market has recently started to resemble the situation in typical advanced economies, i.e. it has become strongly cyclical.

The second part of the paper is model-based. We ask whether the comovements can be replicated by standard demand and supply factors (such as technology shocks) in a consistent general equilibrium framework. To contribute to this enquiry, we present a cascade of increasingly complex models which explicitly incorporate the housing sector and we compare their performance. The cascade starts with a typical DSGE model carefully calibrated for a small open economy like the Czech Republic. Additional features of the housing sector are added in each extension. We then evaluate the merits of each extension. We conclude with suggestions for modelling the housing sector using DSGE models.

The paper is organised as follows. Section 2 discusses related literature. Section 3 contains the empirical analysis. Section 4 describes the models investigated, while Section 5 describes their properties. The last section 6 concludes. Appendices contain additional materials.

2. Literature

As we noted above, understanding housing price determinants seems to be important for central banks. The spectacular fall in house prices before and during the Great Recession caused a surge of interest in this topic. 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 have been proposed to explain and model the observed statistical association, and structural macroeconomic models have been built to replicate observed features, to shed light on house price dynamics and to assess the role of policy in mitigating house price fluctuations. We can divide the modelling effort into several streams. One of the most popular macroeconomic approaches is centred 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 through financial imperfections. The alternative explanations propose that house price fluctuations are merely a *symptom*, rather than a *cause*, of the business cycle, as in Davis and Heathcote (2005). Moreover, expectations about future economic growth are the source of house price dynamics in Kahn (2008) and Tomura (2010). Finally, some papers claim that significant surges and busts in house prices are due to disagreements among agents about fundamentals – see Tomura (2013) and Piazzesi et al. (2007).

The lack of a consensus is unfortunate, as different mechanisms naturally have different implications. If house prices cause business and financial cycles, it is reasonable to consider including them in monetary, or more generally stabilisation, policy objectives, because house price stabilisation would then help to reduce economic fluctuations with all their social costs.

If, however, house prices are a mere symptom of cyclical fluctuations, then it is less obvious why stabilisation policy should react to them. Of course, a situation may arise where house prices threaten, for example, financial stability, and in such case policymakers may react in an appropriate way. But such an idiosyncratic reaction, however appropriate in some situations, is not the same as making house prices part of the systematic policy function.

Finally, if studies asserting that house price fluctuations are caused by behavioural failures (irrationality) are right, house prices should be the domain of financial literacy policy rather than macroeconomic stabilisation policy. Again, under this hypothesis, macroeconomic policymakers may find it necessary to react to house price fluctuations in some special situations, but the response should not consist in changing the systematic part of macroeconomic policy.

For this reason, it is important to analyse the mechanisms underlying the observed relationship between house prices and macroeconomic dynamics.

As stated above, Iacoviello and Neri (2010) is the workhorse of structural macroeconomic models with a housing sector and financial frictions through collateral-constrained households. They 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 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 as loan collateral, leading to credit expansion. This expansion increases aggregate demand, which, in turn, fosters a temporary rise in economic activity.

The popularity of the Iacoviello and Neri (2010) framework has resulted in a number of followers who have used this framework to enquire about important monetary policy issues.[1] The empirical relevance of this framework was confirmed by Christensen et al. (2009) on Canadian data. On the other hand, Tonner and Brůha (2014) use the Iacoviello-Neri framework and extend the CNB's g3 core forecasting model. They find that for realistic calibration, house price fluctuations do not have a significant impact on consumption or output. They conclude that for the Czech Republic, the mechanism that links the housing sector with the rest of the economy through the collateral constraint is not important. This is in line with the empirical study by Brůha et al. (2013a).

There are interesting alternatives. For example, Bajari et al. (2013) propose a model with heterogeneous agents to study the interaction between house prices, housing choice and consumption through the life cycle. They find significant evidence for non-separability between consumption and housing in the utility function.

2.1 Empirical Studies

Although macroeconomic structural modelling is dominated by models with credit-constrained households (although with the exceptions outlined above), empirical microeconomic studies do not unanimously find support for a credit channel between house price fluctuations and the consumption choice of households.

Campbell and Cocco (2007) on UK data find that although there is a link between the financial market (easing)[2] and house prices (positive effect), they do not confirm the collateral effect of house prices on consumption. Attanasio et al. (2009) provide evidence on UK data that the collateral channel is probably not the source of the comovement between house prices and consumption and identify expectations as the likely cause. This is because the estimated effect is roughly the same for both homeowners and renters, which casts the credit constraint channel in doubt. Likewise, McCarthy and McQuinn (2013) on Irish data find significant responses of consumption to house price shocks, but not through any form of credit constraint.

Cooper (2013) is one of the few empirical papers to report a significant collateral channel, but unlike the above-mentioned studies it does not control for household characteristics (home ownership) and therefore we consider the identification less plausible than the above-mentioned studies.

There has been some interesting research on the relation between the macroeconomy and the housing market in the Czech Republic, too. Hlaváček and Komárek (2011) use econometric analysis to

[1] For example, Walentin and Sellin (2010) aim at quantifying the role played by housing collateral in the monetary transmission mechanism, specifically the impact of the loan-to-value ratio. They 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. Lambertini et al. (2010) analyse housing market boom-bust cycles driven by changes in households' expectations. They investigate the role of expectations. They find that, in the presence of nominal rigidities, expectations on 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.

[2] This channel has been confirmed by a number of subsequent studies and is intuitive: the decision to buy a house is usually made by young and financially constrained agents, so alleviation of the financial constraints on such agents results in increased demand.

enquire about the macroeconomic determinants of house prices. Brůha et al. (2013a) use a matching estimator to estimate the effect of house price changes on the consumption, savings and indebtedness of households, with an identification strategy based on house ownership and spatial patterns of house price changes. They find little evidence for the effect of house price changes on consumption.

3. Empirical Analysis

This part of the paper contains the contribution to analysing the comovements between housing sector data and economic activity. In the first part of this section we carry out the analysis on a set of advanced economies, while the second subsection concentrates on the Czech data. We are mainly concerned with house prices and housing construction quantities and also with labour inputs into the housing sector. On the other hand, we do not discuss wages in the construction sector. This because wages, unlike hours worked or employment, do not display a clear cyclical pattern in most advanced countries (Abraham and Haltiwanger, 1995; Brůha and Polanský, 2015). There are several possible reasons for this, but we do not discuss them here.[3]

3.1 International Data

In this part of the paper, we provide international evidence on the comovement between housing market variables and economic activity using data from advanced countries. We deliberately use a large cross-section of countries since the length of the relevant time series is typically not impressive. If we find that some feature is stable across countries, we can be more certain that this is a genuine feature of market economies, not just an outcome of statistical chance.

Our dataset consists of the following countries: Austria, Belgium, Bulgaria, Croatia, the Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, the UK and the U.S. Our sample starts at 1980Q1 and ends at 2014Q1. Although some countries have data right from 1980, not all countries have all the time series available. We therefore include a particular country in our sample only if it has the relevant time series with a length of at least 12 quarters. For most macroeconomic series, our data come from Eurostat.

First, we investigate the cyclicality of house prices in advanced countries. We therefore compute sample correlations of the cyclical component of output with house prices. We concentrate on the cyclical component from each series since we are interested in business cycle dynamics.[4] It is difficult to obtain good and long house price data series for a large sample of countries. We are aware of two sources: Eurostat and the BIS.[5] The Eurostat data should be methodologically homogeneous[6], but they have the disadvantage of starting at 2005 for almost all countries. The BIS

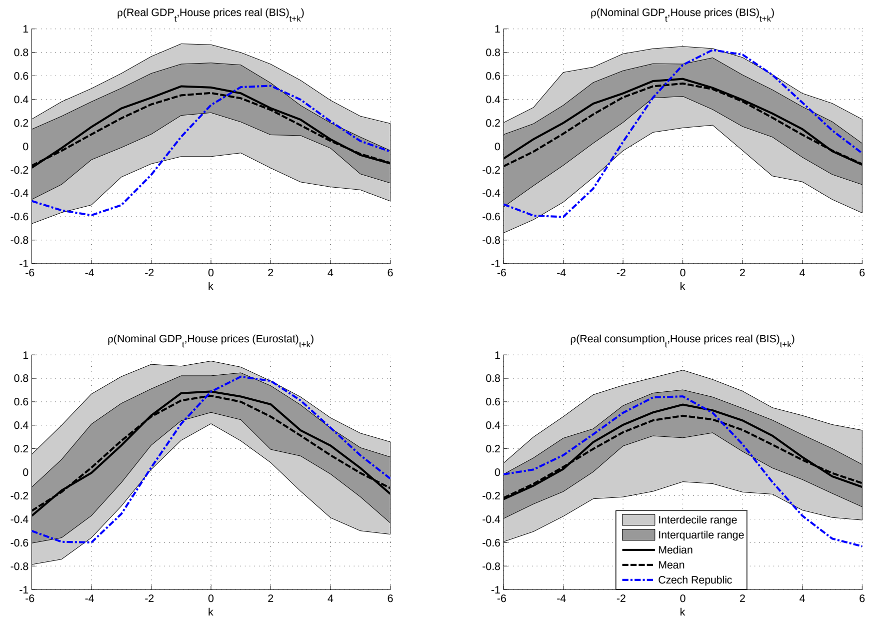
[3] The reader may consult Brůha et al. (2013b), who describe several issues associated with (whole-economy) wages which one should take into account carefully during real-time forecasting. The evolution of average measures can be affected by wage distribution effects or tax optimisation, and we conjecture that these factors may be responsible for hindering wage cyclicality.

[4] By default, we isolate cycles using the Christiano and Fitzgerald (2003) filter. As a robustness check we also consider the Lesser filter (known in macroeconomics also as the Hodrick-Prescott filter (Hodrick and Prescott, 1997) and the results are almost the same. We will be happy to provide details upon request.

[5] Sources: national sources, BIS Residential Property Price database, `http://www.bis.org/statistics/pp.htm`.

[6] See `http://epp.Eurostat.ec.europa.eu/cache/ITY_SDDS/EN/prc_hps_esms.htm` for the data methodology.

Figure 1: Cyclicality of House Prices



dataset contains longer series for some countries, but the series are not fully harmonised despite serious efforts to choose as similar series as possible from each country. The BIS dataset contains both nominal series and real series (deflated by the CPI), while the Eurostat house price data contain only nominal indices. We therefore compute three types of correlations: (i) the nominal BIS data index versus nominal GDP, (ii) the real BIS data index versus real GDP and (iii) the Eurostat index versus nominal GDP. The results are almost the same for all three types of comparison, which could have been expected as the cyclical dynamics are dominated by real movements. Finally, we consider (iv) the correlation of real house prices with real consumption.

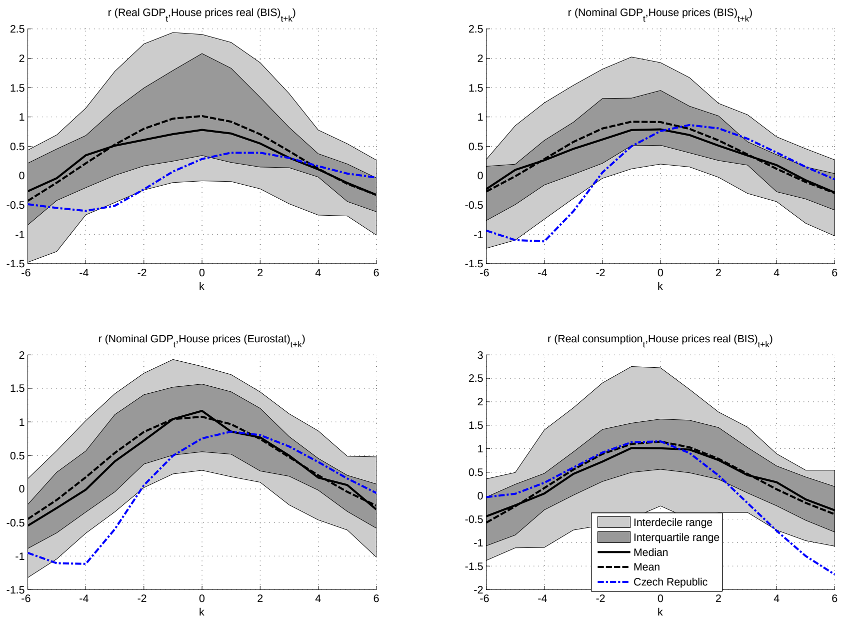
The results can be seen in Figure 1, which shows the correlation of the cyclical component of output with the cyclical components of various house price indices at lags ranging from -6 quarters to 6 quarters. In the figure, we display the mean and median correlations and also the interquartile and interdecile ranges for the cross-section of countries in the sample. Moreover, we display the sample correlation for the Czech data. Apparently, house prices are cyclical. A more detailed analysis based on individual countries reveals that the house price cycle usually lag the output cycle.[7] The Czech Republic is in accordance with the other countries in this respect, as its correlations peak at $k = 2$ (real variables) or $k = 1$ (nominal variables).[8]

The correlation of house prices with real consumption usually peaks with the lag of several quarters, and the point estimate of the maximum of this correlation is slightly lower than for the correlation of house prices and output. Our understanding of this finding is that, if nothing else, it does not point to the collateral channel, because if the collateral channel were responsible for the cyclicality of house prices, one would not expect the correlation of consumption with house prices to peak typically *after* the correlation of house prices with output.

[7] To keep the paper as short as possible, we do not present figures for individual countries (except for the Czech Republic). These figures can be provided on request.

[8] This is because the Czech house price data in *both* datasets start in 2005, i.e. the 2002–2004 episode is not included. This issue will be described later.

Figure 2: Elasticity of House Prices (Cyclical Frequencies)



Being a measure of cyclicality, the correlations are silent on the relative variances. It may also be revealing to look at the regression coefficient[9] as a measure of the *elasticity* of a variable to the cycle. Elasticity measures how much one variable is *responsive* to movements in another rather than the *intensity* of comovement, which is measured by correlation.[10]

The median (and mean) regression coefficient peaks at 1, which means that in an 'average' country, house price cyclical dynamics are volatile to about the same degree as the output cycle. In the Czech Republic, the house price cycle is slightly less volatile than the output cycle, but still, the Czech Republic is not an exceptional country in this regard.

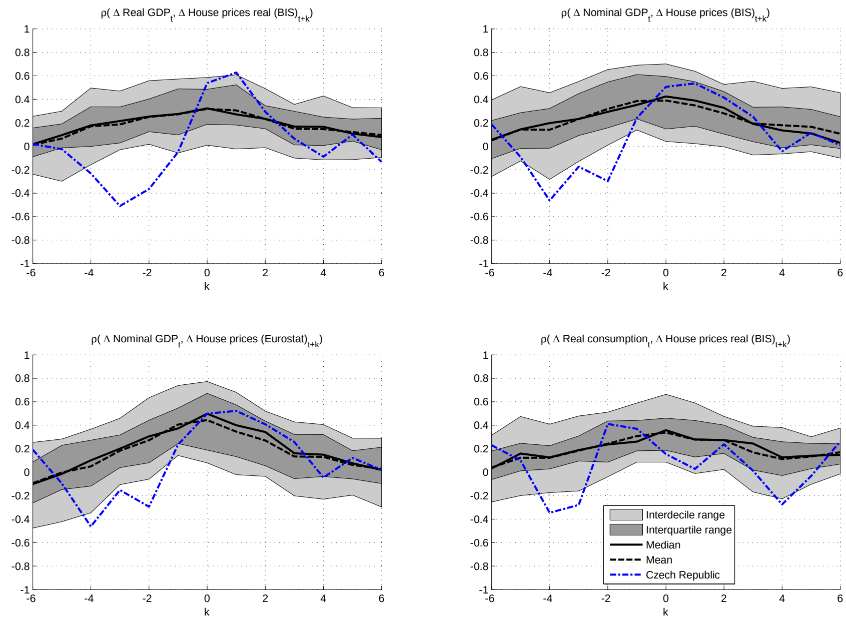
As noted above, all these conclusions remain valid if we use the Lesser-Hodrick-Prescott filter to isolate the cyclical components. The situation is different, however, if we analyse the growth rates. Then, both the cyclicality (correlations) and the elasticity disappear. For the case of correlations, this is illustrated in Figure 3. This phenomenon is caused by the nature of the difference filter, which amplifies the short-run dynamics,[11] i.e. the noise in both series, which, in turn, lowers both measures of interest.

[9] The regression coefficient is defined as $\mathrm{r}_{yx} = cov(y,x)/var(x)$ and it is obviously linked to the correlation coefficient $\rho_{x,y}$ as follows: $\mathrm{r}_{yx} = \sqrt{var(y)/var(x)}\rho_{x,y}$. Hence, for a given correlation, the regression coefficient is high if the variance of y is high relative to the variance of x.

[10] One can easily imagine a situation of high correlation and low elasticity (if the movement in one variable is perfectly synchronised with that in the second variable, but the former variable is much less volatile) and a situation of low correlation but high elasticity (if one variable responds strongly to the second one, but is subject to other orthogonal driving forces).

[11] One sometimes encounters objections to the isolation of specific frequencies using linear filters, with the implicit suggestion that growth rates are somehow 'better' as they are not subject to ad-hoc filtration. We do not share this view: the differencing of a time series *also* involves the application of a linear filter, which has its own transfer function. And this transfer function rises from zero at frequency $\omega = 0$ to 2 at frequency $\omega = \pi$, which means that it amplifies high frequencies.

Figure 3: Correlation of Growth Rates of House Prices and Output



Another important dimension of the data is the output of the construction sector, or more specifically buildings (we are not interested in civil engineering projects). We can also consider other related variables, such construction dwelling permits, which should in principle be a forward-looking indicator. Figure 4 shows the correlation of the volume of constructed buildings[12] and dwelling permits measured both by number and by square metres. For comparison, we also include office permits measured by square metres.[13]

In all countries, including the Czech Republic, the building volume is a cyclical variable. In a typical country, permits and building volumes both lag by one quarter, while in the Czech Republic the lag is about two quarters. In most countries, all these variables are very elastic: the standard errors of the cyclical parts of these variables are usually several times higher than the standard error of the output cycle (see Figure 5). In other words, prices in many countries are more cyclical but less elastic to the cycle than the quantities considered here. Again, one can consider growth rates instead of cyclical components, but as with prices the growth rates are less correlated.

Finally, we look at the correlation of cycles in labour input into construction and output cycles. For the purposes of this paper, it would be nice to have labour inputs going only into house construction, but such data are not available to us. Therefore, we use three measures: (i) persons employed in the subsector of the construction sector related to buildings, (ii) hours worked in the same subsector and (iii) hours worked in the whole of NACE F (construction in the national accounts). For comparison, we also include total hours worked[14] according to the national accounts. The results are presented in Figure 6.

[12] See `http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/EN/sts_esms.htm` for a description of the data.

[13] Construction of offices is also a part of building construction, and we are interested in knowing whether office permit dynamics are very different from dwelling permit dynamics to gauge what might be hidden in the dynamics of building volumes.

[14] Brůha and Polanský (2015) and Ohanian and Raffo (2012) find that hours worked are more cyclical than the number of persons employed.

Figure 4: Correlation of Construction Output and Real Output (Cyclical Frequencies)

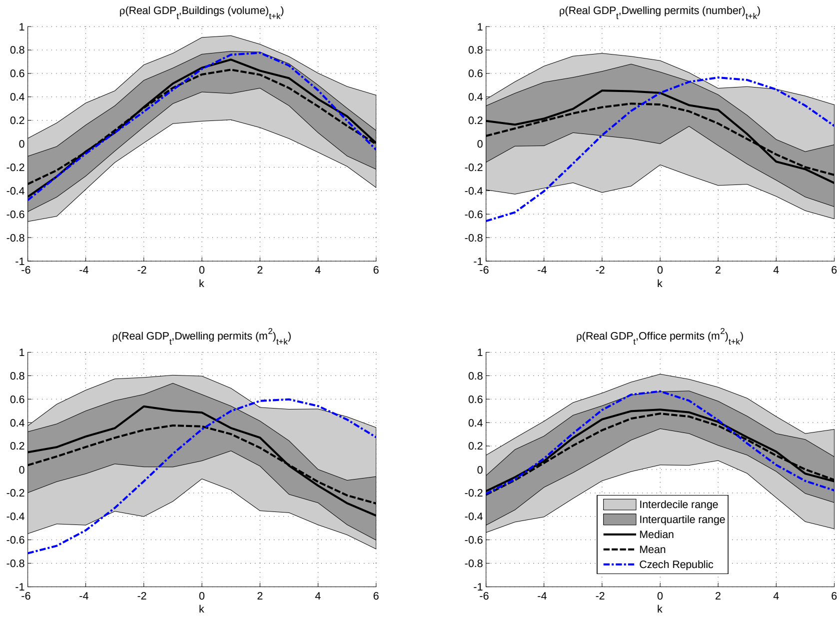


Figure 5: Elasticity of Construction Output to Output Cycle

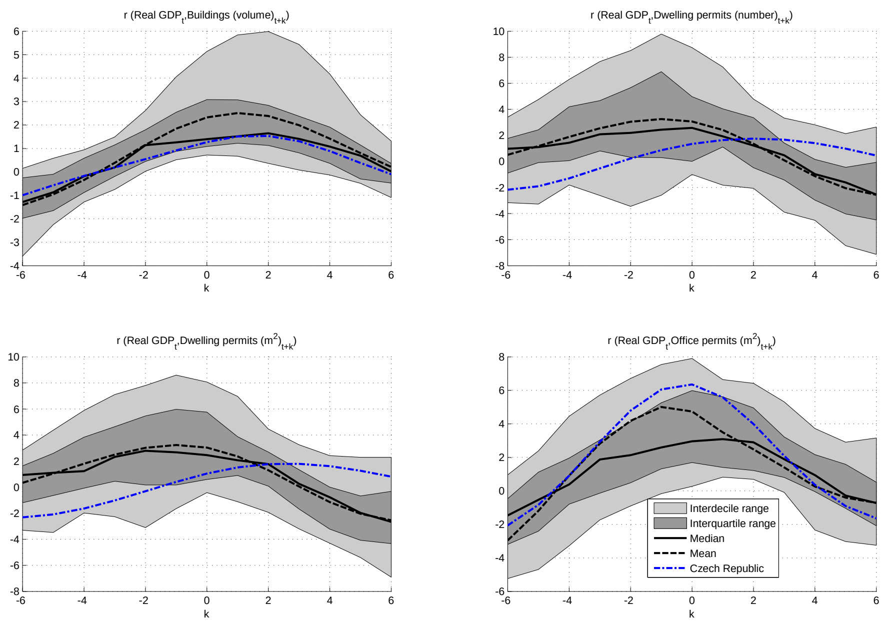
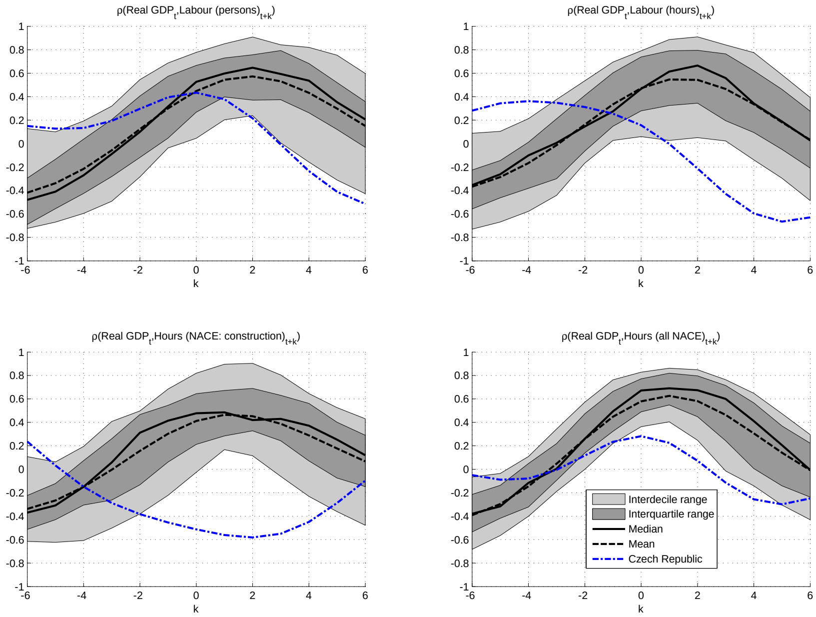


Figure 6: Correlation of Labour Inputs into Construction Sector and Output (Cyclical Frequencies)



In a typical country, employment and hours worked in construction as well as total hours worked are cyclical variables, lagging behind the cycle by one or two quarters. In the Czech Republic, labour input into NACE F as a whole is acyclical, due to civil engineering.

In the next subsection, we show that the Czech housing sector data are similar in many respects to what is observed in advanced countries, i.e. they are synchronised at business cycle frequency.

3.2 Czech Economy Data

The preceding subsection described the stylised facts for a sample of advanced countries. In this subsection, we concentrate in more detail on Czech data, as for the Czech Republic we were able to collect more detailed and longer time series than those available in international databases.

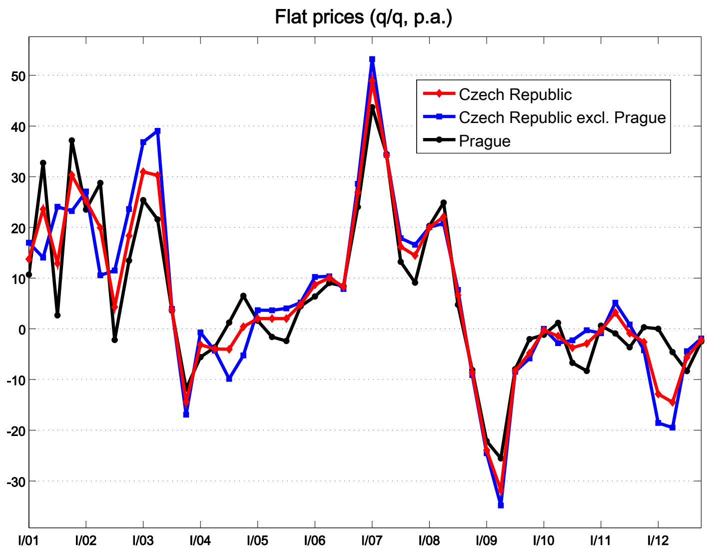
For modelling purposes, we consider it more appropriate to link our model-based house prices to the observed time series of *flat* (apartment) prices rather than *house* prices in the Czech Republic.[15] The reason for this choice is the following: flats are the dominant way of living in larger towns and cities, where their prices should reflect business cycles. House prices, on the other hand, are influenced by several factors which we do not focus on. Examples include demographic factors, job opportunities in rural areas and the development of railways and highways allowing for long-distance commuting.[16] Also, houses in villages and small towns are built by residents who usually plan to live there. Since trade in these houses is not deep, house prices are not subject to business cycles as much as flat prices in cities are.

[15] The international datasets contain an average of the two.

[16] In the Czech Republic in the 1990s, there was a significant surge in demand for new houses on the outskirts of big cities (in satellite villages). We assume that this tendency is no longer dominant, since this type of 'commuter' has started to again prefer smaller towns with good public transport connections and public services.

Figure 7 depicts the quarter-on-quarter per annum (q/q, p.a.) growth rate of flat prices for the whole economy and for the economy excluding Prague, and of flat prices in Prague. The evolution (and thus the economic story) of each time series is similar in all cases, allowing us to choose the whole economy index as our observable for house prices.

Figure 7: Flat Prices (q/q, p.a.)

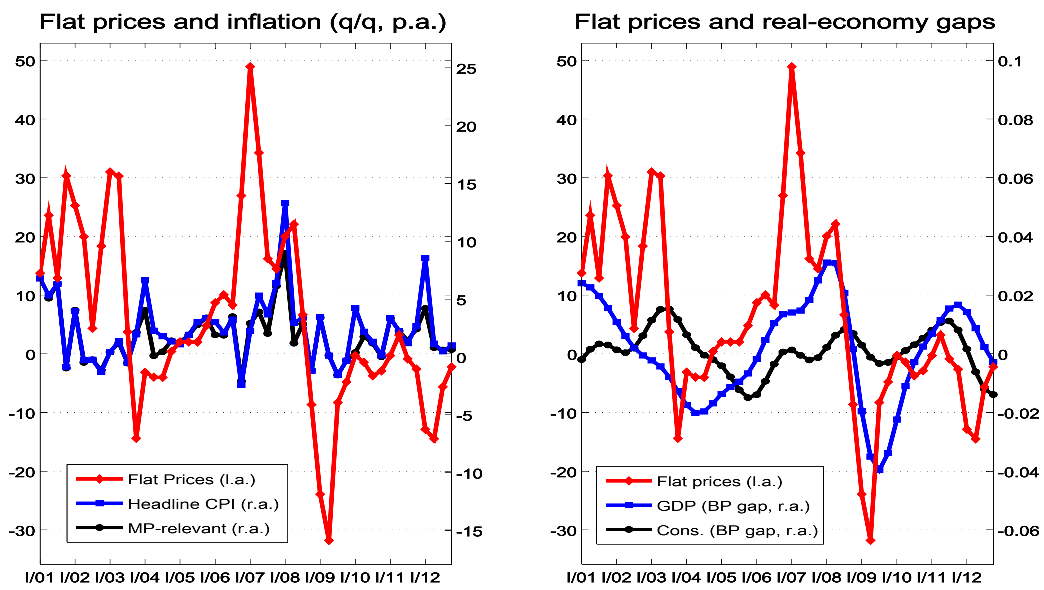


The evolution of flat prices can be divided into several historical episodes. First, the beginning of the series shows relatively high (although volatile) growth in flat prices, followed by a drop in 2003. The significant rise in flat prices in 2002 is often attributed to expectations of increased demand for apartments after the Czech Republic's expected entry into the European Union in May 2004 (see Hlaváček and Komárek, 2009). The popular story then continues that during 2003, when it became clear that there would no massive inflow of EU citizens into the Czech Republic, flat prices decreased sharply. Thus, the data may contain an irrational surge in house prices (an irrational bubble) which was pricked in 2003.

Second, the 2004–2006 period is characterised by a gradual recovery of flat prices. This was followed by a steep increase in 2006–2007. The growth of flat prices stayed high during the first half of 2008, maybe reflecting the significant economic boom the Czech economy was undergoing at the time. The developments in 2007 and 2008 are sometimes referred to as a bubble (see Hlaváček and Komárek, 2011) due to the magnitude of the increase. And third, the Great Recession caused a deep slump in flat prices. From 2010 onwards, flat prices are (on average) decreasing, possibly waiting for a recovery of the Czech economy.

In Figure 8 we compare flat prices in the Czech economy with inflation and real-economy gaps. Flat prices (on the left-hand axis) are much more volatile than headline and monetary policy-relevant inflation (both on the right-hand axis). Moreover, their comovement is not strong. In the right panel, we compare flat prices (on the left-hand axis) with the GDP and consumption cycles (both on the right-hand axis). We interpret the evidence in the figures as follows: first, the comovement between flat prices and the GDP gap is strong. This may indicate that flat prices in the Czech economy reflect the cycle and demand-driven factors. Second, despite this comovement, flat prices decoupled from GDP in 2002–2003, possibly indicating a bubble. Third, the comovement between flat prices and consumption is less strong than that between flat prices and GDP. This does not support the existence of strong wealth channels.

Figure 8: Comovement of Flat Prices with Inflation and Real-Economy Gaps



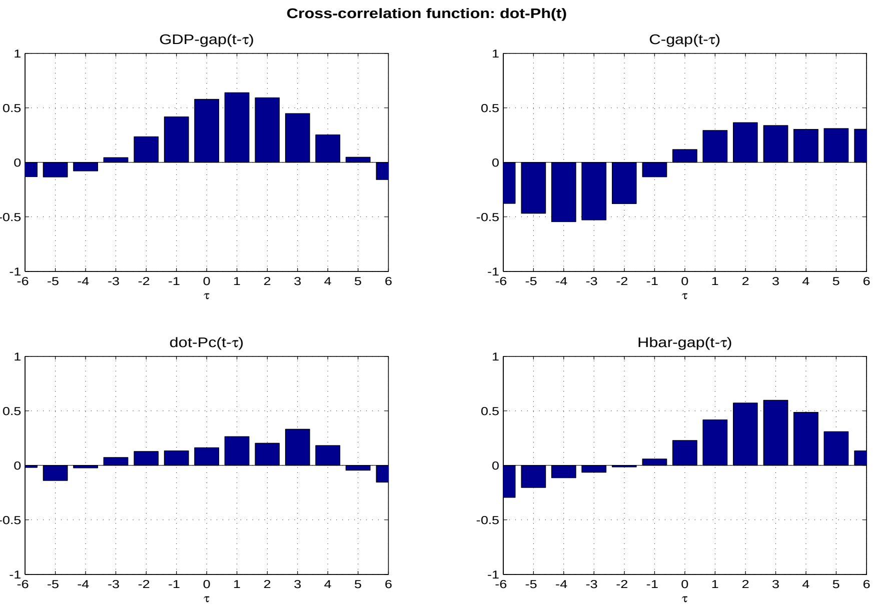
To sum up, prior to 2005 house prices were driven by forces other than cyclical fluctuations alone. Since 2010, prices have been more aligned with the cycle.

As a measure of volumes in the Czech Republic we choose the time series of construction production in the housing sector. In general, we want a variable which captures the dynamics of new house construction or investment in the housing sector. This is the main reason why we are not interested in linking the housing stock implied by the model to some observed counterpart. Due to the high possible uncertainty and difficulty in measuring the housing stock in an economy, we focus on construction production, which should bear more information about business cycles. This is equivalent to the investment-capital law of motion in production sectors.

Figure 9 shows the correlation histogram of flat prices (dot-Ph) with the GDP gap, the consumption gap (C-gap), MP-relevant inflation (dot-Pc) and the housing construction gap (Hbar-gap).[17] The figure shows a relatively significant correlation between flat prices and the business cycle (the GDP gap). The correlation between flat prices and inflation or the consumption gap is negligible.[18] These panels confirm that flat prices reflect business cycles and do not indicate significant wealth effects in the Czech economy. The last panel shows that housing construction lags behind prices. This can be partly explained by the fact that construction investment is linked more strongly with GDP.

[17] The gaps are acquired using the band pass filter (Christiano and Fitzgerald, 2003) at 6–32 quarter frequency. As a check, we use the HP filter (Hodrick and Prescott, 1997) with the standard value for the smoothing parameter ($\lambda = 1{,}600$), which gives similar results.
[18] The high negative correlation in the four-period lag is probably caused by a previous cycle.

Figure 9: Correlation of Flat Prices with Inflation and Real-Economy Gaps



Figures 10 and 11 present a detailed inspection of construction production. The comovement (the third panel in 10) between housing construction and economic activity is relatively strong, except in 2003–2004. Moreover, construction lags behind the GDP gap in 2006–2009, but evolves contemporaneously from 2010 onwards. This can be explained by the rapid increase in housing construction in 2006, when the Czech business cycle (then in a boom phase) switched to a more robust position. As the impact of the recession was not anticipated in real time, the lag of housing construction in 2009 can be explained by construction firms' expectations of a rapid return to economic growth and also probably by the fact that it was less costly to finish some construction projects than to stop them. Since 2010, construction developers seem to have been careful to follow the business cycle.[19] Figure 11 presents the correlation between the housing construction gap and several variables and shows that housing construction lags behind the GDP gap, does not co-move strongly with the consumption gap and MP-relevant inflation, and also lags behind house prices.

All in all, although the housing market has become cyclical, the correlations between housing market variables and macro aggregates are not always impressive even at business cycle frequencies. We argued that the relatively low correlations (compared to advanced countries) may be due to short time series that are contaminated by the particular episode of 2002–2004 (see above for a discussion). Nevertheless, we still think that the housing market dynamics are dominated by standard demand and supply effects that can be related to the real economy. Moreover, given the recent developments, we consider it likely that the Czech housing sector will move closer to the cyclical patterns observed in advanced countries.

[19] The latest development (change in behaviour) is one of the reasons why we do not incorporate time-to-build housing investment (Kydland and Prescott, 1982) into the model described in the next sections.

Figure 10: Housing Construction

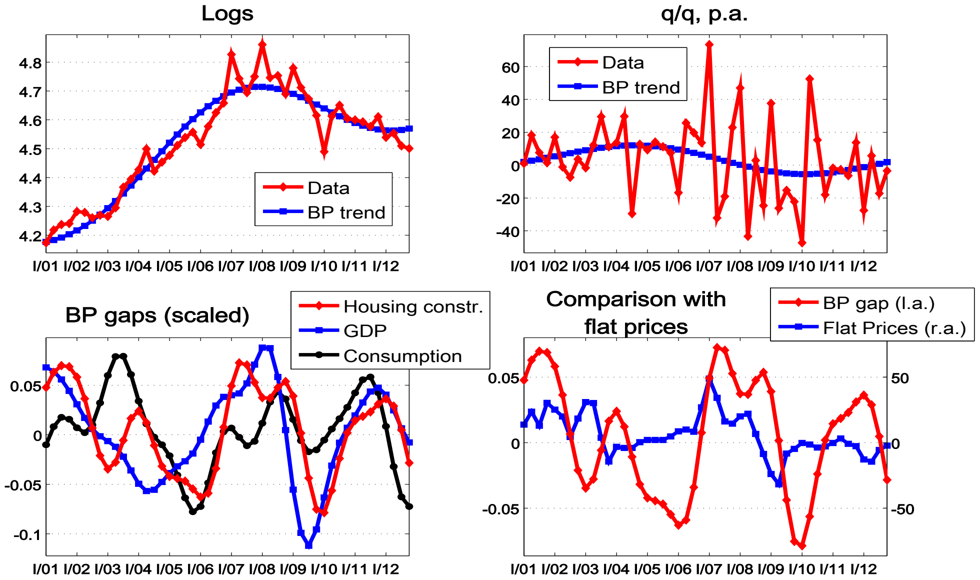
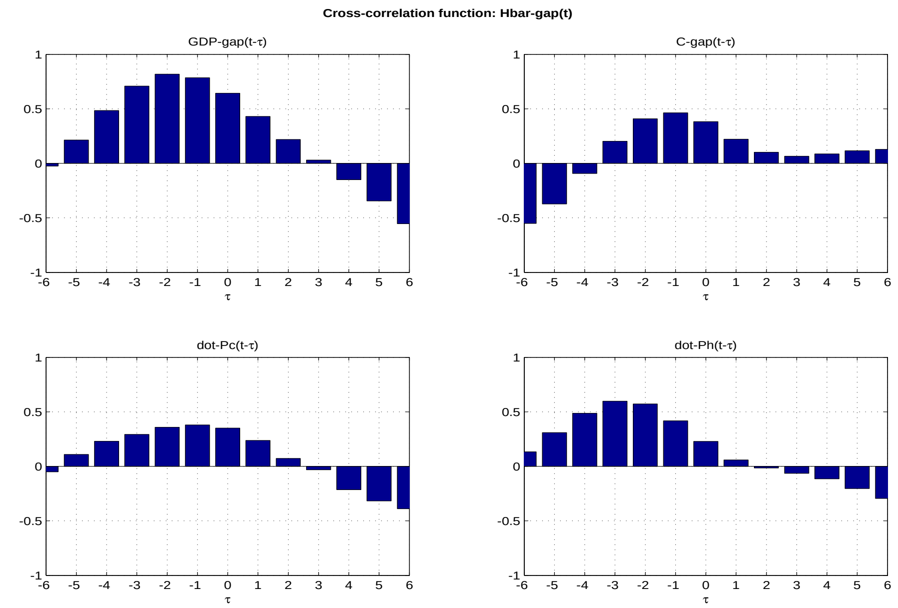


Figure 11: Correlation of Housing Construction with Real-Economy Gaps and Flat Prices



4. Models

In this section, we introduce a cascade of DSGE models containing the housing sector. To keep the analysis concise, we focus mainly on the motivation behind the model structures, our assumptions, and subsequent optimisation problems. The first-order conditions can be found in Appendix A. We start with the baseline framework without the housing sector and then continue with several model extensions in the next subsections. The complexity of the models gradually increases.[20]

The notation of the models is as follows:

- Bars denote economy-wide variables, which are considered to be exogenous from the perspective of optimising households and firms. We therefore refrain from using indices for the continua of monopolistic competitive households and firms in order to provide a more lucid description of the model. All individual households and firms are assumed to be too small to affect aggregate variables.
- All models are derived up to the first order, then a symmetric equilibrium is assumed, e.g. $\bar{C}_t = C_t$ for aggregate consumption.
- Dots over variables denote quarter-on-quarter (q/q) growth rates.
- Tildes over variables denote denomination in foreign currency.

4.1 Baseline Model

The baseline framework (Figure 12) is inspired by the g3 model (Andrle et al., 2009) in terms of its overall structure and some important features. We consider this framework to be suitable for modelling the Czech economy, and it can thus be used as a starting framework for the housing sector extensions.[21] Although our baseline model is rather simpler than g3, i.e. it does not contain regulated prices, quality of goods and so on, it inherits most importantly g3's balanced growth path with long-run real exchange rate appreciation and export-specific and openness technologies. These features are important for capturing Czech stylised facts and also significantly reduce the drifting of structural parameters due to structural changes and the ongoing convergence process of the Czech economy (Tonner et al., 2011). Also, the model contains a cascade of nominal rigidities within its production structure, which, together with local currency pricing, implies multiple stages of gradual exchange rate pass-through (Andrle et al., 2009).

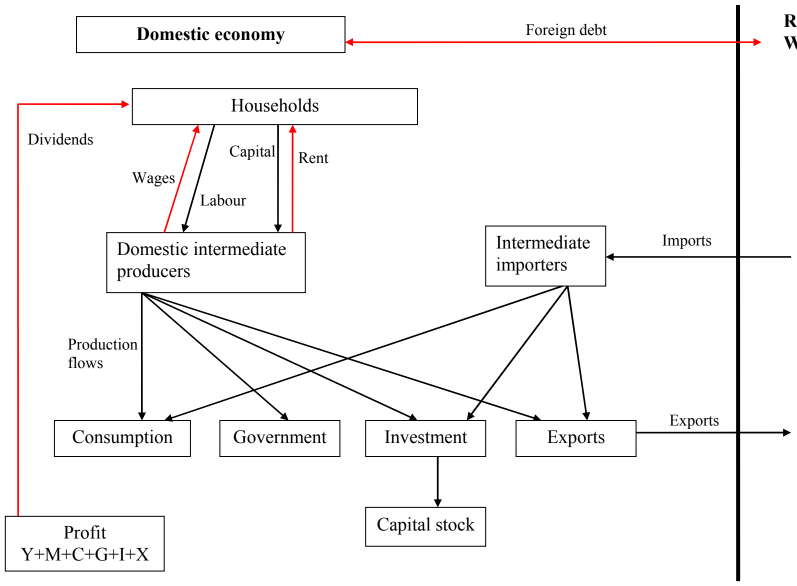
4.1.1 Households

Households consume, make investment decisions, supply differentiated labour, rent capital and trade domestic government bonds. Also, they own all firms in the domestic economy and thus receive dividends (or finance those firms internally).

Formally, they maximise a utility function separable in logarithmic consumption with external habit formation (Abel, 1990) and linear leisure (Hansen, 1985) subject to the budget constraint and a

[20] Although we analyse a different topic, we are inspired by the structure of the paper by Schmitt-Grohé and Uribe (2003).
[21] The model has also proved itself to be useful for regular forecasting during turbulent times such as the Great Recession (Brůha et al., 2013b).

Figure 12: Model Structure – Baseline



Black lines – real flows, red lines – financial flows

downward-sloping labour demand curve:[22]

$$\max_{C_t,B_t,I_t,K_t,L_t,W_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \right) \Bigg\{ (1-\chi)\log(C_t - \chi \bar{C}_t^F) + \phi_L a_t^L (1-L_t)$$
$$-\lambda_t \Bigg[P_t^C C_t + P_t^I I_t + B_t - W_t L_t - R_{t-1} B_{t-1} - Q_t K_{t-1} - P_t^C T_t - \Phi_t$$
$$+\lambda_t^K \left[K_t - K_{t-1}^{1-\delta_K} \left(\frac{I_t}{\delta_K} \right)^{\delta_K} + \frac{\eta_K}{2} \left(\frac{I_t}{I_{t-1}} \frac{1}{\alpha \alpha^I} - 1 \right)^2 K_{t-1} \right] \Bigg] \Bigg\},$$

where $\mathbb{E}_0$ is an expectations operator conditional on the information available up to period 0, C_t is real consumption, $\bar{C}_t^F \equiv \exp(\varepsilon_t^C)\bar{C}_{t-1}$ denotes external habit formation with habit (demand) shocks ε_t^C, I_t is real investment, K_t is the capital stock, B_t denotes domestic government bonds, L_t denotes hours worked, W_t is the nominal wage, R_t is the domestic interest rate, Q_t denotes rent from capital, P_t^C is the consumption deflator, P_t^I is the price of investment, T_t denotes lump-sum transfers, Φ_t denotes dividend payments, λ_t is the shadow price of wealth, λ_t^K is the price of capital,[23] a_t^L is a temporary process for labour supply shocks, β_τ is the discount factor, χ is a habit formation parameter, ϕ_L is a parameter scaling hours worked in the utility function, δ_K denotes the capital depreciation rate, η_K is an investment adjustment costs parameter, α is the long-run aggregate growth of the economy and α^I determines the long-run growth of real investment.

[22] The Calvo-Yun setup (Calvo, 1983; Yun, 1996) with a full indexation scheme for Phillips curve derivation is used for all monopolistically competitive sectors in all models. During model development, we also used a setup with quadratic costs of price adjustment (Rotemberg, 1982a,b; Beneš et al., 2009), which yielded similar dynamics.
[23] Note that the law of motion of capital is inserted into the budget constraint.

The downward-sloping labour demand is

$$L_t = \left(\frac{W_t}{\bar{W}_t}\right)^{-\nu_w} \bar{L}_t,$$

where ν_w is the elasticity of substitution among differentiated labour types.

4.1.2 Domestic Intermediate Firms

There is a continuum of domestic intermediate producers. Using hired labour and rented capital from households, firms produce differentiated intermediate goods, which are used consecutively in the next stage of production (final-goods sectors).

Domestic intermediate producers minimise their costs subject to the Cobb-Douglas production technology

$$\min_{k_t,L_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0}\right) \left[Q_t k_t + W_t L_t + q_t^Y (Y_t - a_t^Y k_t^{1-\gamma_L} (A_t L_t)^{\gamma_L})\right],$$

where Y_t is domestic intermediate output, a_t^Y denotes total factor productivity (TFP), k_t is the capital stock substituted into period t, i.e. $k_t \equiv K_{t-1}$, q_t^Y denotes nominal marginal costs in intermediate production, A_t is labour-augmenting technology,[24] γ_L denotes the share of labour in production and $\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0}$ is the nominal pricing kernel.[25]

Also, domestic intermediate firms maximise their profits subject to the downward-sloping demand curve and the Calvo-Yun setup with a full indexation scheme:

$$\max_{Y_t,P_t^Y} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0}\right) \left[P_t^Y Y_t - q_t^Y Y_t\right],$$

where P_t^Y is the price of domestic intermediate goods. The downward-sloping demand curve is

$$Y_t = \left(\frac{P_t^Y}{\bar{P}_t^Y}\right)^{-\nu_y} \bar{Y}_t,$$

where ν_y is the elasticity of substitution among differentiated domestic intermediate products.

4.1.3 Intermediate Importers

A continuum of importers costlessly differentiate a single foreign bundle.[26] Due to the local currency pricing, imported goods are sticky in the domestic currency.

[24] The two technology shocks are allowed to have different persistence. Introducing labour-augmenting (Harrod-neutral) technology is necessary to ensure a balanced growth path of the model (Barro and Sala-i-Martin, 2004).

[25] Since firms are owned by households, the firms' discount factor contains the marginal utility of real wealth (Dib, 2001). Andrle et al. (2009) define a kernel between periods s and t as $\beta^{s-t}\frac{\lambda_s}{\lambda_t}$. Since β is not a constant in our case, the kernel is modified to $\prod_{\tau=t+1}^{s} \beta_\tau \frac{\lambda_s}{\lambda_t}$.

[26] Following Andrle et al. (2009), there is a continuum of countries in the world, where one of them is the home country. In the first step, a continuum of exporters in each country compete only within their own country, which results in a single bundle from each country. In the second step, an international bundler packs all these bundles together into a single good, which is subsequently differentiated costlessly by a continuum of importers in each country.

Importers maximise their profits analogously to domestic intermediate-goods producers, i.e.

$$\max_{M_t, P_t^M} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[P_t^M M_t - P_t^* M_t \right],$$

where the downward-sloping demand curve and the indexation scheme are analogous to the previous case. Nominal marginal costs P_t^* are world prices in the domestic currency.

4.1.4 Consumption Goods-Producing Firms

Each consumption goods-producing firm uses domestic and imported intermediate inputs via Leontief technology.[27] Each firm minimises its costs of production

$$\min_{Y_t^C, M_t^C} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \Bigg[P_t^Y Y_t^C + (P_t^M A_t^X)(M_t^C / A_t^X) \\ - q_t^C \left(C_t - \min \left(\frac{Y_t^C}{1-\omega_C}, \frac{(M_t^C / A_t^X)}{\omega_C} \right) \right) \Bigg],$$

where Y_t^C and M_t^C are domestic and imported intermediate goods, which are used for the production of consumption goods, and A_t^X is export-specific technology, which makes the use of imported goods less productive and more expensive (Andrle et al., 2009).

Profit maximisation (price setting) is analogous to other production sectors. Firms in each final goods-producing sector are monopolistically competitive and face a downward-sloping demand curve with a full indexation scheme

$$\max_{C_t, P_t^C} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[P_t^C C_t - q_t^C C_t \right].$$

4.1.5 Government Goods-Producing Firms

Government goods-producing firms use only domestic intermediate goods for their production purposes. The production technology is

$$G_t = Y_t^G,$$

where G_t denotes real government consumption and Y_t^G is the part of domestic intermediate production used for the production of government goods.

Profit maximisation is of the same form as in previous cases, i.e.

$$\max_{G_t, P_t^G} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[P_t^G G_t - q_t^G G_t \right],$$

where the downward-sloping demand curve is analogous to that for other final goods-producing sectors.

[27] Using CES production technology instead of the Leontief function does not have any significant effects on the behaviour or performance of the models.

4.1.6 Investment Goods-Producing Firms

The investment goods-producing sector faces similar optimisation problems to consumption goods-producing firms, i.e.

$$\min_{Y_t^I, M_t^I} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[P_t^Y Y_t^I + (P_t^M A_t^X)(M_t^I / A_t^X) - q_t^I \left(I_t - \min\left(\frac{Y_t^I}{1-\omega_I}, \frac{(M_t^I/A_t^X)}{\omega_I} \right) \right) \right]$$

and

$$\max_{I_t, P_t^I} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[P_t^I I_t - q_t^I I_t \right].$$

4.1.7 Export Goods-Producing Firms

As for the consumption and investment sectors, final export goods are produced from both domestic and imported intermediate goods. Due to local currency pricing, export prices are sticky in the foreign currency

$$\min_{Y_t^X, M_t^X} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[P_t^Y Y_t^X + (P_t^M A_t^X)(M_t^X / A_t^X) - q_t^X \left(X_t - \min\left(\frac{Y_t^X}{1-\omega_X}, \frac{(M_t^X/A_t^X)}{\omega_X} \right) \right) \right]$$

and

$$\max_{X_t, \widetilde{P}_t^X} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[\widetilde{P}_t^X X_t - q_t^X X_t \right].$$

4.1.8 Forex Dealers

The UIP equation is derived under the assumption that foreign bond traders face quadratic trading costs, i.e.

$$\max_{B_t^*} \mathbb{E}_0 \left[\left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) S_{t+1} B_t^* R_t^* - S_t B_t^* - S_t \frac{\zeta}{2} \Im_t^{uip} (B_t^*)^2 \right],$$

where S_t is the nominal exchange rate, B_t^* denotes foreign government bonds, R_t^* is the foreign interest rate and ζ is a parameter governing trading costs denoted by $\Im_t^{uip}$.

4.1.9 Monetary and Fiscal Policy

The central bank targets year-on-year inflation four periods ahead via open market operations

$$\log R_t = \rho_R \log R_{t-1} + (1-\rho_R) \left[\log R + \psi \log \left(\frac{\dot{P}_{t+4}^{yy}}{\dot{P}^{yy}} \right) \right] + \varepsilon_t^{mp},$$

where $\frac{\dot{P}^{yy}_{t+4}}{\dot{P}^{yy}}$ is the deviation of year-on-year inflation four periods ahead from the target, ρ_R is the parameter governing interest rate smoothing and ψ is the weight on the deviation from the target capturing the reactiveness of the central bank. As the model contains the national accounts, the consumption deflator appears in equation (A.1). To simplify the framework we assume that the consumption deflator equals the CPI in each period.

Fiscal policy is Ricardian. Nominal government consumption is linked to nominal private consumption

$$\log\left(\frac{P^G_t G_t}{P^C_t C_t}\right) = \rho_G \log\left(\frac{P^G_{t-1} G_{t-1}}{P^C_{t-1} C_{t-1}}\right) + (1-\rho_G)\log\left(\frac{P^G G}{P^C C}\right) + \varepsilon^G_t.$$

4.2 Extension I: Houses Fall from the Sky

First, we capture a hypothetical situation in which the quantity of houses is exogenous – as if houses fall from the sky. Such a framework, although unsuitable for practical purposes (historical filtration and forecasting), can be considered a very first confrontation with real house price data. Of course, such a model does not contain a mechanism for explaining volumes.

Compared with the baseline model, households have direct utility from ownership of houses.[28] Also, households can trade their houses (the equilibrium, of course, implies zero net trade). The structure of the model is presented in Figure 13, where the green lines depict flows associated with the housing sector.

We index utility from houses using parameter η, which can vary from 0 to infinity. By manipulating this parameter, one can model different situations, such as housing as a luxury or inferior good relative to non-durable consumption:

$$\begin{aligned}\max_{C_t,B_t,I_t,K_t,L_t,W_t,H_t} \mathbb{E}_0 \sum_{t=0}^{\infty}\left(\prod_{\tau=0}^{t}\beta_\tau\right)\Bigg\{ & (1-\chi)\log(C_t-\chi\bar{C}^F_{t-1}) + \frac{\phi_H \exp(\varepsilon^H_t) H_t^{1-\eta}}{1-\eta} + \phi_L a^L_t (1-L_t) \\ & -\lambda_t\Bigg[P^C_t C_t + P^I_t I_t + B_t + \lambda^H_t H_t - W_t L_t - R_{t-1}B_{t-1} - \lambda^H_t H_{t-1} - Q_t K_{t-1} - P^C_t T_t - \Phi_t \\ & + \lambda^K_t\left[K_t - K_{t-1}^{1-\delta_K}\left(\frac{I_t}{\delta_K}\right)^{\delta_K} + \frac{\eta_K}{2}\left(\frac{I_t}{I_{t-1}}\frac{1}{\alpha\alpha^I}-1\right)^2 K_{t-1}\right]\Bigg]\Bigg\},\end{aligned}$$

where H_t denotes the stock of houses, ε^H_t is a housing preference shock, $\lambda^H_t \equiv P^H_t$ is the price of the housing stock,[29] ϕ_H is a scaling parameter and η is the utility curvature with respect to the stock of houses.

The process for the amount of houses is an exogenous AR(1) defined as follows:

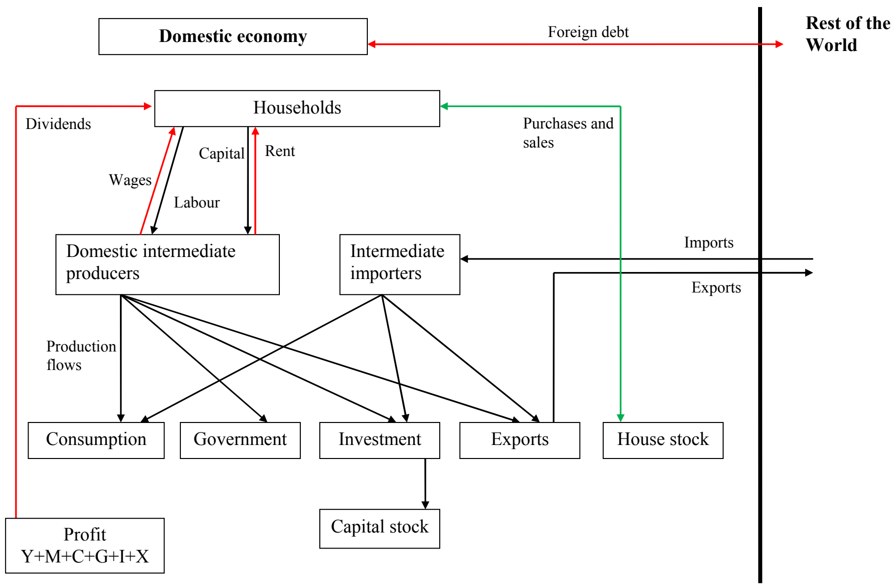
$$\log H_t = \rho_H \log H_{t-1} + (1-\rho_H)\log H + \varepsilon^{\mathfrak{H}}_t,$$

where ρ_H is an autoregressive parameter and $\varepsilon^{\mathfrak{H}}_t$ is the exogenous shock.

[28] Throughout the paper, we do not distinguish between houses and flats and denote their volume as 'houses', 'the stock of houses' or 'the housing stock'.

[29] We denote house prices by λ^H_t (instead of P^H_t) to be compatible with the rest of the housing sector models presented in the next subsections.

Figure 13: Model Structure – Houses Fall from the Sky



Black lines – real flows, red lines – financial flows, green lines – housing sector

4.3 Extension II: Houses Are Produced from Intermediate Output

In the second extension, we assume that new houses are produced from domestic intermediate output. As in other production sectors in the model(s), new house-producing firms are monopolistically competitive and owned by households. After new houses are produced, they become a part of the housing stock H_t (via the law of motion), which enters the utility function in the same way as in the previous model. Also, households do not trade or rent the stock of houses. The structure of the model is shown in Figure 14.

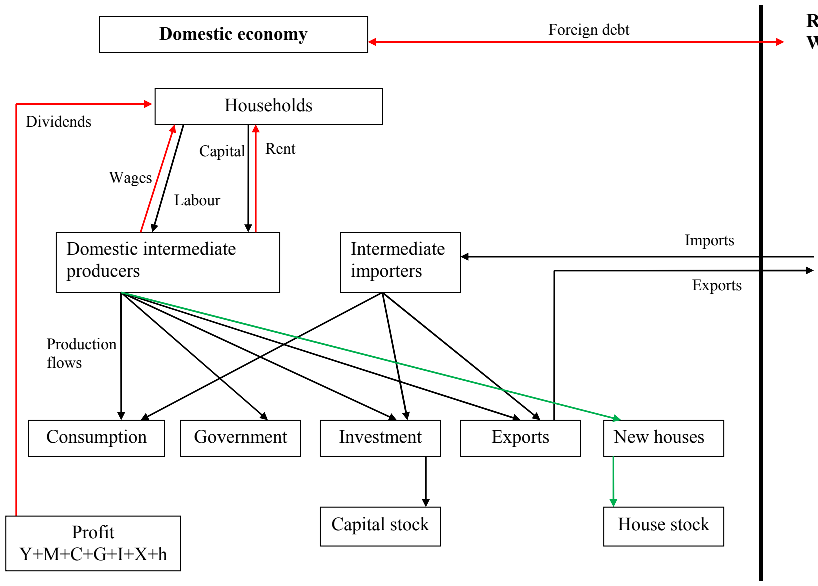
4.3.1 Households

The optimisation problem of households is

$$\max_{C_t,B_t,I_t,K_t,L_t,W_t,H_t,\hbar_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \right) \Bigg\{ (1-\chi)\log(C_t - \chi \bar{C}_t^F) + \frac{\phi_H \exp(\varepsilon_t^H) H_t^{1-\eta}}{1-\eta} + \phi_L a_t^L (1-L_t)$$
$$-\lambda_t \Big[P_t^C C_t + P_t^I I_t + B_t + P_t^{\hbar} \hbar_t - W_t L_t - R_{t-1} B_{t-1} - Q_t K_{t-1} - P_t^C T_t - \Phi_t$$
$$+\lambda_t^K \left[K_t - K_{t-1}^{1-\delta_K} \left(\frac{I_t}{\delta_K} \right)^{\delta_K} + \frac{\eta_K}{2} \left(\frac{I_t}{I_{t-1}} \frac{1}{\alpha \alpha^I} - 1 \right)^2 K_{t-1} \right]$$
$$+\lambda_t^H \left[H_t - H_{t-1}^{1-\delta_H} \left(\frac{\hbar_t}{\delta_H} \right)^{\delta_H} + \frac{\eta_H}{2} \left(\frac{\hbar_t}{\hbar_{t-1}} \frac{1}{\alpha \alpha^H} - 1 \right)^2 H_{t-1} \right] \Big] \Bigg\},$$

where λ_t^H is the price of the housing stock, $P_t^{\hbar}$ is the price of new houses, $\hbar_t$ denotes new houses and η_H is an adjustment cost parameter, and α^H determines the long-run growth of newly produced

Figure 14: Model Structure – Houses Are Produced from Intermediate Output



Black lines – real flows, red lines – financial flows, green lines – housing sector

houses. The law of motion for the housing stock is analogous to the one used for the capital stock, i.e. the modified adjustment cost function of Kim (2003) used by Andrle et al. (2009) in the g3 model.

4.3.2 New House-Producing Sector

Similarly to the government goods-producing sector, monopolistically competitive firms produce new houses only from domestic intermediate goods. The production function is therefore

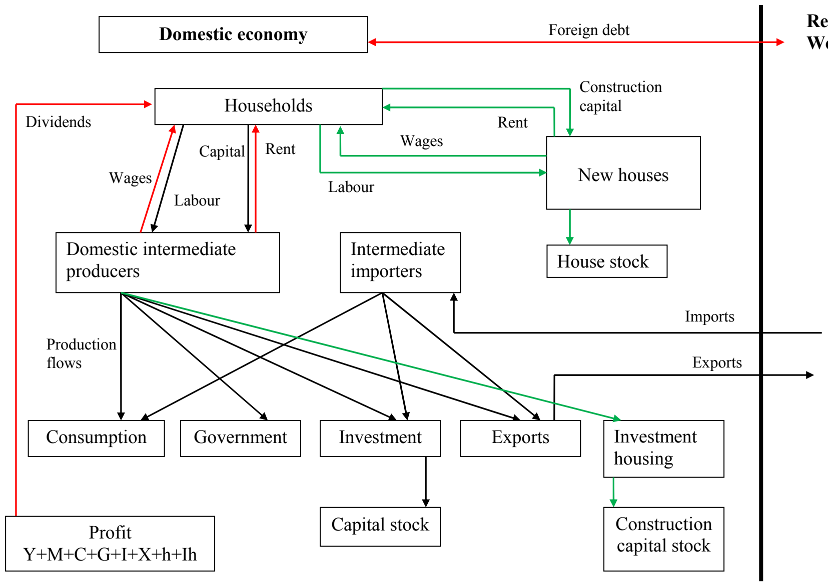
$$Y_t^{\hbar} = \hbar_t,$$

where $Y_t^{\hbar}$ denotes the part of domestic intermediate goods Y_t which is used for the production of new houses.

4.4 Extension III: Houses Are Produced from Sector-Specific Inputs

In the next extension we assume that new houses are produced from sector-specific inputs. Besides providing labour and capital to domestic intermediate firms, households supply labour and rent construction capital to firms which produce new houses. Newly produced houses become a part of the housing stock, which is an argument of households' utility function. The construction capital is transformed (via a law of motion) from housing investment final goods. We assume that firms which produce housing investment final goods are monopolistically competitive and use only domestic intermediate goods as their production input. The structure of the model is shown in Figure 15.

Figure 15: Model Structure – Houses Are Produced from Sector-Specific Inputs



Black lines – real flows, red lines – financial flows, green lines – housing sector

4.4.1 Households

Households supply sector-specific labour and capital to new house-producing firms. They receive payments for these inputs (sector-specific wages and rent) and also dividends from both types of newly introduced firms, i.e. new house-producing firms and housing investment-producing firms. On the expenditure side of the budget constraint they purchase new houses and housing investment. Households maximise a utility function which has the form

$$
\begin{aligned}
\max_{C_t,B_t,I_t,K_t,L_t,W_t,H_t,\hbar_t,\mathscr{I}_t,\mathscr{K}_t,\ell_t,\mathscr{W}_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \right) \Bigg\{ & (1-\chi)\log(C_t - \chi \bar{C}_t^F) + \frac{\phi_H \exp(\varepsilon_t^H) H_t^{1-\eta}}{1-\eta} \\
& + \phi_L a_t^L (1-L_t) + \phi_\ell a_t^\ell (1-\ell_t) - \lambda_t \Big[P_t^C C_t + P_t^I I_t + B_t + P_t^{\hbar} \hbar_t + P_t^{\mathscr{I}} \mathscr{I}_t \\
& - W_t L_t - \mathscr{W}_t \ell_t - R_{t-1} B_{t-1} - Q_t K_{t-1} - \mathscr{Q}_t \mathscr{K}_{t-1} - P_t^C T_t - \Phi_t \\
& + \lambda_t^K \left[K_t - K_{t-1}^{1-\delta_K} \left(\frac{I_t}{\delta_K} \right)^{\delta_K} + \frac{\eta_K}{2} \left(\frac{I_t}{I_{t-1}} \frac{1}{\alpha \alpha^I} - 1 \right)^2 K_{t-1} \right] \\
& + \lambda_t^H \left[H_t - H_{t-1}^{1-\delta_H} \left(\frac{\hbar_t}{\delta_H} \right)^{\delta_H} + \frac{\eta_H}{2} \left(\frac{\hbar_t}{\hbar_{t-1}} \frac{1}{\alpha \alpha^H} - 1 \right)^2 H_{t-1} \right] \\
& + \lambda_t^{\mathscr{K}} \left[\mathscr{K}_t - \mathscr{K}_{t-1}^{1-\delta_{\mathscr{K}}} \left(\frac{\mathscr{I}_t}{\delta_{\mathscr{K}}} \right)^{\delta_{\mathscr{K}}} + \frac{\eta_{\mathscr{K}}}{2} \left(\frac{\mathscr{I}_t}{\mathscr{I}_{t-1}} \frac{1}{\alpha \alpha^{\mathscr{I}}} - 1 \right)^2 \mathscr{K}_{t-1} \right] \Big] \Bigg\},
\end{aligned}
$$

where ℓ_t denotes labour in the housing sector, $\mathscr{W}_t$ is the nominal wage in the housing sector, $\mathscr{I}_t$ denotes real housing investment, $P_t^{\mathscr{I}}$ is the housing investment deflator, $\mathscr{Q}_t \mathscr{K}_{t-1}$ is households' income from the rented capital stock, $\lambda_t^{\mathscr{K}}$ is the price of construction capital, a_t^{ℓ} is a labour supply shock in the housing sector and ϕ_ℓ is a scaling parameter.

4.4.2 Production of New Houses

A continuum of monopolistically competitive firms produce new houses by hiring labour and renting capital from households. Based on the Cobb-Douglas production technology, the cost minimisation is

$$\min_{\kappa_t,\ell_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \right) \left[\mathscr{Q}_t \kappa_t + \mathscr{W}_t \ell_t + q_t^{\hbar} (\hbar_t - a_t^{\hbar} \kappa_t^{1-\gamma_\ell} (A_t \ell_t)^{\gamma_\ell}) \right],$$

where $\mathscr{Q}$ is the rent from construction capital, $\kappa_t \equiv \mathscr{K}_{t-1}$ is the construction capital substituted into period t, $q_t^{\hbar}$ denotes nominal marginal costs, $a_t^{\hbar}$ is a sector-specific TFP shock and γ_ℓ is the labour share. We assume that there is only one labour-augmenting technology in the model, i.e. A_t is the same as for domestic intermediate producers.

Firms maximise their profits subject to the downward-sloping demand curve and the Calvo-Yun setup with a full indexation scheme

$$\max_{\hbar_t, P_t^{\hbar}} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \right) \left[P_t^{\hbar} \hbar_t - q_t^{\hbar} \hbar_t \right],$$

where

$$\hbar_t = \left(\frac{P_t^{\hbar}}{\bar{P}_t^{\hbar}} \right)^{-\nu_{P\hbar}} \bar{\hbar}_t.$$

4.4.3 Housing Investment Goods-Producing Firms

Monopolistically competitive firms produce housing investment final goods only from domestic intermediate goods. The production function is

$$Y_t^{\mathscr{I}} = \mathscr{I}_t,$$

where $Y_t^{\mathscr{I}}$ denotes the part of domestic intermediate goods Y_t used for the production of new houses.

Profit maximisation is

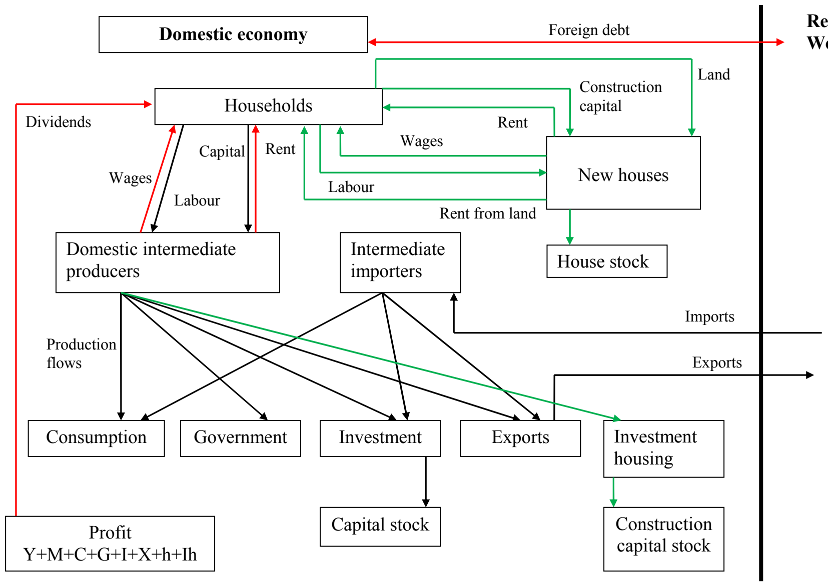
$$\max_{\mathscr{I}_t, P_t^{\mathscr{I}}} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[P_t^{\mathscr{I}} \mathscr{I}_t - q_t^{\mathscr{I}} \mathscr{I}_t \right],$$

where $q_t^{\mathscr{I}}$ denotes nominal marginal costs.

4.5 Extension IV: Houses Are Produced from Sector-Specific Inputs and Land

As an extension of the previous version of the model, we incorporate land into the model. Households can trade in land and also rent it to new house producers, who use it as a third production input (besides labour and capital). The structure of the model is presented in Figure 16.

Figure 16: Model Structure – Houses Are Produced from Sector-Specific Inputs and Land



Black lines – real flows, red lines – financial flows, green lines – housing sector

4.5.1 Households

In contrast to the previous model, households supply land to new house-producing firms and receive rent. They can also trade in land. The utility maximisation is

$$
\begin{aligned}
\max_{C_t,B_t,I_t,K_t,L_t,W_t,H_t,\hbar_t,\mathscr{I}_t,\mathscr{K}_t,\ell_t,\mathscr{W}_t,\mathscr{L}_t} \mathbb{E}_0 \sum_{t=0}^{\infty}\left(\prod_{\tau=0}^{t}\beta_\tau\right)\Bigg\{ & (1-\chi)\log(C_t-\chi\bar{C}_t^F)+\frac{\phi_H\exp(\varepsilon_t^H)H_t^{1-\eta}}{1-\eta} \\
& +\phi_L a_t^L(1-L_t)+\phi_\ell a_t^\ell(1-\ell_t)-\lambda_t\Big[P_t^C C_t+P_t^I I_t+B_t+P_t^{\hbar}\hbar_t+P_t^{\mathscr{I}}\mathscr{I}_t+P_t^{\mathscr{L}}\mathscr{L}_t \\
& -W_tL_t-\mathscr{W}_t\ell_t-R_{t-1}B_{t-1}-Q_tK_{t-1}-\mathscr{Q}_t\mathscr{K}_{t-1}-\mathscr{Q}_t^{\mathscr{L}}\mathscr{L}_{t-1}-P_t^{\mathscr{L}}\mathscr{L}_{t-1}-P_t^C T_t-\Phi_t \\
& +\lambda_t^K\left[K_t-K_{t-1}^{1-\delta_K}\left(\frac{I_t}{\delta_K}\right)^{\delta_K}+\frac{\eta_K}{2}\left(\frac{I_t}{I_{t-1}}\frac{1}{\alpha\alpha^I}-1\right)^2K_{t-1}\right] \\
& +\lambda_t^H\left[H_t-H_{t-1}^{1-\delta_H}\left(\frac{\hbar_t}{\delta_H}\right)^{\delta_H}+\frac{\eta_H}{2}\left(\frac{\hbar_t}{\hbar_{t-1}}\frac{1}{\alpha\alpha^H}-1\right)^2H_{t-1}\right] \\
& +\lambda_t^{\mathscr{K}}\left[\mathscr{K}_t-\mathscr{K}_{t-1}^{1-\delta_{\mathscr{K}}}\left(\frac{\mathscr{I}_t}{\delta_{\mathscr{K}}}\right)^{\delta_{\mathscr{K}}}+\frac{\eta_{\mathscr{K}}}{2}\left(\frac{\mathscr{I}_t}{\mathscr{I}_{t-1}}\frac{1}{\alpha\alpha^{\mathscr{I}}}-1\right)^2\mathscr{K}_{t-1}\right]\Big]\Bigg\},
\end{aligned}
$$

where $P_t^{\mathscr{L}}$ is the price of land, $\mathscr{L}_t$ denotes land and $\mathscr{Q}_t^{\mathscr{L}}$ is the rent from land.

4.5.2 Production of New Houses

Firms use construction capital, labour and land to produce new houses. They minimise their production costs

$$\min_{\kappa_t,\ell_t,\mathscr{L}_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \frac{\lambda_t}{\lambda_0} \right) \left[\mathscr{Q}_t \kappa_t + \mathscr{W}_t \ell_t + \mathscr{Q}_t^{\mathscr{L}} \mathscr{L}_t + q_t^{\hbar} (\hbar_t - A_t^{\hbar} \kappa_t^{\gamma_\kappa} (A_t \ell_t)^{\gamma_\ell} \mathscr{L}_t^{(1-\gamma_\kappa-\gamma_\ell)}) \right].$$

The profit maximisation has the same form as in the previous model, except that the nominal marginal costs of the new house-production process $q_t^{\hbar}$ are now a function also of the costs of renting land from households.

4.6 Extension V: Non-separable Utility Function

In this framework we assume a non-separable utility function of households in consumption and ownership of houses. We choose the model in which houses are produced from intermediate output due to its medium complexity among the four housing sector extensions. The rest of the assumptions (model structure, pricing behaviour etc.) are unchanged.

4.6.1 Households

Households maximise utility, which has the form

$$\begin{aligned} \max_{C_t,B_t,I_t,K_t,L_t,W_t,H_t,\hbar_t} E_t \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t} \beta_\tau \right) \Bigg\{ & (1-\chi)\log(\daleth_t - \chi \bar{\daleth}_t^F) + \phi_L a_t^L (1-L_t) \\ -\lambda_t \Bigg[& P_t^C C_t + P_t^I I_t + B_t + P_t^{\hbar} \hbar_t - W_t L_t - R_{t-1} B_{t-1} - Q_t K_{t-1} - P_t^C T_t - \Phi_t \\ & + \lambda_t^K \left[K_t - K_{t-1}^{1-\delta_K} \left(\frac{I_t}{\delta_K} \right)^{\delta_K} + \frac{\eta_K}{2} \left(\frac{I_t}{I_{t-1}} \frac{1}{\alpha \alpha^I} - 1 \right)^2 K_{t-1} \right] \\ & + \lambda_t^H \left[H_t - H_{t-1}^{1-\delta_H} \left(\frac{\hbar_t}{\delta_H} \right)^{\delta_H} + \frac{\eta_H}{2} \left(\frac{\hbar_t}{\hbar_{t-1}} \frac{1}{\alpha \alpha^H} - 1 \right)^2 H_{t-1} \right] \Bigg] \Bigg\}, \end{aligned}$$

where

$$\daleth_t \equiv \begin{cases} \left[(1-\phi_H) C_t^{-\rho_{ns}} + \phi_H \exp(\varepsilon_t^H) \left(\frac{H_t}{A_t^H} \right)^{-\rho_{ns}} \right]^{\frac{-1}{\rho_{ns}}} & \text{if } \rho_{ns} \neq 0 \\ C_t^{1-\phi_H} \left(\exp(\varepsilon_t^H) \frac{H_t}{A_t^H} \right)^{\phi_H} & \text{if } \rho_{ns} = 0 \end{cases}.$$

The scaling of H_t in the utility function reflects the need for stationarity of the model steady state. However, it should be noted that – in addition to this pragmatic reason – the scaling used can serve as a device for modelling slowly changing preferences about the relative desirability of housing services.

The external habit formation is

$$\bar{\daleth}_t^F \equiv \begin{cases} \exp(\varepsilon_t^C) \left[\left[(1-\phi_H) \bar{C}_{t-1}^{-\rho_{ns}} + \phi_H \left(\frac{\bar{H}_{t-1}}{A_{t-1}^H} \right)^{-\rho_{ns}} \right]^{\frac{-1}{\rho_{ns}}} \right] & \text{if } \rho_{ns} \neq 0 \\ \exp(\varepsilon_t^C) \left[\bar{C}_{t-1}^{1-\phi_H} \left(\frac{\bar{H}_{t-1}}{A_{t-1}^H} \right)^{\phi_H} \right] & \text{if } \rho_{ns} = 0 \end{cases}.$$

4.7 Calibration of Models

This section discusses the calibration of the models. Since the housing sector implementation is an extension rather than a *new model*, we first set the baseline framework parameters that are common across all the housing sector extensions. We distinguish, and calibrate successively, four groups of parameters, namely (i) the calibration of the BGP, (ii) other deep parameters defining the steady state, (iii) adjustment costs and persistence parameters, and (iv) standard deviations of structural shocks and measurement errors. After this, we proceed to calibration of the housing sector extensions.

Balanced Growth Path

The model has a balanced growth path, along which all the model variables either are constant or grow at some growth rate. The aggregate growth is set to 3.5%, which is relevant for (real) consumption, government spending, investment and real wages. The long-run growth of exports and imports is set to 7%. The domestic inflation target is 2% in annual terms, which corresponds to the CNB's current target for MP-relevant inflation. The foreign inflation target is also 2%. The steady-state nominal appreciation rate is set to 2.4% a year.[30] The steady state for domestic and foreign interest rates is 3%. The long-run value of foreign GDP growth is 1.8%.

Deep Parameters

The deep parameters are set with respect to the data and model properties. The steady state of the discount parameter β is set to 0.99 in annual terms. The share of labour in domestic intermediate production γ is 0.7. We set the capital depreciation parameter δ to 0.015, which implies depreciation of 6% in per annum terms.[31] The scale parameter of hours worked in the utility function ϕ_N is set to 0.34. The habit formation parameter χ is 0.7, reflecting the inertia of consumption dynamics in the data. There are seven parameters for the elasticities of substitution among differentiated goods and labour types. Given the data uncertainties and lack of micro data analyses, they are set to 6, so the average markup is 20% in each sector. The Leontief shares for imported production components are 0.12 for consumption production (ω_C), 0.27 for investment production (ω_I) and 0.60 for export production (ω_X).[32]

Adjustment Costs and Persistence Parameters

The calibration of adjustment costs and persistence parameters determines the business cycle properties of the model. The weight on the deviation of inflation from the target in the reaction function ψ is 2, which ensures that inflation returns to the target within the MP horizon (approx. 4–6 quarters ahead). The Calvo parameter for inflation in the consumption sector is 0.65, implying a stickiness

[30] This value was set with respect to the past evolution of the Czech economy. Although the value of this parameter is currently probably rather lower, due, for example, to the ongoing convergence process, we do not change it.
[31] Christiano and Vigfusson (2003) estimate the depreciation rate at 0.73, which is larger than would seem plausible. They discuss this issue in greater detail.
[32] Note that these parameters do not correspond to the overall import intensities in the economy. For example, the import intensity of investment is set to 60%.

lasting around three quarters.[33] The Calvo parameter for wage-setting is 0.8, as wage stickiness is higher than price stickiness in the Czech economy.[34] Except for the Calvo parameter for the government goods-producing sector (0.75), the rest of the sectors are assumed to have higher flexibility. Specifically, the value for the import sector is 0.6, export sector stickiness is calibrated to 0.55 and the Calvo parameters in the investment and domestic intermediate sectors are set to 0.5. The adjustment cost parameter for investment (η_K) is 0.2. The persistences of the domestic interest rate (ρ_R) and exchange rate (ρ_S) are set to 0.75 and 0.7 respectively. The persistence of government spending is 0.9. The persistence parameters for exogenous (technology) processes range between 0.1 and 0.7. The persistence parameters for foreign variables are 0.75 for the foreign interest rate and foreign demand and 0.3 for foreign inflation.

Housing Sector Parameters

We do not need to change any deep parameters when incorporating the housing sector. For simplicity, we solve the models numerically. This implies that the values of some of the parameters may be relatively sensitive in order for the model(s) to have a solution. We tested this 'robustness', and the 'boundaries' turned out to be relatively far from our calibration for the parameters tested, even for the most complex models. Also, we do not implement any strong or contentious assumptions into the models. For example, we do not assume the presence of house prices in the reaction function of the central bank (the CB targets inflation only) and we assume the same values of housing sector parameters as for their standard counterparts.[35]

We thus set the housing sector parameters in line with the baseline model. Specifically, the share of labour in the production function is 0.7 and the investment adjustment cost parameter for the housing sector law of motion is also 0.2. We assume a 20% markup for monopolistically competitive firms and the same stickiness of wages and investment prices (Calvo parameters 0.8 and 0.5 respectively). The rate of depreciation is 0.0115. The Calvo parameter for prices of new houses is 0.6, implying slightly higher flexibility than in the consumption sector. In the model with land, we assume that land has a 5% share in the Cobb-Douglas function, implying a 0.25% share for capital. The housing sector parameter η is set to 1 as a benchmark. This value implies that the marginal utilities of consumption and housing have the same shape. We discuss the results of this and alternative assumptions in the next part of the paper.

[33] There are some empirical papers which deal with nominal price rigidities. In the Czech case, Murárik (2011) uses the detailed database from the Czech Statistical Office. He finds that the average period without a price change is between 6 and 11 months for the whole consumption basket. The lower value is the result of a direct calculation, whereas the upper value stems from an implicit calculation concerning data uncertainty. He claims that the 'true' period probably lies near the upper bound. These values are in line with Nakamura and Steinsson (2008), who estimate a range of 8–11 months for the US economy.

[34] This is consistent with the empirical analyses by Babecký et al. (2008) and Druant et al. (2012) and with the setting in (Andrle et al., 2009).

[35] The only exception is the rate of depreciation of construction capital, which, for numerical reasons, is calibrated at a value slightly lower than the rate of depreciation of the baseline model capital stock.

5. Model Properties

This section presents the properties of the models and compares their performance on data. For the simulation of the model (impulse responses) and the derivation of the model moments, we used the IRIS toolbox (Beneš et al., 2014). All figures are given in the Appendix.

5.1 Impulse Responses

In this part we present the impulse responses of our models. We divide this subsection into three parts. First, we discuss impulse responses to 'standard shocks' among several models. Specifically, we compare the IRFs of the baseline model with the housing sector extensions. Second, we compare the impulse responses to housing sector shocks. Since a number of these shocks increase with the complexity of the housing sector in each model, we select the most common shocks. Specifically, we are interested in a housing preference shock, a cost-push shock to prices of new houses and a housing technology shock. And third, we solve the models for multiple parameterisations to show the sensitivity of housing sector variables.

We denote our cascade of models containing the housing sector as follows: ***Baseline*** is the model without the housing sector, ***fS*** denotes the model with an exogenous number of houses, ***fY*** denotes the model in which houses are produced using the domestic intermediate good, ***fKL*** denotes the model in which houses are produced from sector-specific labour and capital, ***fKLP*** denotes the version of the model with land, and finally ***fYns*** is the model with non-separable utility in which houses are produced using the domestic intermediate good.

Impulse Responses to Standard Shocks

Figure B.1 shows the reactions of the model variables to a monetary policy shock. After an interest rate increase, consumption, investment expenditure, exports, imports and nominal wages fall. The nominal exchange rate appreciates, implying additional anti-inflationary pressures in the economy via lower import prices. The MP shock implies a decrease in new house construction and in both housing sector prices (house prices and prices of newly constructed houses). The incorporation of the housing sector does not change the responses of the other model variables.[36] The reaction of housing sector variables is similar across the model frameworks: because the MP shock is contractionary, it also suppresses housing demand, hence lowering house prices and house production. This is a realistic feature.

Figure B.2 shows the impulse responses to a habit shock. Consumption expenditure increases. Since investment spending and exports are almost untouched, the higher consumption leads to an increase in imports. Facing inflationary pressures stemming from domestic demand, the central bank increases interest rates, although this reaction is relatively moderate as we assume a non-persistent shock. The volume of new houses decreases negligibly in more complex models due to both an increase in the interest rate and a substitution effect towards consumption. The same effects explain why house prices decrease slightly in all the models. The producer prices of new houses increase if the houses are produced from domestic intermediate goods (because the price of

[36] In general, we welcome this result, as we do not regard the housing sector as a factor which *should* change the behaviour of the (model or real) economy significantly. On the other hand, we do not consider the specific situation of a pricking of a bubble (together with a deep recession) and its adverse effects on banks' balance sheets.

domestic intermediate goods, *dot_Py*, increases as well), but decrease if houses are produced from sector-specific inputs (because of the substitution effect).

Figure B.3 presents a total factor productivity shock. Since the economy is temporarily more productive, intermediate output rises. Consumption and net exports increase, while investment expenditure falls slightly.[37] The monetary authority cuts the interest rate to push the lower headline inflation back to the target. The nominal exchange rate depreciates temporarily.[38] Because of the demand effect, house prices and the production of new houses both increase, but because of the higher productivity, the *producer prices* of new houses decline.

Figure B.4 presents the model behaviour after a cost-push shock to headline inflation. After such a shock, consumption expenditure decreases and investment expenditure temporarily increases due to substitution effects. The nominal exchange rate depreciates due to the inflation differential between the home and foreign economy (relative PPP theory). The monetary authority increases interest rates to bring inflation back to the target. House prices react to the increase in overall inflation in the economy, although their reaction is slightly smaller. The construction of new houses rises, while their prices show a hump-shaped response.

Figure B.5 presents the impulse responses to a wage-push shock. Household consumption and exports fall, while investment expenditure rises slightly due to the substitution effect. Since wage growth is not supported by higher productivity and thus creates inflationary pressures in the domestic intermediate sector which spill over into headline inflation, the monetary authority increases interest rates and hence the nominal exchange rate appreciates. House prices decrease. The size of the reaction of new house construction differs between the fY version (where it corresponds to consumption expenditure) and the fLK and fLKP models, where this sector is more isolated from the domestic intermediate sector. Moreover, the producer price of new houses initially increases in the fY version (as the intermediate good is now more expensive) but decreases slightly in the fLK and fLKP models.

Figure B.6 shows the impulse responses to a UIP shock. The depreciated nominal exchange rate implies inflationary pressures in the import intermediate sector. The central bank increases interest rates to bring inflation back to the target. Net exports increase and consumption and investment expenditures fall due to the production switch and higher import prices. The responses of new house production are negligible. House prices fall in reaction to the lower domestic demand and higher interest rates.

Figure B.7 shows the impulse responses to a foreign interest rate shock. The exchange rate depreciates due to the negative interest rate differential, and import price inflation increases. The monetary authority hikes interest rates to bring headline inflation back to the target. Net exports increase and consumption and investment expenditure fall. Similarly to a UIP shock, house prices decrease in response to the lower domestic demand and the monetary tightening. The price and volume of new houses fall with similar magnitude.

Figure B.8 presents the impulse responses to an increase in foreign prices in the foreign currency. Since there is a negative inflation differential, the exchange rate appreciates. Net exports increase

[37] In the closed economy version of the model, a positive TFP shock implies an increase in both consumption and investment.

[38] In contrast to a (permanent) labour-augmenting technology shock, a transient TFP shock implies higher supply of goods (with respect to the steady state of the economy). Given the same foreign demand, the real exchange rate must depreciate for the economy to be able to sell more exports in foreign markets.

after the shock. The central bank increases domestic interest rates slightly.[39] The shock has only limited effects on housing sector variables; house prices decrease (due to lower domestic demand).

Figure B.9 shows the reaction of the model variables to a foreign demand shock. Consumption, investment, net exports and nominal wages increase. Domestic intermediate inflation rises. The exchange rate appreciates and import price inflation falls. Since the anti-inflationary pressures from the imported goods sector outweigh the inflationary pressures from the domestic economy, the monetary authority lowers interest rates. House prices increase in reaction to the higher domestic demand. Both new house production and new house prices increase, although the magnitude is relative small since the shock primarily affects exports.

Figure B.10 shows the reaction of the model variables to a shock to the discount factor. Imports and consumption (through their significant import content) fall, implying negative domestic demand pressures. The monetary authority reduces interest rates to bring inflation back to the target and hence the nominal exchange rate temporarily depreciates due to the negative interest rate differential. House prices increase as households switch current consumption expenditure for housing (and investment) demand. The production of new houses rises and the (producer) price of new houses falls.

All in all, we think that the extended models produce reasonable stories and the introduction of the housing market does not destroy the conventional wisdom of New Keynesian economics.

Impulse Responses to Housing Sector Shocks

Figure B.11 presents the impulse responses to a shock to households' utility from the stock of houses (a housing preference shock). After the shock, which approximates higher demand for housing, house prices increase in all the models. The production of new houses rises, but the size of this increase is much lower due to the model mechanisms (the new house production process as compared to the immediate reaction of house prices). The price of new houses also rises, but the increase is negligible. The magnitude of the reaction of the standard variables is small in all the models except for the framework with a non-separable utility function, as we do not incorporate strong assumptions such as house price (inflation) targeting or about the specification of the production process. In the extension with a non-separable utility function, since consumption is linked to the housing stock, households increase their consumption in reaction to the increase in house prices.

Figure B.12 shows the reactions of the model variables to a cost-push shock to prices of new houses. Higher prices of new houses push new house volumes (construction) downwards and marginally increase house prices. Similarly to the previous case, the reactions of other variables are negligible for practical purposes.

Figure B.13 presents the impulse responses to a housing technology shock. Since the shock improves the new house production process, the volume of new houses increases and the prices of new houses fall. Except for the fS and fYns models, the reaction of house prices is negligible. In the model with a non-separable utility function, house prices increase and so does households'

[39] There are two channels with opposite effects for the domestic interest rate response. First, the higher foreign inflation implies inflationary effects and the central bank, ceteris paribus, increases the interest rate to prevent the economy from importing higher inflation. Second, since the nominal exchange rate appreciates, it creates, ceteris paribus, anti-inflationary pressures in the model.

consumption and investment expenditure. This increase in economic activity, coupled with higher nominal wages, mitigates the anti-inflationary pressures from the lower prices of new houses. Thus, the reaction of the central bank is larger in the fY model than in the same framework with a non-separable utility function.

To sum up, there are two important findings. First, incorporating the housing sector into a DSGE model need not (negatively) affect the behaviour of the model in a way that would significantly change the impulse responses of the baseline framework, provided, at least, that one does not make any strong assumptions regarding the central bank's objectives or include any additional linkages or sectors. Second, although the fY and fLK(P) models imply different model mechanisms and assumptions, their behaviour is relatively similar, allowing researchers to choose the specification they prefer. Of course, we do not aim to explicitly capture the differences between the same types of characteristics in standard sectors and their housing sector counterparts. For example, we assume the same steady-state and Calvo parameters for wages in both the standard and housing sectors. We believe that in the majority of cases, such objectives (differences) are academic issues rather than regular real-time forecasting topics (due to a wide range of uncertainties). We are thus concerned more with the calibration of key housing sector parameters (see the next part) than with model selection.

Impulse Responses – Comparing Parameterisations of the Utility Function

In this subsection we show the impulse responses to multiple parameterisations of the housing curvature parameter in the utility function. In the impulse responses of the previous part, we assumed η calibrated to 1. In this part of the paper, we discuss various parameterisations of the utility function, especially coefficient η.

For the sake of brevity, we show and comment on two selected impulse responses: the impulse response to the labour-augmenting technology shock and the impulse response to the housing preference shock (see Figures B.14 and B.15). This is done for the version of the model with houses produced using the intermediate sector.

There are two main results. First, different values of η do not change the responses of standard variables to standard shocks. After housing sector shocks, the responses of standard variables change, but the magnitudes of these changes are negligible. Second, a different curvature of η implies a change in the magnitude of the reactions of housing sector variables. Thus, in line with the previous part of the paper, one can set the volatilities of housing sector variables with this parameter instead of using any strong assumptions. Preserving the impulse responses of the baseline model for standard variables is a promising feature. For models with sector-specific inputs, the results are qualitatively similar, with one caveat: the models with sector-specific inputs have stability problems for low values of η.

5.2 Forecast Error Variance Decomposition

As an additional model diagnostic, we report the forecast error variance decomposition (FEVD) for selected models. We are mainly interested in the number of shocks that drive the main variables of interest (both the main macroeconomic variables and the variables related to the housing market). The motivation is that if the main macroeconomic variables are driven by 'standard' shocks (such as technology) and the housing variables are driven by housing sector shocks, our quest to explain the housing market via standard demand and supply mechanisms will be unsuccessful. Moreover, it would mean that house price fluctuations are not influenced by economic cycles and other driving forces are in place. Given the conclusions in the empirical part of the paper, such a result would be unsatisfactory.

First, in Table 1, we present the FEVD for model fY under our preferred calibration. The curvature parameter η is calibrated to 1. In the rows, *dot_C* is real consumption growth, *dot_I* is real investment growth, *dot_W* denotes nominal wage growth, *dot_Pc* is headline inflation, *R* is the domestic interest rate, *dot_Ph* denotes growth of house prices, *dot_Phbar* is growth of prices of new houses and *dot_Hbar* is the production of new houses. In the columns, *A* denotes labour-augmenting technology shocks, *MP* is a monetary policy shock, *Pc* denotes a cost-push shock to headline inflation, *W* denotes wage-push shocks in the wage Phillips curve, R^* is a foreign interest rate shock, β denotes shocks to the discount factor, *C* is a habit shock, A^Y denotes TFP shocks, *UIP* denotes UIP shocks, *H* is a housing preference shock, A^H is a housing technology shock and $P^{\hbar}$ is a cost-push shock in the Phillips curve of prices of new houses.

Table 1: Forecast Error Variance Decomposition (Model fY, $\eta = 1$)

	A	MP	Pc	W	R^*	β	C	A^Y	UIP	H	A^H	$P^{\hbar}$
dot_C	0.56	0.08	0.00	0.01	0.09	0.05	0.18	0.00	0.00	0.00	0.00	0.00
dot_I	0.75	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
dot_W	0.23	0.01	0.01	0.72	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
dot_Pc	0.00	0.02	0.93	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00
dot_S	0.02	0.17	0.00	0.07	0.45	0.00	0.00	0.02	0.18	0.00	0.00	0.00
R	0.02	0.80	0.04	0.01	0.09	0.00	0.00	0.02	0.00	0.00	0.00	0.00
dot_Ph	0.72	0.11	0.02	0.01	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
dot_Phbar	0.00	0.01	0.01	0.04	0.01	0.00	0.00	0.05	0.00	0.00	0.29	0.57
dot_Hbar	0.74	0.02	0.01	0.03	0.02	0.00	0.00	0.01	0.00	0.00	0.15	0.01

From the table, it is clear that most housing sector variables are driven by technology, which also explains the standard macroeconomic variables. This confirms that our objective to explain house price fluctuations by standard mechanisms is successful. Moreover, we thereby avoid the tendency of some DSGE models to head towards a degenerate research programme in which new shocks are constantly added to drive newly added variables (Farmer, 2010).

Obviously, the FEVD depends on the calibration of the standard errors. To prove the robustness of our results, we report the FEVD for the calibration where we increase the standard errors of housing sector shocks by 10 and 100. The results are shown in Table 2, in which the first three rows present a tenfold increase in the standard deviations of the last three shocks (H, A^H, $P^{\hbar}$) and the last three rows show the results when the magnitudes of these standard deviations are multiplied by a factor of 100. From the table, it is apparent that our conclusion still holds for house prices and new house construction (a tenfold increase). Prices of new houses are of course driven by their own cost-push shock under these circumstances.

In Table 3, we show the FEVD for model fY with multiple parameterisations of the curvature parameter η. The results indicate that house prices and quantities are still significantly influenced by productivity, although its influence changes to a limited extent with different values of η.

Table 2: Forecast Error Variance Decomposition (Model fY, $\eta = 1$, Increased Std. Dev.)

	A	*MP*	*Pc*	*W*	*R**	A^Y	*H*	A^H	$P^{\hbar}$
dot_Ph	0.72	0.11	0.02	0.01	0.11	0.00	0.00	0.00	0.00
dot_Phbar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.99
dot_Hbar	0.39	0.01	0.01	0.02	0.01	0.00	0.00	0.08	0.49
dot_Ph	0.62	0.10	0.01	0.01	0.09	0.00	0.13	0.00	0.01
dot_Phbar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
dot_Hbar	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99

Table 3: Forecast Error Variance Decomposition (Model fY, $\eta = \{1, 0.5, 2\}$)

	A (1 / 0.5 / 2)	*H*	A^H	$P^{\hbar}$
dot_Ph	0.72 / 0.79 / 0.65	0.00 / 0.00 / 0.00	0.00 / 0.05 / 0.01	0.00 / 0.00 / 0.00
dot_Phbar	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	0.29 / 0.36 / 0.28	0.57 / 0.52 / 0.57
dot_Hbar	0.74 / 0.73 / 0.74	0.00 / 0.00 / 0.00	0.15 / 0.22 / 0.09	0.01 / 0.00 / 0.02

Finally, we report the FEVD for the model with non-separable utility for multiple parameterisations of parameter ρ_{ns}. From Table 4, there are two results. First, housing sector variables are driven by productivity with a higher share than in models with separable utility functions. Second, there are minor changes in the productivity share with respect to parameter ρ_{ns}.

Table 4: Forecast Error Variance Decomposition (Model fYns, $\rho_{ns} = \{1, 0.5, 10\}$)

	A (1 / 0.5 / 10)	*H*	A^H	$P^{\hbar}$
dot_Ph	0.80 / 0.78 / 0.80	0.00 / 0.00 / 0.00	0.02 / 0.01 / 0.13	0.00 / 0.00 / 0.00
dot_Phbar	0.01 / 0.01 / 0.01	0.00 / 0.00 / 0.00	0.27 / 0.27 / 0.27	0.58 / 0.58 / 0.58
dot_Hbar	0.77 / 0.76 / 0.76	0.00 / 0.00 / 0.00	0.17 / 0.16 / 0.21	0.00 / 0.01 / 0.00

5.3 Moments

In this subsection we compare the second moments between the data and our housing sector models.

Figure B.16 shows the correlation of house prices with consumption growth (C), investment growth (I), MP-relevant inflation (Pc), the policy rate (R), exchange rate change (S) and new houses (H) both in the Czech data and in our models. The green sign denotes data. The red sign denotes the point estimate based on the estimated VAR and the shadow bars denote the bootstrapped estimates of this correlation. The other signs denote the correlations implied by our baseline calibration of the model. Our model roughly corresponds to the bootstrapped confidence intervals for the correlation of house prices with consumption and investment. The model-implied correlations are rather higher than the point estimates, but given the contamination of Czech house price data (discussed in Section 3), we do not see this as a problem. The model-implied correlations with consumer inflation are rather lower than the point estimate, but well within the confidence intervals. We match the correlations of house prices and exchange rate changes, and the model-implied correlations between the housing stock and house prices are higher in the models than in the data. Again, however, this is not necessarily a vice given the contamination of Czech housing data by non-fundamental factors.

Figure B.17 shows the correlation of new houses with aggregates. Here, our models imply rather higher correlations between houses and macroeconomic aggregates than in the data. This can be partly solved by increasing the value of η, as shown in Figure B.18.[40] Nevertheless, we are now unsure whether this would really be a plausible thing to do: our models imply higher comovements among the variables than what is observed in the Czech data, but this may only reflect the pre-2005 sample and it is not completely unrealistic to expect the comovement to increase to what is observed in advanced economies.

6. Conclusion

In this paper, we make two contributions to the understanding of housing market dynamics and their relationship with the macroeconomy.

First, we analyse housing market data for a large set of advanced countries and place the dynamics of the Czech housing market in this context. We show that in most advanced countries, housing market variables (prices, quantities, labour inputs) are cyclical and that in the pre-2005 period this was not always the case for the Czech economy. However, since 2005, it seems that the alignment of the housing market with the business cycle has increased in the Czech Republic as well.

Second, we present a cascade of DSGE models which incorporate the housing market. We analyse their impulse responses and show that the introduction of the housing market does not destroy the conventional wisdom of New Keynesian economics, even if the housing market extension is rather complex. We confront the model-based moments implied by the models with data and the results are not unsatisfactory. We achieve this without introducing collateral constraints or other exotic features, using just standard demand and supply mechanisms. We conclude that to incorporate the housing market into DSGE models, the standard mechanisms are sufficient. We also provide a limited sensitivity analysis with respect to the parameterisation of the utility function and discuss its impacts on the model's properties.

In the future, the research could be extended along several dimensions. Especially, we are considering introducing non-fundamental movements in house prices (aka bubbles) to be able to filter out non-fundamental episodes in the Czech housing market (such as the surge in house prices prior to EU entry). However, this is left for future research.

[40] This would also be the case for the correlations of aggregates with house prices: higher values of η would bring them closer towards the data.

References

ABEL, A. B. (1990): "Asset Prices under Habit Formation and Catching up with the Joneses." *The American Economic Review,* 80(2):38–42.

ABRAHAM, K. G. AND J. C. HALTIWANGER (1995): "Real Wages and the Business Cycle." *Journal of Economic Literature,* 33(3):1215–1264.

ANDRLE, M., T. HLÉDIK, O. KAMENÍK, AND J. VLČEK (2009): "Implementing the New Structural Model of the Czech National Bank." Czech National Bank, Working Paper Series 2.

ATTANASIO, O. P., L. BLOW, R. HAMILTON, AND A. LEICESTER (2009): "Booms and Busts: Consumption, House Prices and Expectations." *Economica, London School of Economics and Political Science,* 76(301):20–50.

BABECKÝ, J., K. DYBCZAK, AND K. GALUŠČÁK (2008): "Survey on Wage and Price Formation of Czech Firms." Working Papers 2008/12, Czech National Bank

BAJARI, P., P. CHAN, D. KRUEGER, AND D. MILLER (2013): "A Dynamic Model of Housing Demand: Estimation and Policy Implications." *International Economic Review,* 54(2):409–442.

BARRO, R. J. AND X. SALA-I-MARTIN (2004): *Economic Growth.* The MIT Press, 2 edition.

BENEŠ, J., A. BINNING, M. FUKAČ, K. LEES, AND T. MATHESON (2009): "K.I.T.T.: Kiwi Inflation Targeting Technology." Reserve Bank of New Zealand.

BENEŠ, J., M. JOHNSTON, AND S. PLOTNIKOV (2014): "IRIS Toolbox (Macroeconomic modeling toolbox)." http://iristoolbox.codeplex.com/.

BRŮHA, J. AND J. POLANSKÝ (2015): "Empirical Analysis of Labour Markets: An International Comparison." Mimeo, to be submitted to the CNB WP Series, Czech National Bank

BRŮHA, J., M. HLAVÁČEK, AND L. KOMÁREK (2013): *Impacts of housing prices on the financial position of households.* In *CNB Financial Stability Report 2012/2013,* pages 120–127. Czech National Bank.

BRŮHA, J., T. HLÉDIK, T. HOLUB, J. POLANSKÝ, AND J. TONNER (2013): "Incorporating Judgments and Dealing with Data Uncertainty in Forecasting at the Czech National Bank." Research and Policy Notes 2013/02, Czech National Bank

CALVO, G. A. (1983): "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics,* 12:383–398.

CAMPBELL, J. Y. AND J. F. COCCO (2007): "How do house prices affect consumption? Evidence from micro data." *Journal of Monetary Economics, Elsevier,* 54(3):591–621.

CHRISTENSEN, I., P. CORRIGAN, C. MENDICINO, AND S.-I. NISHIYAMA (2009): "Consumption, Housing Collateral, and the Canadian Business Cycle." Working Papers 09-26, Bank of Canada

CHRISTIANO, L. J. AND T. J. FITZGERALD (2003): "The Band Pass Filter." *International Economic Review,* 44(2):435–465.

CHRISTIANO, L. J. AND R. J. VIGFUSSON (2003): "Maximum Likelihood in the Frequency Domain: The Importance of Time-to-Plan." *Journal of Monetary Economics,* 50(4):789–815.

COOPER, D. (2013): "House Price Fluctuations: The Role of Housing Wealth as Borrowing Collateral." *The Review of Economics and Statistics,* 95(4):1183–1197.

DAVIS, M. A. AND J. HEATHCOTE (2005): "Housing and the Business Cycle." *International Economic Review,* 46(3):751–784.

DIB, A. (2001): "An Estimated Canadian DSGE Model with Nominal and Real Rigidities." Bank of Canada, Working Paper 2001-26.

DRUANT, M., S. FABIANI, G. KEZDI, A. LAMO, F. MARTINS, AND R. SABBATINI (2012): "Firms' price and wage adjustment in Europe: Survey evidence on nominal stickiness." *Labour Economics,* 19(5):772–782.

FARMER, R. E. (2010): "Animal Spirits, Persistent Unemployment and the Belief Function." NBER Working Papers 16522, National Bureau of Economic Research

HANSEN, G. D. (1985): "Indivisible Labor and the Business Cycle." *Journal of Monetary Economics,* 16:309–327.

HLAVÁČEK, M. AND L. KOMÁREK (2011): "Regional Analysis of Housing Price Bubbles and Their Determinants in the Czech Republic." *Czech Journal of Economics and Finance,* 61 (1):67–91.

HLAVÁČEK, M. AND L. KOMÁREK (2009): "Housing Price Bubbles and their Determinants in the Czech Republic and its Regions." Working Paper 2009/12, Czech National Bank

HODRICK, R. J. AND E. C. PRESCOTT (1997): "Postwar U.S. Business Cycles: An Empirical Investigation." *Journal of Money, Credit and Banking,* 29(1):1–16.

IACOVIELLO, M. AND S. NERI (2010): "Housing Market Spillovers: Evidence from an Estimated DSGE Model." *American Economic Journal: Macroeconomics,* 2(2):125–64.

KAHN, J. (2008): "What Drives Housing Prices?" FED Staff Report no. 345.

KIM, J. (2003): "Functional equivalence between intertemporal and multisectoral investment adjustment costs." *Journal of Economic Dynamics and Control,* 27(4):533–549.

KYDLAND, F. E. AND E. C. PRESCOTT (1982): "Time to Build and Aggregate Fluctuations." *Econometrica,* 50(6):1345–1370.

LAMBERTINI, L., C. MENDICINO, AND M. T. PUNZI (2010): "Expectations-Driven Cycles in the Housing Market." Working Papers 1021, Banco de Portugal

LEAMER, E. E. (2007): "Housing IS the Business Cycle." NBER Working Papers 13428, National Bureau of Economic Research

MCCARTHY, Y. AND K. MCQUINN (2013): "Price expectations, distressed mortgage markets and the housing wealth effect." Research Technical Paper 6/RT/13, Central Bank of Ireland

MURÁRIK, R. (2011): "Price Setting Behaviour in the Czech Republic, Micro Data Evidence." *Statistika - Economy and Statistics Journal,* 48(2):24–41.

NAKAMURA, E. AND J. STEINSSON (2008): "Five Facts about Prices: A Reevaluation of Menu Cost Models." *The Quarterly Journal of Economics,* 1415–1464.

OHANIAN, L. E. AND A. RAFFO (2012): "Aggregate hours worked in OECD countries: New measurement and implications for business cycles." *Journal of Monetary Economics, Elsevier,* 59(1):40–56.

PIAZZESI, M., M. SCHNEIDER, AND S. TUZEL (2007): "Housing, consumption and asset pricing." *Journal of Financial Economics,* 83(3):531–569.

ROTEMBERG, J. J. (1982): "Monopolistic Price Adjustment and Aggregate Output." *The Review of Economic Studies,* 49(4):517–531.

ROTEMBERG, J. J. (1982): "Sticky Prices in the United States." *Journal of Political Economy,* 90 (6):1187–1211.

SCHMITT-GROHÉ, S. AND M. URIBE (2003): "Closing Small Open Economy Models." *Journal of International Economics,* 61:163–185.

TOMURA, H. (2010): "International capital flows and expectation-driven boom-bust cycles in the housing market." *Journal of Economic Dynamics and Control,* 34(10):1993–2009.

TOMURA, H. (2013): "Heterogeneous beliefs and housing-market boom-bust cycles." *Journal of Economic Dynamics and Control,* 37(4):735–755.

TONNER, J. AND J. BRŮHA (2014): "Czech Housing Market through Lens of a DSGE model with Collateral Constrained Households." Working Paper 9/2014, Czech National Bank

TONNER, J., J. POLANSKÝ, AND O. VAŠÍČEK (2011): "Parameter Drifting in a DSGE Model Estimated on Czech Data." *Czech Journal of Economics and Finance,* 61(5).

WALENTIN, K. AND P. SELLIN (2010): "Housing collateral and the monetary transmission mechanism." Working Paper Series 239, Sveriges Riksbank

YUN, T. (1996): "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles." *Journal of Monetary Economics,* 37:345–370.

Appendix A: Model Equations

In this section we present the model equations. We focus mainly on the first-order conditions of the optimisation problems described above. On the other hand, we do not explicitly describe the definitions, identities or AR processes. Also, since the production functions and laws of motion are presented in the optimisation problems in Section 4, we do not repeat them in this section, although they are a necessary part of the model codes.

A.1 Baseline Model

Households

The first-order conditions of households with respect to consumption, government bonds, investment and the capital stock are

$$\frac{1-\chi}{C_t - \chi \bar{C}^F_{t-1}} = \lambda_t P^C_t, \tag{A.1}$$

$$\lambda_t = \beta_t \lambda_{t+1} R_t, \tag{A.2}$$

$$\begin{aligned} P^I_t = \lambda^K_t \left(\frac{\delta_K K_{t-1}}{I_t}\right)^{1-\delta_K} - \eta_K \lambda^K_t \frac{K_{t-1}}{I_{t-1}} \left(\frac{I_t}{I_{t-1}} \frac{1}{\alpha\alpha^I} - 1\right) \frac{1}{\alpha\alpha^I} \\ + \beta_t \eta_K \frac{\lambda_{t+1}}{\lambda_t} \lambda^K_{t+1} \frac{K_t}{I_t} \frac{I_{t+1}}{I_t} \left(\frac{I_{t+1}}{I_t} \frac{1}{\alpha\alpha^I} - 1\right) \frac{1}{\alpha\alpha^I}, \end{aligned} \tag{A.3}$$

$$\lambda^K_t = \beta_t \frac{\lambda_{t+1}}{\lambda_t} \left[Q_{t+1} + (1-\delta_K)\lambda^K_{t+1} \left(\frac{I_{t+1}}{\delta_K K_t}\right)^{\delta_K} - \frac{\eta_K}{2} \lambda^K_{t+1} \left(\frac{I_{t+1}}{I_t} \frac{1}{\alpha\alpha^I} - 1\right)^2 \right]. \tag{A.4}$$

Assuming the Calvo-Yun setup with a full indexation scheme, the first-order condition with respect to labour and wages is[41]

$$\log\left(\frac{\dot{W}_t}{\dot{W}_{t-1}}\right) = \beta_t \log\left(\frac{\dot{W}_{t+1}}{\dot{W}_t}\right) + \frac{(1-\beta_t \Xi_w)(1-\Xi_w)}{\Xi_w} \log\left(\frac{\phi_L a^L_t}{\lambda_t W_t} \frac{\nu_w}{\nu_w - 1}\right) + \varepsilon^W_t. \tag{A.5}$$

In the model we assume persistence (via an AR process) of the discount factor β_t[42] and labour supply shocks a^L_t.

[41] In the first version of the model, we used Rotemberg's (Rotemberg, 1982a,b) setup, which implies an equation of the form

$$\log\left(\frac{\dot{W}_t}{\dot{W}_{t-1}}\right) = \beta_t \log\left(\frac{\dot{W}_{t+1}}{\dot{W}_t}\right) + \frac{\nu_w}{\xi_w}\left(\frac{\phi_L a^L_t}{\lambda_t W_t} - \frac{\nu_w - 1}{\nu_w}\right) + \varepsilon^W_t.$$

The behaviour of the model does not differ much.

[42] The discount factor each time is scaled by β_0, i.e. $\frac{1}{\beta_0}\left[\beta_0 U(C_0, L_0) + \beta_0 \beta_1 U(C_1, L_1) + \cdots\right]$.

Domestic Intermediate Producers

The first-order conditions with respect to capital and labour are

$$Q_t k_t = (1-\gamma_L) q_t^Y Y_t, \tag{A.6}$$

$$W_t L_t = \gamma_L q_t^Y Y_t. \tag{A.7}$$

Substituting k_t and L_t from the FOC into the production function implies an equation for nominal marginal costs as a function of the weighted prices of both inputs, i.e.

$$q_t^Y = \frac{1}{a_t^Y} \frac{[Q_t]^{(1-\gamma_L)}[W_t]^{\gamma_L}}{(1-\gamma_L)^{\gamma_L}(\gamma_L)^{\gamma_L}}.$$

The Phillips curve is

$$\log\left(\frac{\dot{P}_t^Y}{\dot{P}_{t-1}^Y}\right) = \beta_t \log\left(\frac{\dot{P}_{t+1}^Y}{\dot{P}_t^Y}\right) + \frac{(1-\beta_t \Xi_{P^Y})(1-\Xi_{P^Y})}{\Xi_{P^Y}} \log\left(\frac{q_t^Y}{P_t^Y}\frac{\nu_{P^Y}}{\nu_{P^Y}-1}\right) + \varepsilon_t^{P^Y}. \tag{A.8}$$

Also, we assume persistence of the TFP shocks a_t^Y.

Intermediate Importers

The Phillips curve is

$$\log\left(\frac{\dot{P}_t^M}{\dot{P}_{t-1}^M}\right) = \beta_t \log\left(\frac{\dot{P}_{t+1}^M}{\dot{P}_t^M}\right) + \frac{(1-\beta_t \Xi_{PM})(1-\Xi_{PM})}{\Xi_{PM}} \log\left(\frac{P_t^*}{P_t^M}\frac{\nu_{PM}}{\nu_{PM}-1}\right) + \varepsilon_t^{PM}, \tag{A.9}$$

where P_t^M is the price of imports in the domestic currency and P_t^* is the price of foreign goods in the domestic currency (nominal marginal costs), which is defined as

$$P_t^* = S_t \widetilde{P}_t^*,$$

where $\widetilde{P}_t^*$ is the price of foreign goods in the foreign currency and S_t is the nominal exchange rate.

Final-Goods Producing Firms

Assuming the Leontief production function, the first-order conditions in the consumption sector are

$$Y_t^C = (1-\omega_C) C_t \tag{A.10}$$

and

$$(M_t^C / A_t^X) = \omega_C C_t. \tag{A.11}$$

The implied nominal marginal (and average) costs are

$$q_t^C = (1-\omega_C)P_t^Y + \omega_C P_t^M A_t^X. \tag{A.12}$$

The Phillips curve in the consumption goods-producing sector is

$$\log\left(\frac{\dot{P}_t^C}{\dot{P}_{t-1}^C}\right) = \beta_t \log\left(\frac{\dot{P}_{t+1}^C}{\dot{P}_t^C}\right) + \frac{(1-\beta_t \Xi_{PC})(1-\Xi_{PC})}{\Xi_{PC}} \log\left(\frac{q_t^C}{P_t^C}\frac{\nu_{PC}}{\nu_{PC}-1}\right) + \varepsilon_t^{PC}. \tag{A.13}$$

The equations for the investment and export goods-producing sectors are analogous, except that export prices are sticky in the foreign currency due to the local currency pricing assumption.

Final government goods are produced from domestic intermediate goods

$$G_t = Y_t^G. \tag{A.14}$$

The Phillips curve in the final government goods-producing sector is

$$\log\left(\frac{\dot{P}_t^G}{\dot{P}_{t-1}^G}\right) = \beta_t \log\left(\frac{\dot{P}_{t+1}^G}{\dot{P}_t^G}\right) + \frac{(1-\beta_t \Xi_{PG})(1-\Xi_{PG})}{\Xi_{PG}} \log\left(\frac{q_t^G}{P_t^G}\frac{\nu_{PG}}{\nu_{PG}-1}\right) + \varepsilon_t^{PG}, \tag{A.15}$$

where nominal marginal costs are

$$q_t^G = P_t^Y. \tag{A.16}$$

Forex Dealers

Substituting the Euler equation into the FOC of forex dealers implies a debt-elastic premium version of the uncovered interest parity

$$\frac{S_{t+1}}{S_t} R_t^* = R_t(1 + \zeta \Im_t^{uip} B_t^*), \tag{A.17}$$

where the domestic interest rate increases with the amount of foreign debt (Schmitt-Grohé and Uribe, 2003). For better model properties, spreading of $\dot{S}$ over time is incorporated. The debt-elastic premium is persistent in time.

Monetary Policy

$$\log R_t = \rho_R \log R_{t-1} + (1-\rho_R)\left[\log R + \psi \log\left(\frac{\dot{P}_{t+4}^{yy}}{\dot{P}^{yy}}\right)\right] + \varepsilon_t^{mp}. \tag{A.18}$$

Fiscal Policy

$$\log\left(\frac{P_t^G G_t}{P_t^C C_t}\right) = \rho_G \log\left(\frac{P_{t-1}^G G_{t-1}}{P_{t-1}^C C_{t-1}}\right) + (1-\rho_G)\log\left(\frac{P^G G}{P^C C}\right) + \varepsilon_t^G. \tag{A.19}$$

Rest of the World

The downward-sloping demand curve for domestic exports is

$$X_t = \left(\frac{P_t^X}{P_t^*}\right)^{-\theta} N_t^*. \tag{A.20}$$

Foreign variables (the foreign interest rate, foreign demand and foreign inflation) evolve according to

$$\log R_t^* = \rho_{R^*} \log R_{t-1}^* + (1-\rho_{R^*})\log R^* + \varepsilon_t^{R^*}, \tag{A.21}$$

$$\log N_t^* = \rho_{N^*} \log N_{t-1}^* + (1-\rho_{N^*})\log N^* + \varepsilon_t^{N^*}, \tag{A.22}$$

$$\log \dot{\tilde{P}}_t^* = \rho_{P^*} \log \dot{\tilde{P}}_{t-1}^* + (1-\rho_{P^*})\log \dot{\tilde{P}}^* + \varepsilon_t^{P^*}. \tag{A.23}$$

Balanced Growth Path

Similarly to Andrle et al. (2009), we assume a balanced growth path where all variables are either constant or grow at a constant pace. The implied (due to the Cobb-Douglas production function) relationship is

$$\dot{Z}_t = \dot{A}_t (\dot{A}_t^I)^{\frac{1-\gamma}{\gamma}}, \tag{A.24}$$

where aggregate growth $\dot{Z}_t$ is implied by labour-augmenting technology growth $\dot{A}$ and growth of investment-specific technology $\dot{A}_t^I$, which evolve according to AR processes.

National Accounting

The market-clearing equations for domestic and imported intermediate goods are

$$Y_t = Y_t^C + Y_t^G + Y_t^I + Y_t^X \tag{A.25}$$

and

$$M_t = M_t^C + M_t^I + M_t^X, \tag{A.26}$$

where both domestic and imported goods are used for the production of consumption, investment and export final goods. Government final goods are produced from domestic intermediate goods only.

The budget constraints of households and government are

$$P_t^C C_t + P_t^I I_t + B_t = W_t L_t + R_{t-1} B_{t-1} + Q_t K_{t-1} + P_t^C F_t + \Phi_t \tag{A.27}$$

and

$$R_{t-1} B_{t-1} + P_t^G G_t + P_t^C F_t = B_t + S_t \frac{\zeta_B}{2} \mathfrak{I}_t^{uip} (B_t^*)^2. \tag{A.28}$$

Households' dividends are

$$\Phi_t = \Phi_t^Y + \Phi_t^M + \Phi_t^C + \Phi_t^G + \Phi_t^I + \Phi_t^X + \Phi_t^F, \tag{A.29}$$

where

$$\begin{aligned}
\Phi_t^Y &= P_t^Y Y_t - W_t L_t - Q_t k_t, \\
\Phi_t^M &= P_t^M M_t - M_t P_t^*, \\
\Phi_t^C &= P_t^C C_t - P_t^Y Y_t^C - P_t^M M_t^C, \\
\Phi_t^G &= P_t^G G_t - P_t^Y Y_t^G, \\
\Phi_t^J &= P_t^I I_t - P_t^M M_t^I, \\
\Phi_t^X &= P_t^X X_t - P_t^Y Y_t^X - P_t^M M_t^X, \\
\Phi_t^F &= S_t B_{t-1}^* i_{t-1}^* - S_t B_t^* - S_t \frac{\zeta_B}{2} \mathfrak{I}_t^{uip} (B_t^*)^2.
\end{aligned}$$

The previous equations imply

$$S_t B_t^* = S_t B_{t-1}^* R_{t-1}^* + P_t^X X_t - P_t^* M_t.$$

Substituting for foreign bonds in the domestic currency $B_t^{*,dc} = S_t B_t^*$ results in

$$B_t^{*,dc} = \dot{S}_t B_{t-1}^{*,dc} R_{t-1}^* + P_t^X X_t - P_t^* M_t.$$

Relating net foreign assets to the volume of nominal exports implies

$$\mathscr{B}_t = \dot{S}_t \mathscr{B}_{t-1} R_{t-1}^* \frac{P_{t-1}^X X_{t-1}}{P_t^X X_t} + 1 - \frac{P_t^* M_t}{P_t^X X_t}, \tag{A.30}$$

where

$$\mathscr{B}_t \equiv \frac{B_t^{*,dc}}{P_t^X X_t}.$$

A.2 Extension I: Houses Fall from the Sky

The first-order condition with respect to the stock of houses is

$$\lambda_t \lambda_t^H = \phi_H H_t^{-\eta} + \beta_t \lambda_{t+1} \lambda_{t+1}^H, \tag{A.31}$$

where we assume an autoregressive process for the (stationarised) housing stock

$$\log H_t = \rho_H \log H_{t-1} + (1-\rho_H) \log H + \varepsilon_t^H. \tag{A.32}$$

Also, we assume that the stock of houses and the price of houses grow by

$$\dot{H}_t = (H_t/H_{t-1})(\dot{Z}_t \dot{A}_t^H)^{\frac{1}{\eta}} \tag{A.33}$$

and

$$\dot{\lambda}_t^H = (\lambda_t^H/\lambda_{t-1}^H)\dot{P}_t^Y/\dot{A}_t^H, \tag{A.34}$$

where A_t^H is a sector-wide technology compatible with the model's balanced growth path. Also, we assume it is persistent over time via an AR process.

A.3 Extension II: Houses Are Produced from Intermediate Output

Apart from the equations in the baseline model, the first-order conditions of the household sector with respect to the stock of houses H_t and new houses $\hbar_t$ are

$$\lambda_t \lambda_t^H = \phi_H \exp(\varepsilon_t^H) H_t^{-\eta} + \beta_t \lambda_{t+1} \lambda_{t+1}^H \left[(1-\delta_H) \left(\frac{\hbar_{t+1}}{\delta_H H_t} \right)^{\delta_H} - \frac{\eta_H}{2} \left(\frac{\hbar_{t+1}}{\hbar_t} \frac{1}{\alpha \alpha^H} - 1 \right)^2 \right], \tag{A.35}$$

$$\begin{aligned} P_t^{\hbar} = \lambda_t^H \left(\frac{\delta_H H_{t-1}}{\hbar_t} \right)^{1-\delta_H} &- \eta_H \lambda_t^H \frac{H_{t-1}}{\hbar_{t-1}} \left(\frac{\hbar_t}{\hbar_{t-1}} \frac{1}{\alpha \alpha^H} - 1 \right) \frac{1}{\alpha \alpha^H} \\ &+ \beta_t \eta_H \frac{\lambda_{t+1}}{\lambda_t} \lambda_{t+1}^H \frac{H_t}{\hbar_t} \frac{\hbar_{t+1}}{\hbar_t} \left(\frac{\hbar_{t+1}}{\hbar_t} \frac{1}{\alpha \alpha^H} - 1 \right) \frac{1}{\alpha \alpha^H}. \end{aligned} \tag{A.36}$$

The Phillips curve for the new house-producing sector is

$$\log \left(\frac{\dot{P}_t^{\hbar}}{\dot{P}_{t-1}^{\hbar}} \right) = \beta_t \log \left(\frac{\dot{P}_{t+1}^{\hbar}}{\dot{P}_t^{\hbar}} \right) + \frac{(1-\beta_t \Xi_{P^{\hbar}})(1-\Xi_{P^{\hbar}})}{\Xi_{P^{\hbar}}} \log \left(\frac{P_t^Y}{P_t^{\hbar}} \frac{\nu_{P^{\hbar}}}{\nu_{P^{\hbar}} - 1} \right) + \varepsilon_t^{P^{\hbar}}. \tag{A.37}$$

The market-clearing condition for domestic intermediate goods is modified to incorporate the production of new houses

$$Y_t = Y_t^C + Y_t^G + Y_t^I + Y_t^X + Y_t^{\hbar}. \tag{A.38}$$

The dividends from the new house sector are

$$\Phi_t^{\hbar} = P_t^{\hbar} \hbar_t - P_t^Y Y_t^{\hbar}, \tag{A.39}$$

which does not imply any change in the NFA equation, since $P_t^{\hbar}\hbar_t$ are purchased by households.

The assumption of a balanced growth path with respect to $\dot{H}_t$ and $\dot{\lambda}_t^H$ does not change (equations A.33 and A.34). The growth rates and prices of new houses are

$$\dot{\hbar}_t = (\hbar_t/\hbar_{t-1})(\dot{Z}_t\dot{A}_t^H)^{\frac{1}{\eta}} \tag{A.40}$$

and

$$\dot{P}_t^{\hbar} = (P_t^{\hbar}/P_{t-1}^{\hbar})\dot{P}_t^Y/\dot{A}_t^H. \tag{A.41}$$

A.4 Extension III: Houses Are Produced from Sector-Specific Inputs

With respect to the housing sector, the model contains the first-order equations described earlier (A.35 and A.36). The first-order conditions of households with respect to investment in houses, capital for house construction and labour and wages in the housing sector (the wage Phillips curve) are

$$\begin{aligned} P_t^{\mathscr{I}} = \lambda_t^{\mathscr{K}} \left(\frac{\delta_{\mathscr{K}}\mathscr{K}_{t-1}}{\mathscr{I}_t}\right)^{1-\delta_{\mathscr{K}}} &- \eta_{\mathscr{K}}\lambda_t^{\mathscr{K}}\frac{\mathscr{K}_{t-1}}{\mathscr{I}_{t-1}}\left(\frac{\mathscr{I}_t}{\mathscr{I}_{t-1}}\frac{1}{\alpha\alpha^{\mathscr{I}}}-1\right)\frac{1}{\alpha\alpha^{\mathscr{I}}} \\ &+\beta_t\eta_{\mathscr{K}}\frac{\lambda_{t+1}}{\lambda_t}\lambda_{t+1}^{\mathscr{K}}\frac{\mathscr{K}_t}{\mathscr{I}_t}\frac{\mathscr{I}_{t+1}}{\mathscr{I}_t}\left(\frac{\mathscr{I}_{t+1}}{\mathscr{I}_t}\frac{1}{\alpha\alpha^{\mathscr{I}}}-1\right)\frac{1}{\alpha\alpha^{\mathscr{I}}}, \end{aligned} \tag{A.42}$$

$$\lambda_t^{\mathscr{K}} = \beta_t\frac{\lambda_{t+1}}{\lambda_t}\left[\mathscr{Q}_{t+1} + (1-\delta_{\mathscr{K}})\lambda_{t+1}^{\mathscr{K}}\left(\frac{\mathscr{I}_{t+1}}{\delta_{\mathscr{K}}\mathscr{K}_t}\right)^{\delta_{\mathscr{K}}} - \frac{\eta_{\mathscr{K}}}{2}\lambda_{t+1}^{\mathscr{K}}\left(\frac{\mathscr{I}_{t+1}}{\mathscr{I}_t}\frac{1}{\alpha\alpha^{\mathscr{I}}}-1\right)^2\right] \tag{A.43}$$

and

$$\log\left(\frac{\dot{\mathscr{W}}_t}{\dot{\mathscr{W}}_{t-1}}\right) = \beta_t\log\left(\frac{\dot{\mathscr{W}}_{t+1}}{\dot{\mathscr{W}}_t}\right) + \frac{(1-\beta_t\Xi_{\mathscr{W}})(1-\Xi_{\mathscr{W}})}{\Xi_{\mathscr{W}}}\log\left(\frac{\phi_\ell a_t^\ell}{\lambda_t\mathscr{W}_t}\frac{\nu_{\mathscr{W}}}{\nu_{\mathscr{W}}-1}\right) + \varepsilon_t^{\mathscr{W}}. \tag{A.44}$$

Production of New Houses

The first-order conditions with respect to both inputs are

$$\mathscr{Q}_t\kappa_t = (1-\gamma_\ell)q_t^{\hbar}\hbar_t \tag{A.45}$$

and

$$\mathscr{W}_t\ell_t = \gamma_\ell q_t^{\hbar}\hbar_t. \tag{A.46}$$

The Phillips curve is

$$\log\left(\frac{\dot{P}_t^{\hbar}}{\dot{P}_{t-1}^{\hbar}}\right) = \beta_t\log\left(\frac{\dot{P}_{t+1}^{\hbar}}{\dot{P}_t^{\hbar}}\right) + \frac{(1-\beta_t\Xi_{P^{\hbar}})(1-\Xi_{P^{\hbar}})}{\Xi_{P^{\hbar}}}\log\left(\frac{q_t^{\hbar}}{P_t^{\hbar}}\frac{\nu_{P^{\hbar}}}{\nu_{P^{\hbar}}-1}\right) + \varepsilon_t^{P^{\hbar}}. \tag{A.47}$$

Housing Investment

The Phillips curve is

$$\log\left(\frac{\dot{P}_t^{\mathscr{I}}}{\dot{P}_{t-1}^{\mathscr{I}}}\right) = \beta_t \log\left(\frac{\dot{P}_{t+1}^{\mathscr{I}}}{\dot{P}_t^{\mathscr{I}}}\right) + \frac{(1-\beta_t \Xi_{P^{\mathscr{I}}})(1-\Xi_{P^{\mathscr{I}}})}{\Xi_{P^{\mathscr{I}}}} \log\left(\frac{P_t^Y}{P_t^{\mathscr{I}}} \frac{\nu_{P^{\mathscr{I}}}}{\nu_{P^{\mathscr{I}}}-1}\right) + \varepsilon_t^{P^{\mathscr{I}}}, \tag{A.48}$$

where nominal marginal costs are $q_t^{\mathscr{I}} = P_t^Y$.

Balanced Growth Path

Since we allow for separate investment-specific technologies in both final investment goods-producing sectors, the Cobb-Douglas technology implies an equation for investment-specific technology in the housing investment sector which has the form

$$(\dot{Z}_t \dot{A}_t^H)^{\frac{1}{\eta_H}} = (\dot{Z}_t \dot{A}_t^{\mathscr{I}})^{1-\gamma_\ell} (\dot{A}_t)^{\gamma_\ell},$$

which becomes

$$\dot{A}_t^{\mathscr{I}} = \frac{(\dot{Z}_t)^{\frac{\frac{1}{\eta_H}-1+\gamma_\ell}{1-\gamma_\ell}} (\dot{A}_t^H)^{\frac{\frac{1}{\eta_H}}{1-\gamma_\ell}}}{(\dot{A}_t)^{\frac{\gamma_\ell}{1-\gamma_\ell}}}. \tag{A.49}$$

Similarly to the investment sector, the growth rates of housing investment and house prices along the balanced growth path are

$$\dot{\mathscr{I}}_t = (\mathscr{I}_t / \mathscr{I}_{t-1})(\dot{Z}_t \dot{A}_t^{\mathscr{I}}) \tag{A.50}$$

and

$$\dot{P}_t^{\mathscr{I}} = (P_t^{\mathscr{I}} / P_{t-1}^{\mathscr{I}}) \dot{P}_t^Y / \dot{A}_t^{\mathscr{I}}. \tag{A.51}$$

National Accounting

The market-clearing condition for domestic intermediate goods is

$$Y_t = Y_t^C + Y_t^G + Y_t^I + Y_t^X + Y_t^{\mathscr{I}} \tag{A.52}$$

and the dividends are

$$\Phi_t^{\mathscr{I}} = P_t^{\mathscr{I}} \mathscr{I}_t - P_t^Y Y_t^{\mathscr{I}}. \tag{A.53}$$

A.5 Extension IV: Houses Are Produced from Sector-Specific Inputs and Land

With respect to the housing sector, the model contains equations (A.35), (A.36), (A.42), (A.43), (A.44), (A.47), (A.48) and (A.52).

Households

The first-order condition with respect to land is

$$P_t^{\mathscr{L}} = \left(\beta_t \frac{\lambda_{t+1}}{\lambda_t}\right)(\mathscr{Q}_{t+1}^{\mathscr{L}} + P_{t+1}^{\mathscr{L}}), \tag{A.54}$$

where we assume stationary (constant) land which evolves temporarily according to an AR process

$$\log \mathscr{L}_t = \rho_{\mathscr{L}} \log \mathscr{L}_{t-1} + (1-\rho_{\mathscr{L}}) \log \mathscr{L} + \varepsilon_t^{\mathscr{L}}. \tag{A.55}$$

The growth of land prices along the balanced growth path is

$$\dot{P}_t^{\mathscr{L}} = (P_t^{\mathscr{L}} / P_{t-1}^{\mathscr{L}}) \dot{Z}_t \dot{P}_t^Y. \tag{A.56}$$

Production of New Houses

The first-order conditions with respect to construction capital, labour and land are

$$\mathscr{Q}_t \kappa_t = \gamma_\kappa q_t^{\hbar} \hbar_t, \tag{A.57}$$

$$\mathscr{W}_t \ell_t = \gamma_\ell q_t^{\hbar} \hbar_t, \tag{A.58}$$

$$\mathscr{Q}_t^{\mathscr{L}} \mathscr{L}_t = (1-\gamma_\kappa-\gamma_\ell) q_t^{\hbar} \hbar_t. \tag{A.59}$$

Balanced Growth Path

The relationship among technologies implies

$$\hbar_t = A_t^{\hbar} \kappa_t^{\gamma_\kappa} (A_t^H \ell_t)^{\gamma_\ell} \mathscr{L}^{(1-\gamma_\kappa-\gamma_\ell)} \quad \Rightarrow \quad (\dot{Z}_t \dot{A}_t^H)^{\frac{1}{\eta_H}} = (\dot{Z}_t \dot{A}_t^{\mathscr{I}})^{\gamma_\kappa} (\dot{A}_t^H)^{\gamma_\ell} \frac{1}{(\dot{A}_t^{\ell})^{\gamma_\ell}} \quad \Rightarrow$$

$$\dot{A}_t^{\mathscr{I}} = (\dot{Z}_t)^{\frac{\frac{1}{\eta_H}-\gamma_\kappa}{\gamma_\kappa}} (\dot{A}_t^H)^{\frac{\frac{1}{\eta_H}-\gamma_\ell}{\gamma_\kappa}} (\dot{A}_t^{\ell})^{\frac{\gamma_\ell}{\gamma_\kappa}}. \tag{A.60}$$

A.6 Extension V: Non-separable Utility Function

The first-order conditions with respect to consumption and the stock of houses are

$$\lambda_t P_t^C = \frac{(1-\chi)(1-\phi_H)}{\gimel_t - \chi \gimel_t^F} \left(\frac{\gimel_t}{C_t} \right)^{1+\rho_{ns}} \tag{A.61}$$

and

$$\begin{aligned} \lambda_t \lambda_t^H = \frac{(1-\chi)\phi_H \exp(\varepsilon_t^H)}{\gimel_t - \chi \gimel_t^F} \left[\frac{\gimel_t A_t^H}{H_t} \right]^{1+\rho_{ns}} \frac{1}{A_t^H} \\ +\beta_t \lambda_{t+1} \lambda_{t+1}^H (1-\delta_H) \left(\frac{h_{t+1}}{\delta_H H_t} \right)^{\delta_H} - \beta_t \lambda_{t+1} \lambda_{t+1}^H \frac{\eta_H}{2} \left(\frac{\hbar_t}{\hbar_{t-1}} \frac{1}{\alpha \alpha^H} - 1 \right)^2 . \end{aligned} \tag{A.62}$$

Appendix B: Model Properties

Figure B.1: Monetary Policy Shock

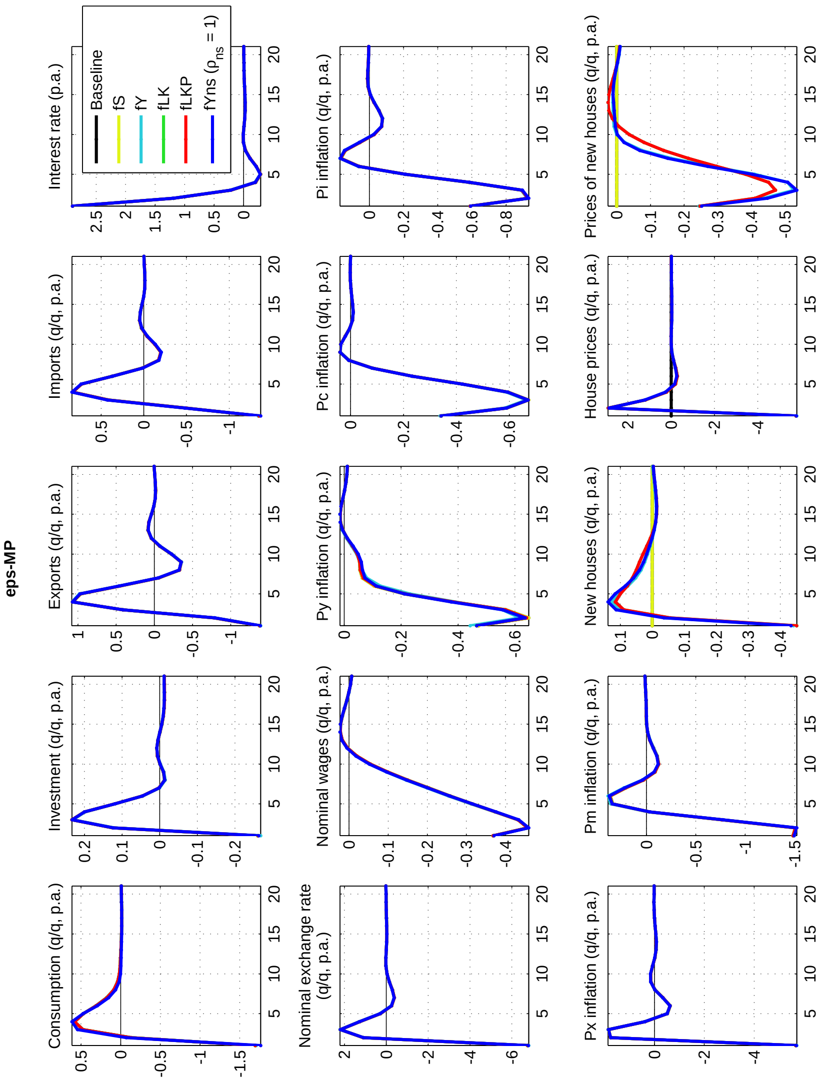


Figure B.2: Habit Shock

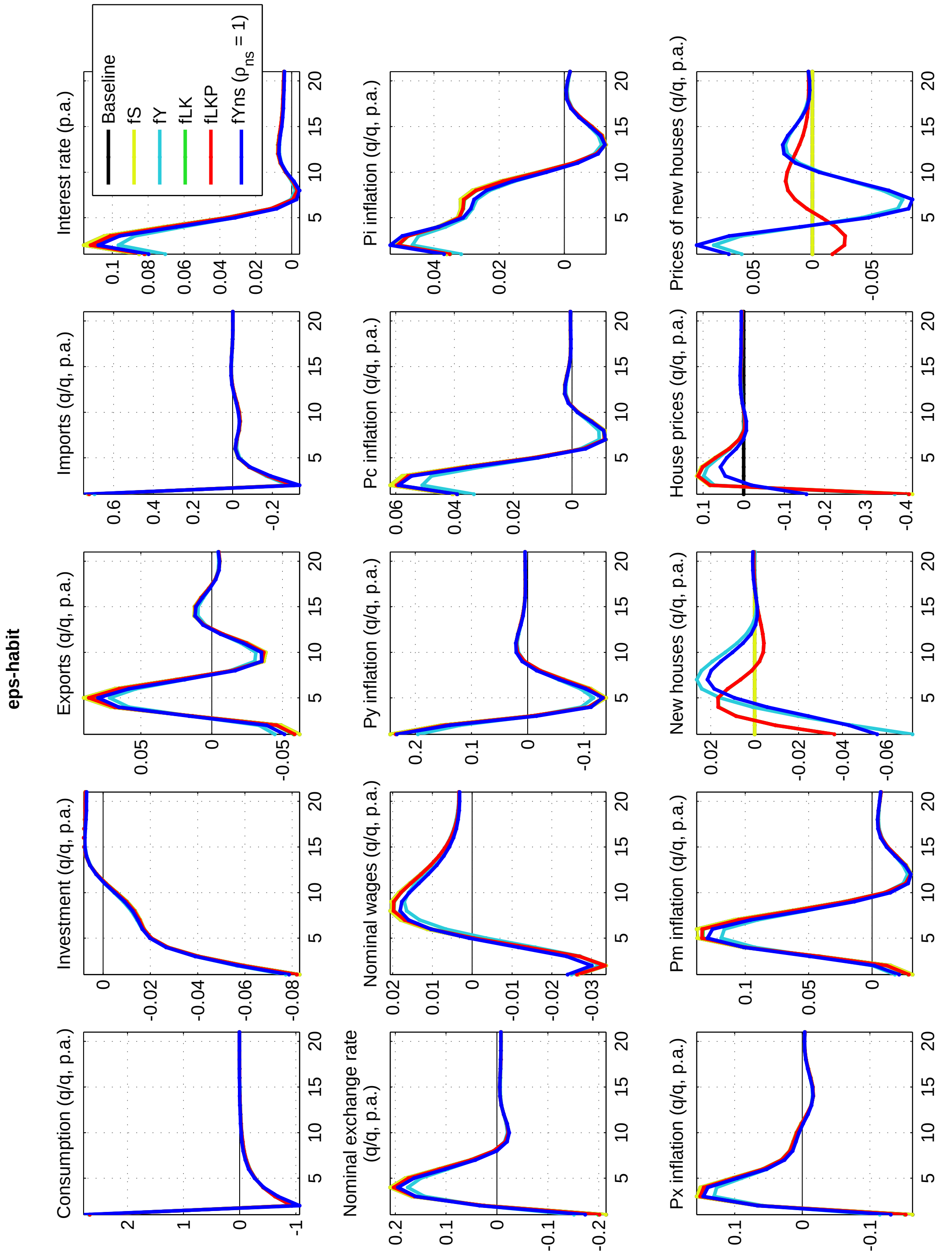


Figure B.3: TFP Shock

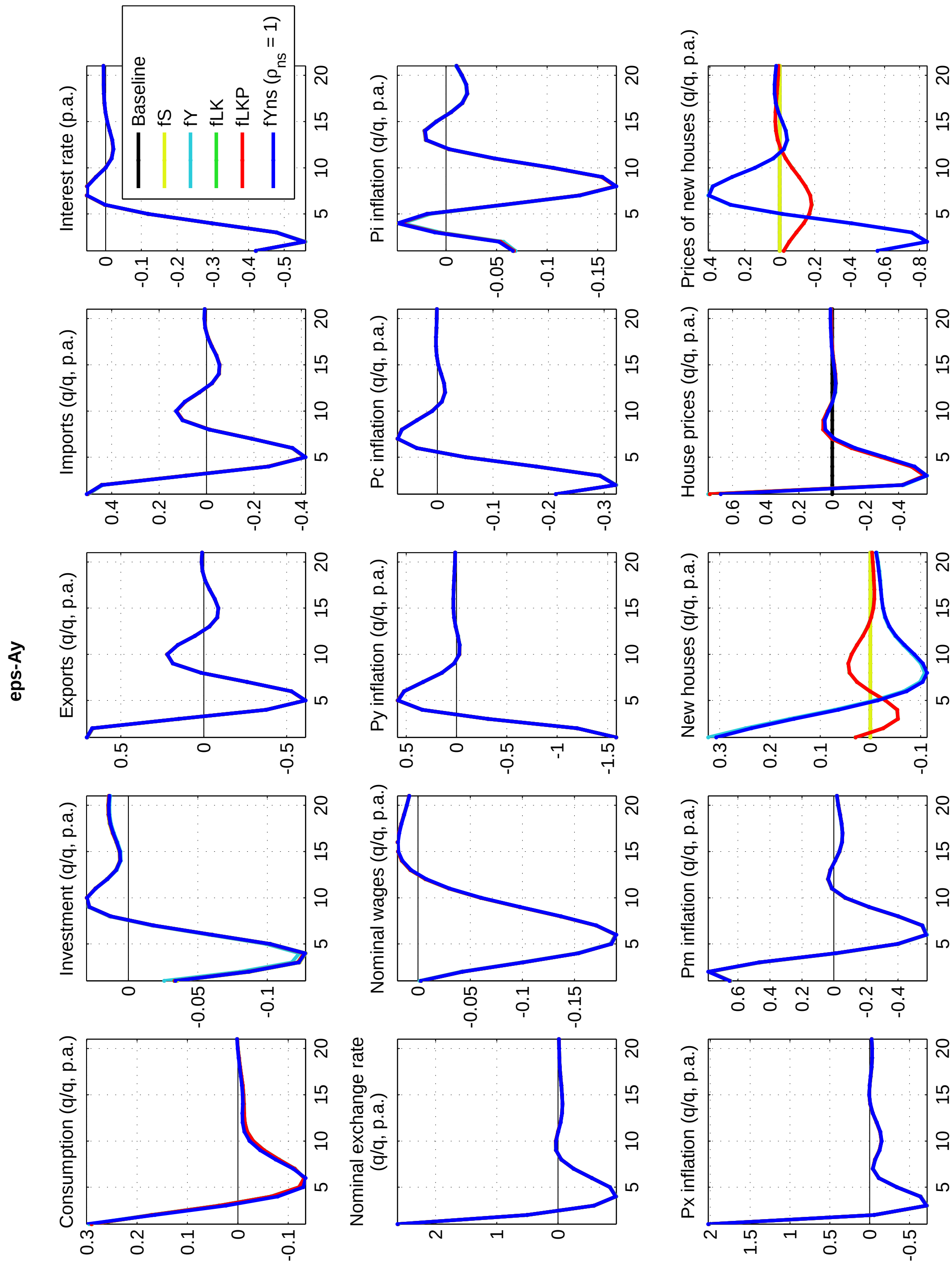


Figure B.4: Cost-Push Shock to Headline Inflation

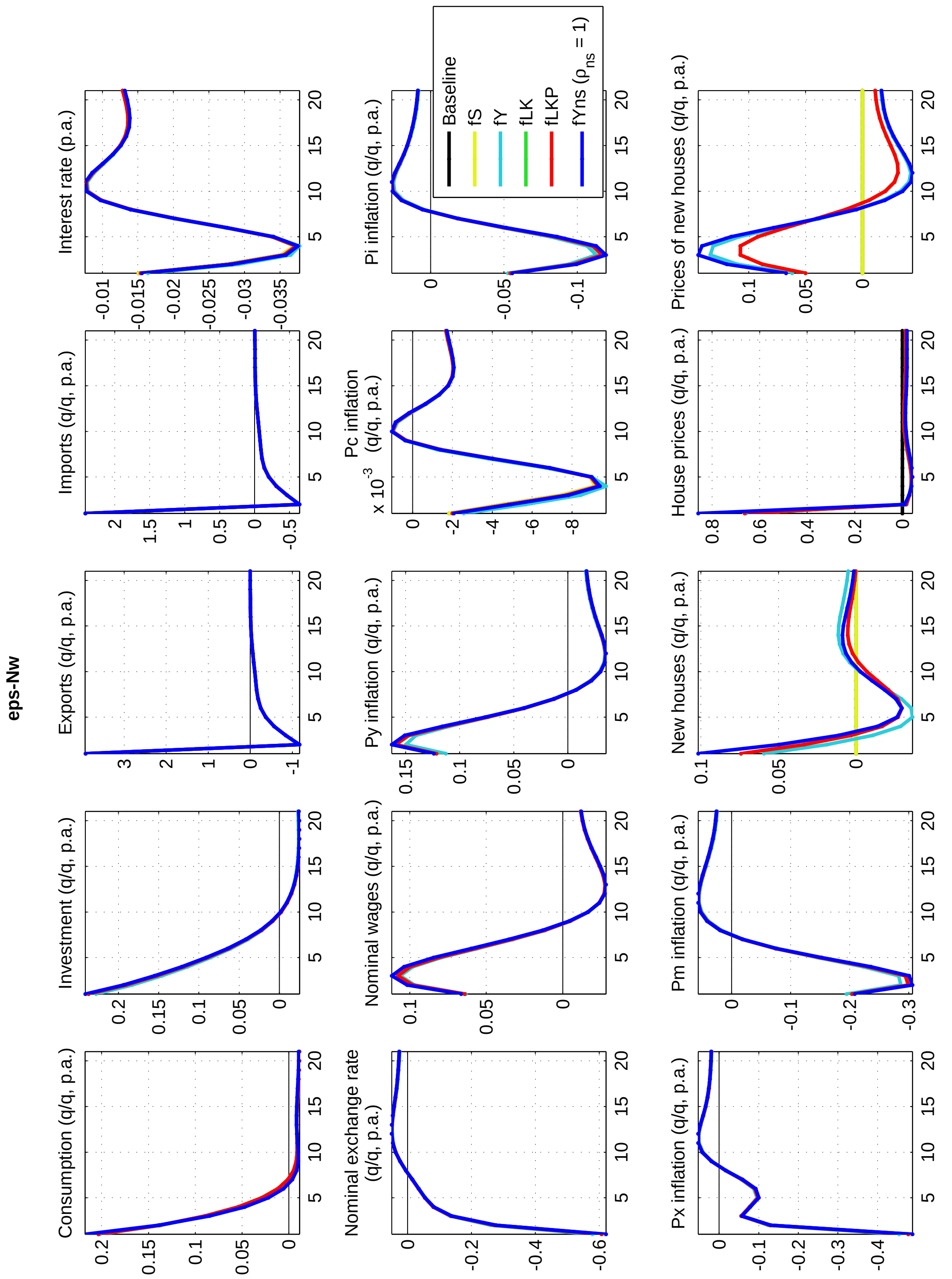


Figure B.5: Wage-Push Shock

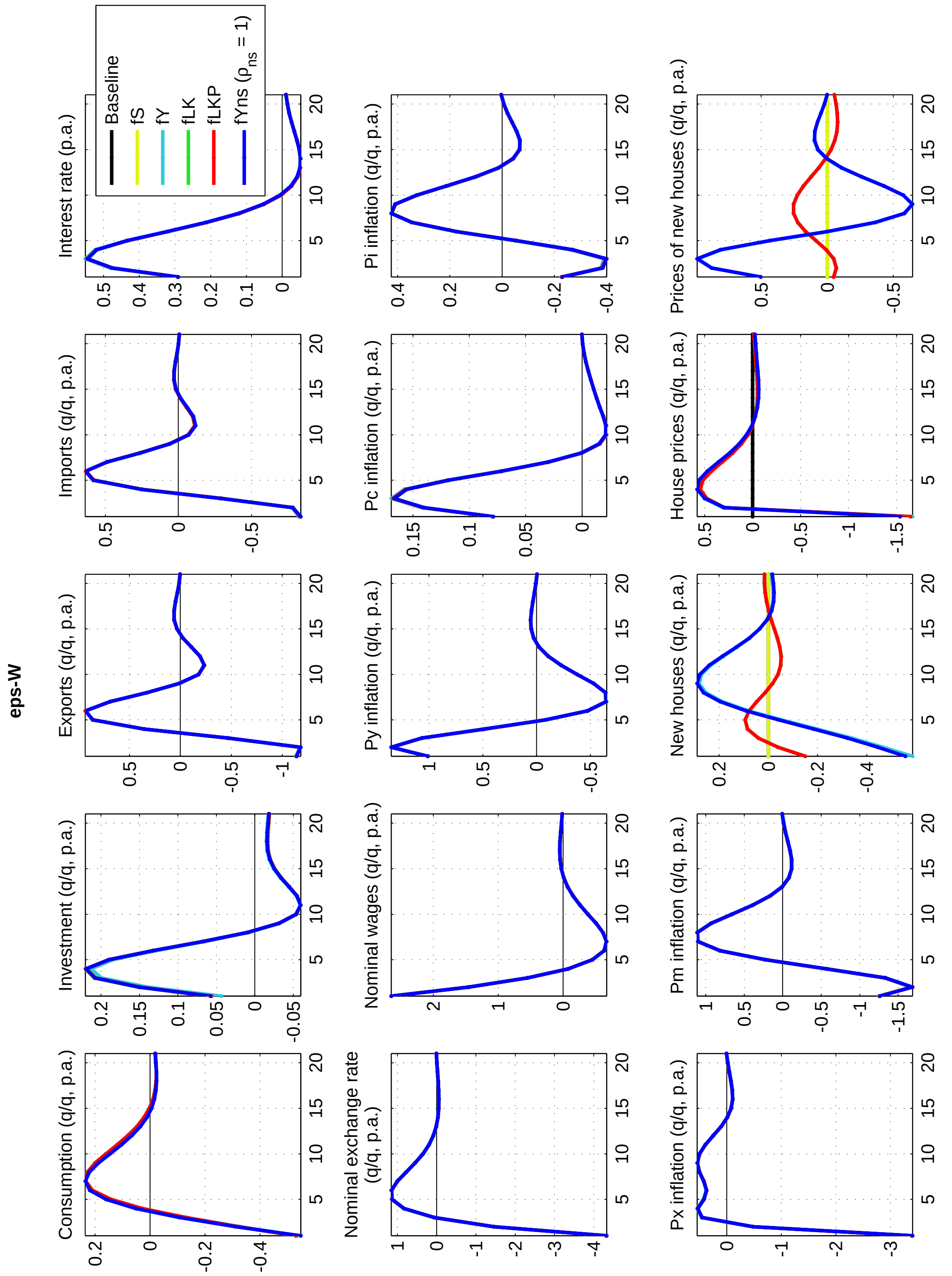


Figure B.6: UIP Shock

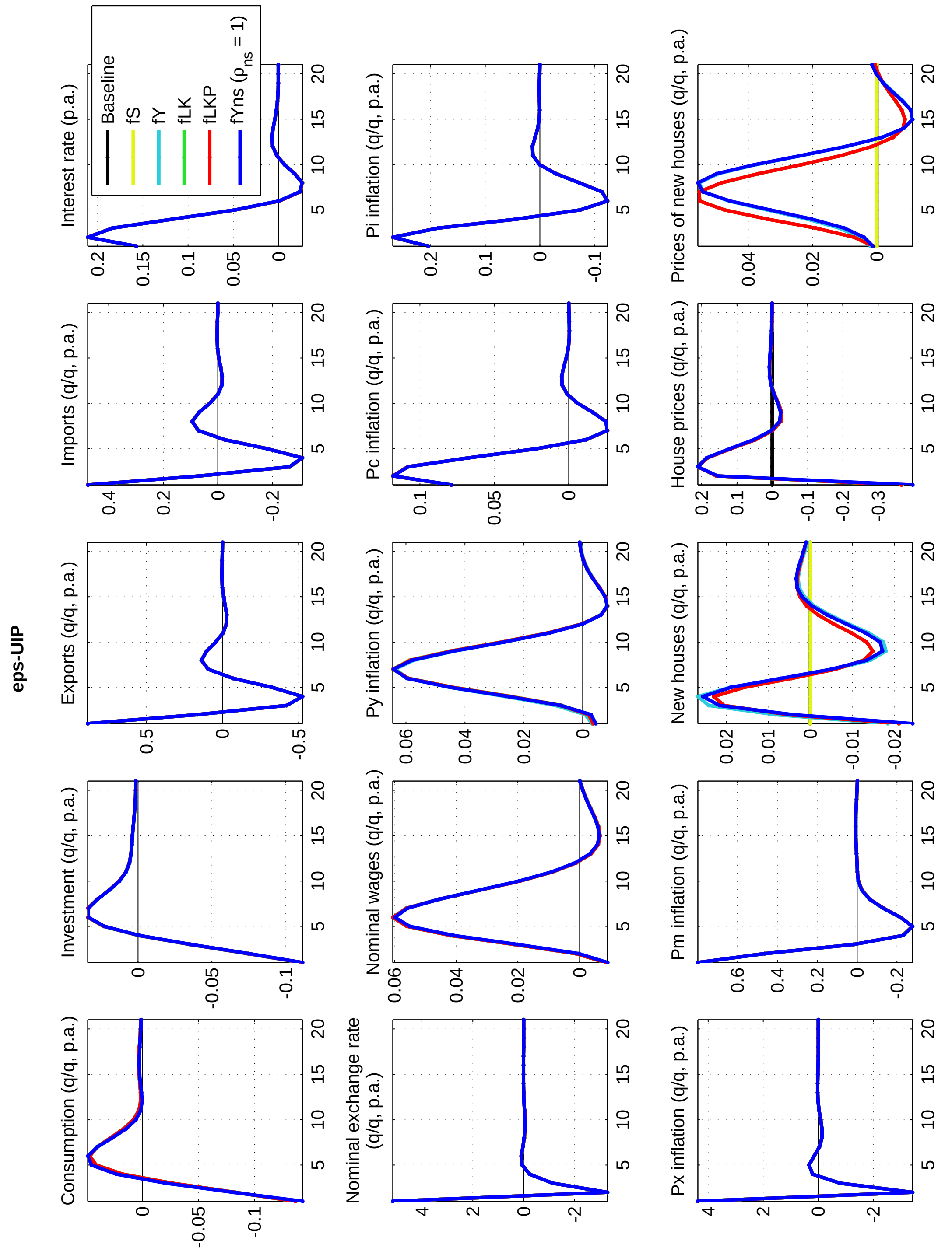


Figure B.7: Foreign Interest Rate Shock

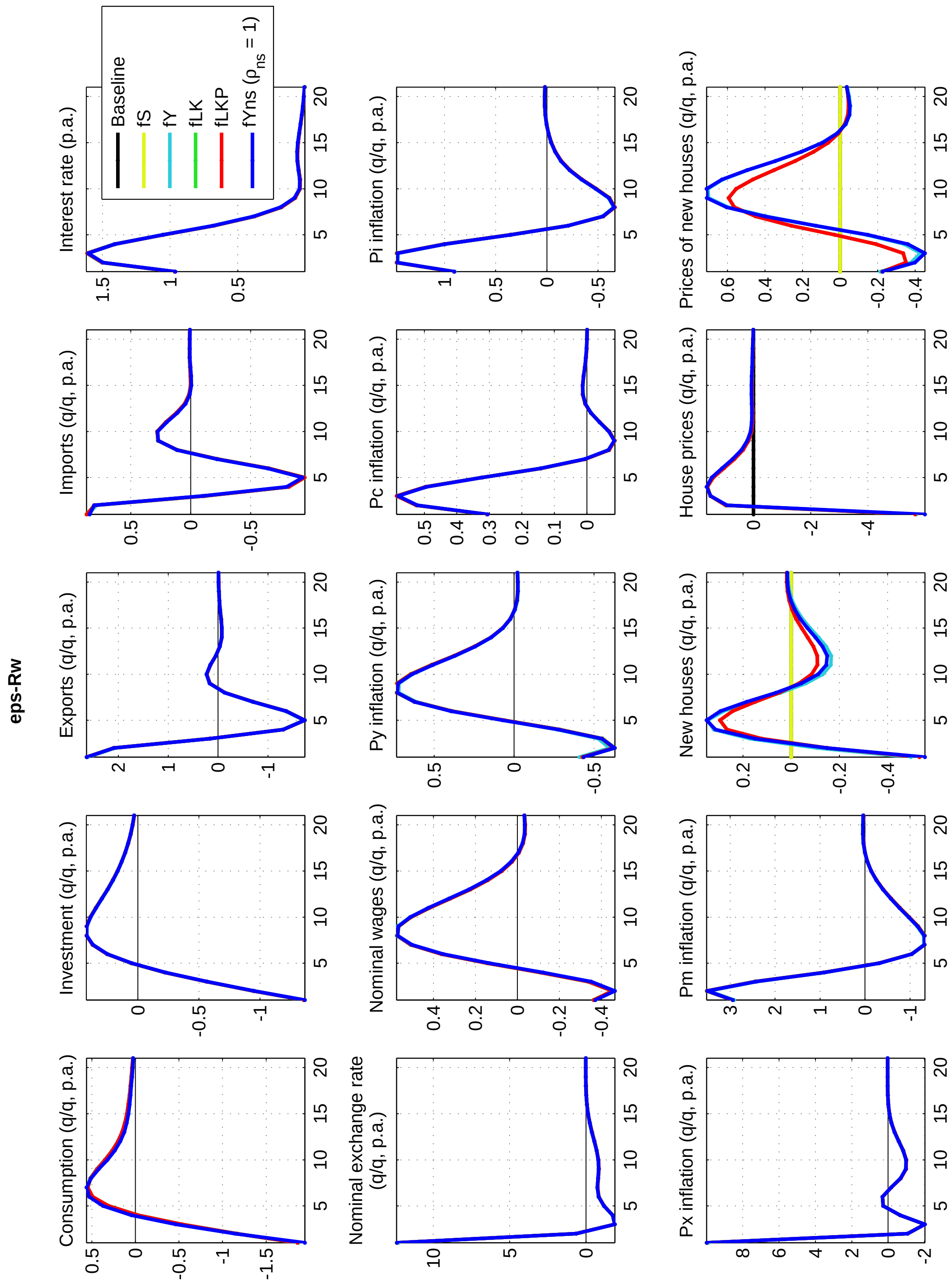


Figure B.8: Foreign Cost-Push Shock

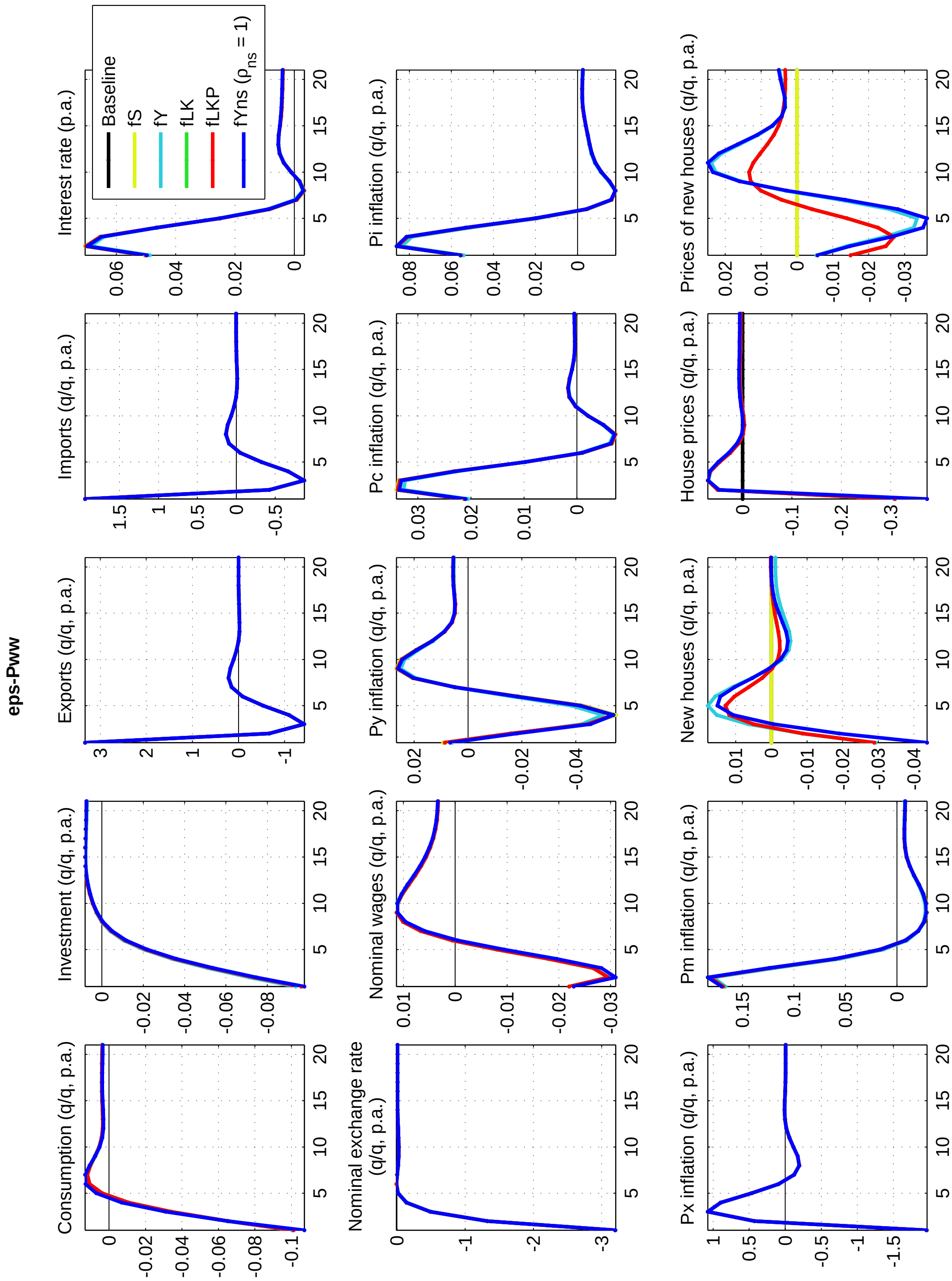


Figure B.9: Foreign Demand Shock

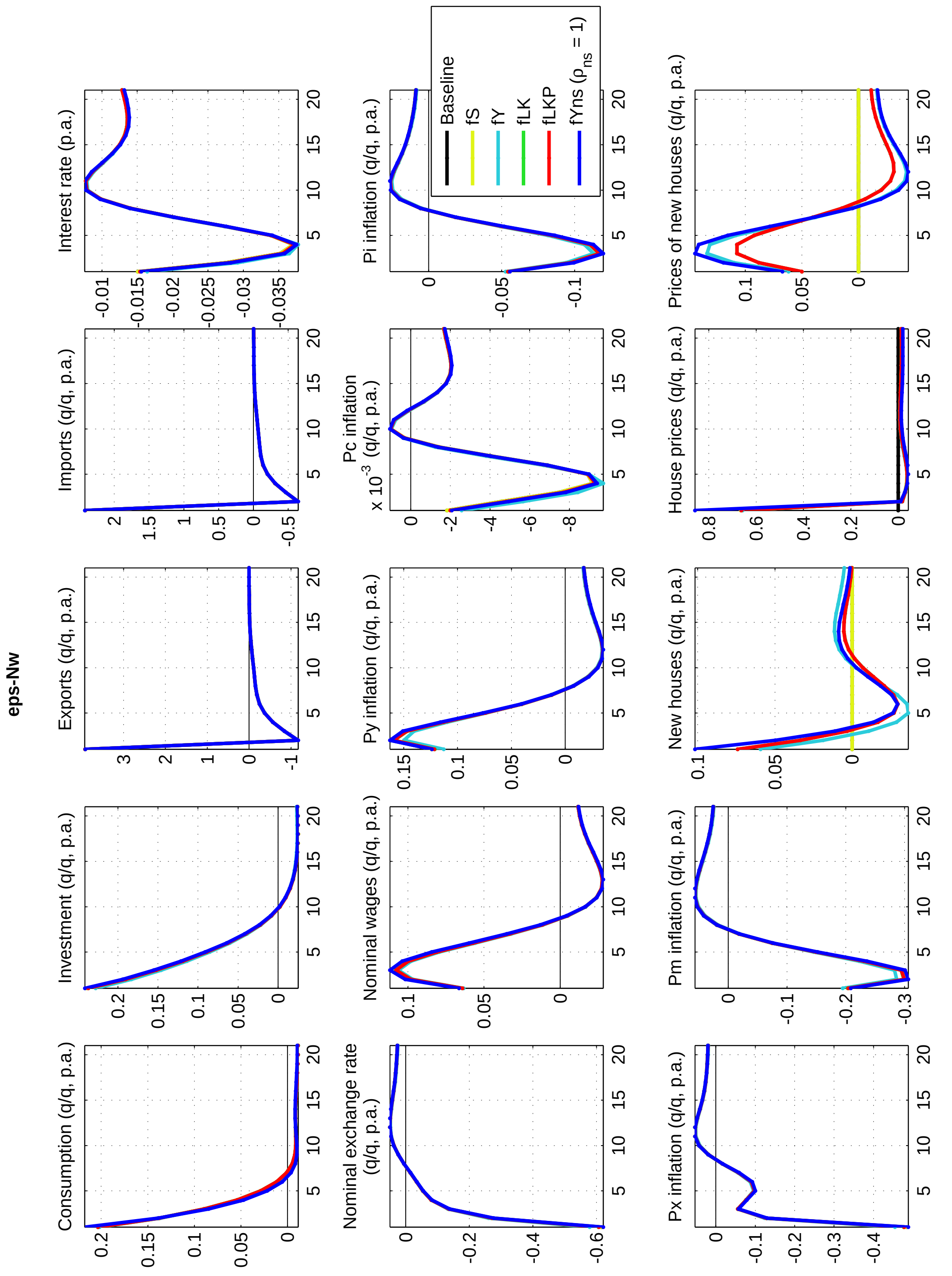


Figure B.10: Shock to the Discount Factor

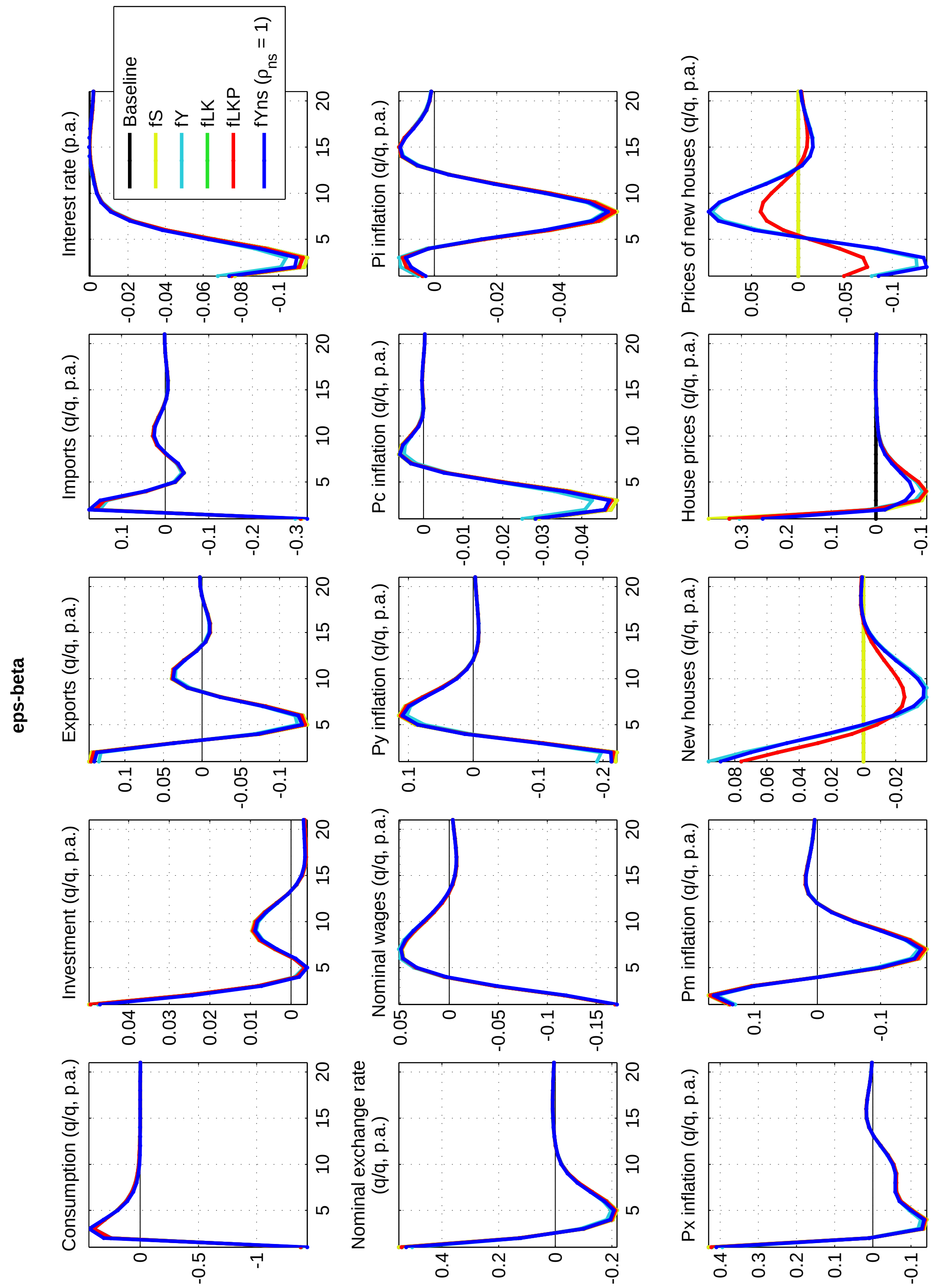


Figure B.11: Housing Preference Shock

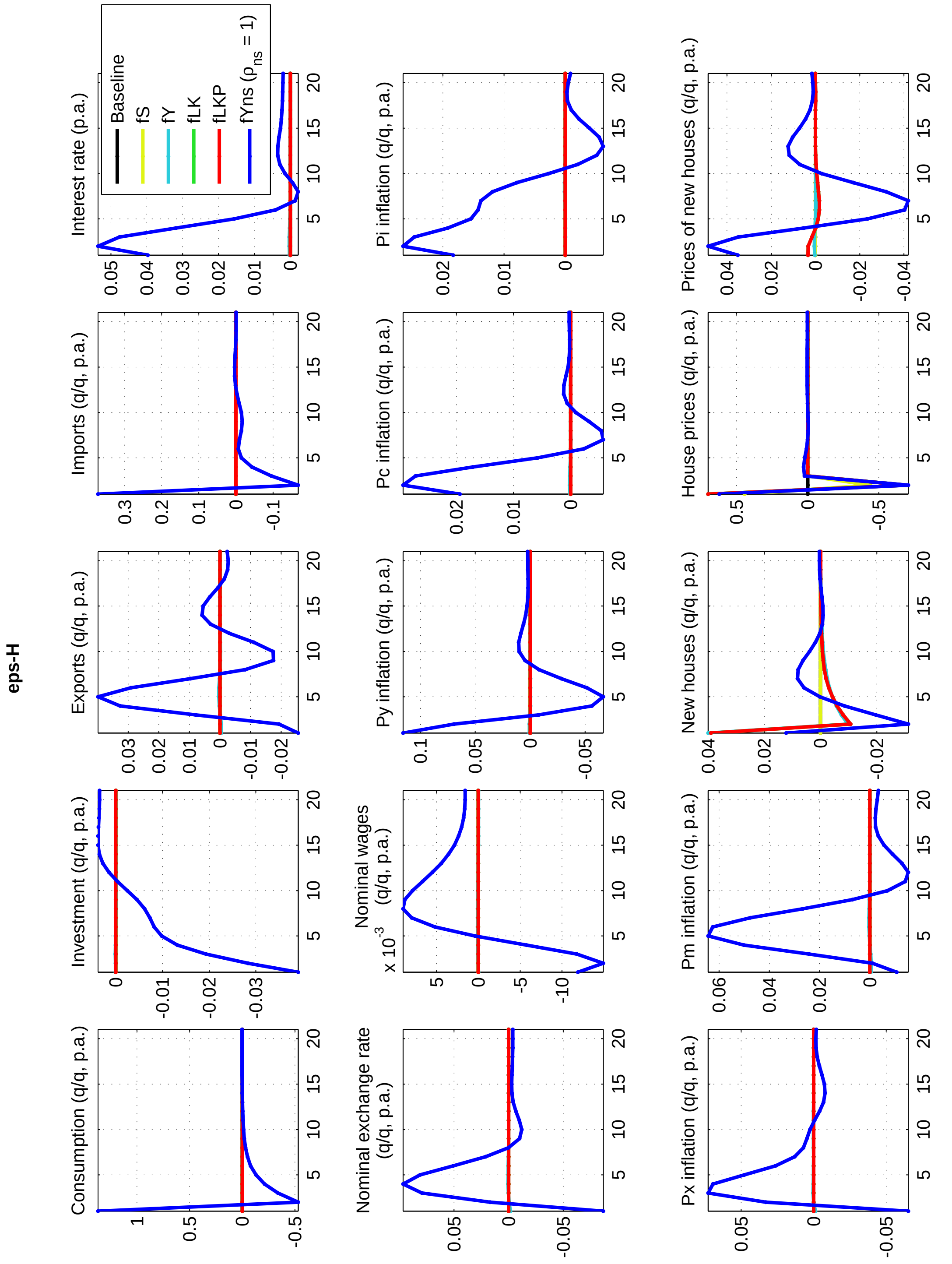


Figure B.12: Shock to Prices of New Houses

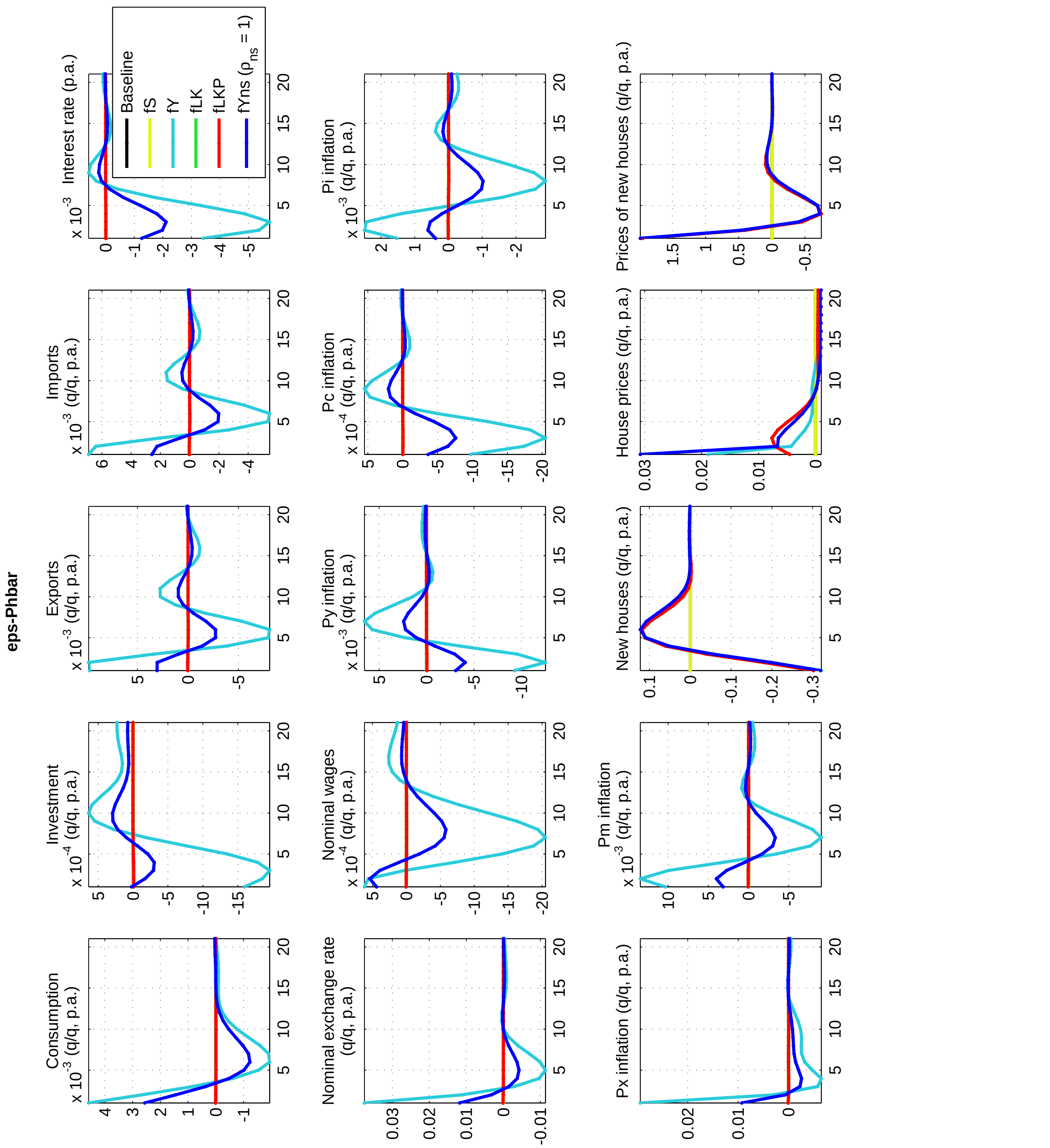


Figure B.13: Shock to House Technology

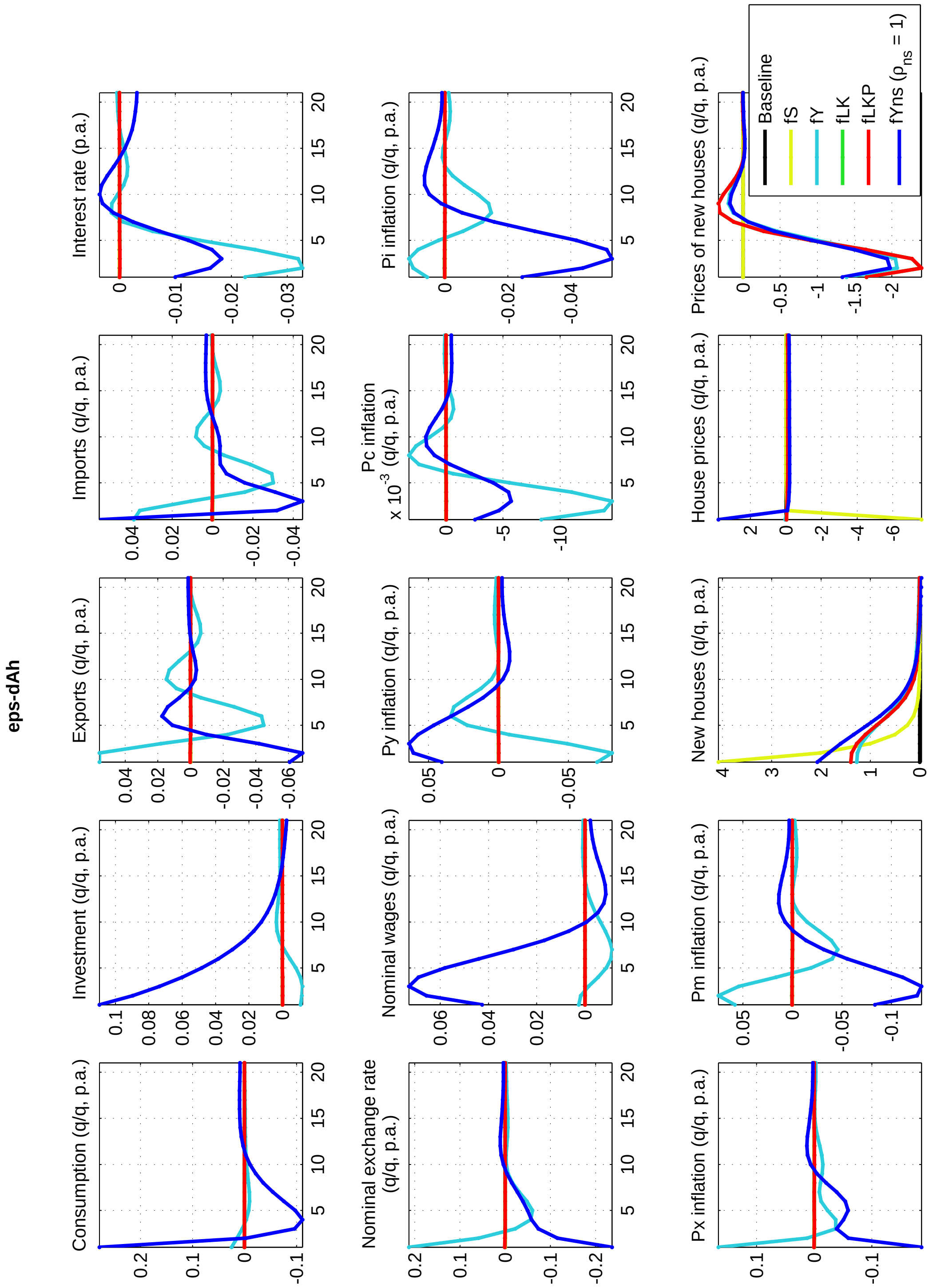


Figure B.14: Labour-Augmenting Technology Shock under Different Values of η (Model fY)

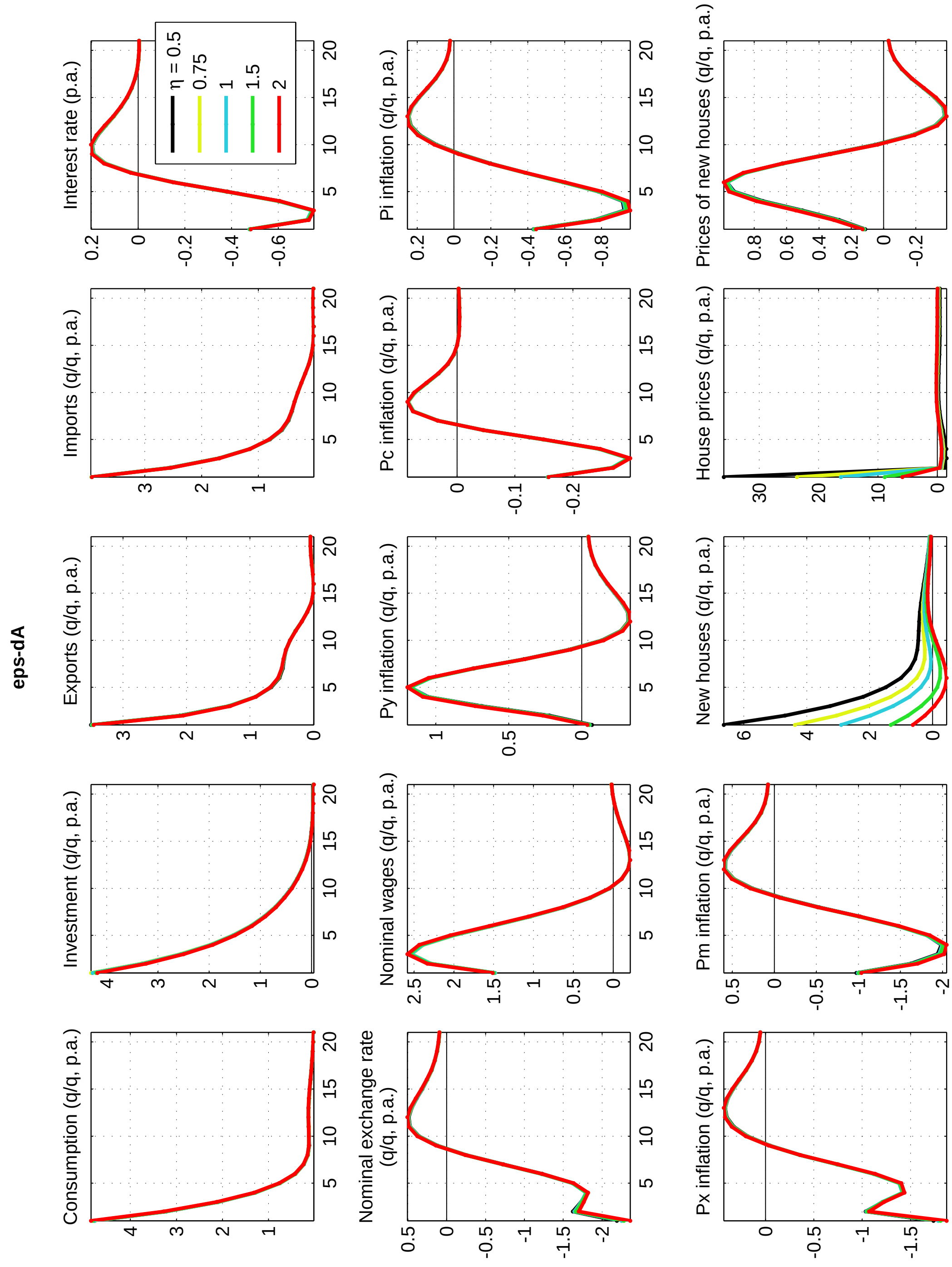


Figure B.15: Housing Preference Shock under Different Values of η (Model fY)

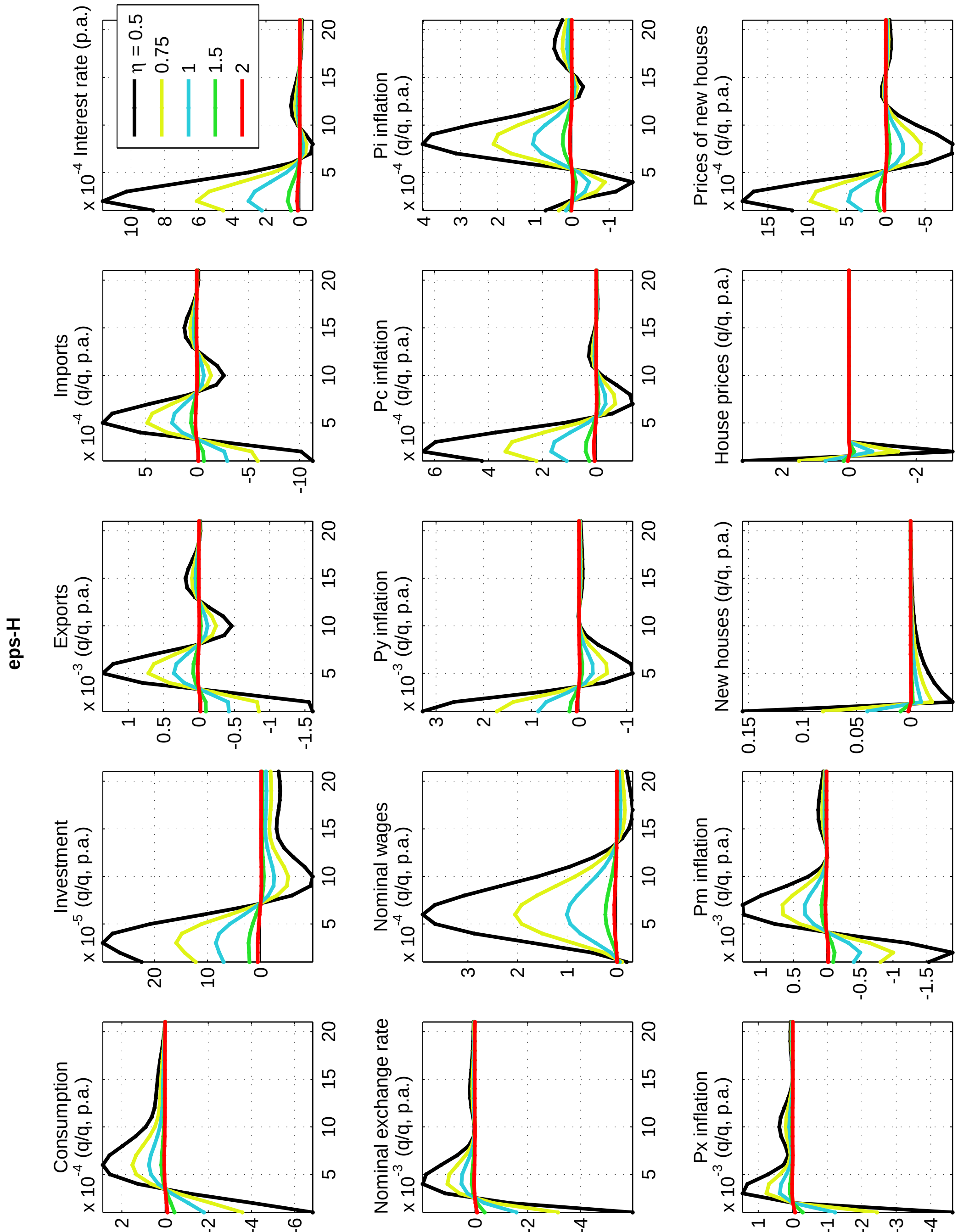


Figure B.16: Correlation of House Prices with Selected Variables

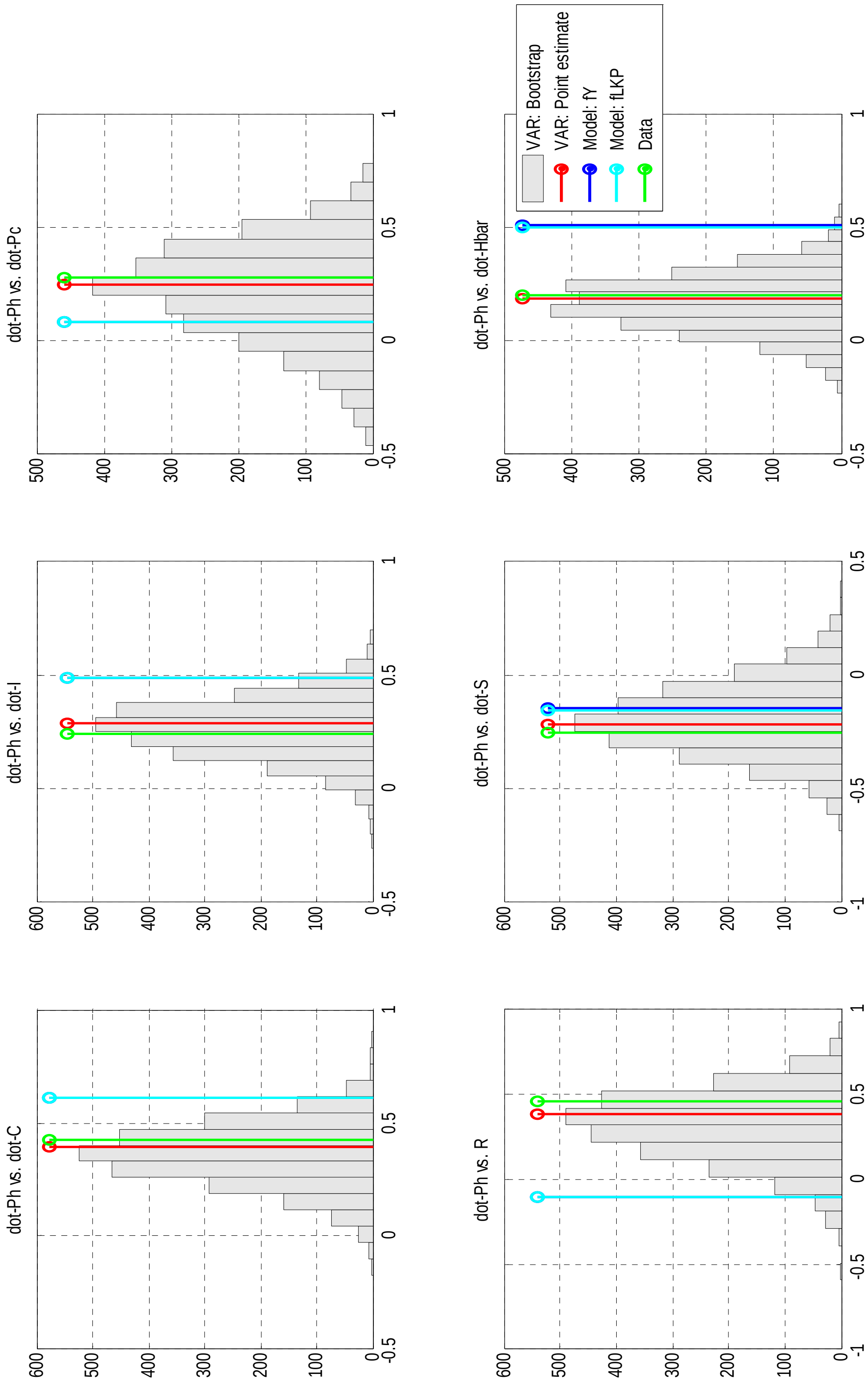


Figure B.17: Correlation of New Houses with Selected Variables

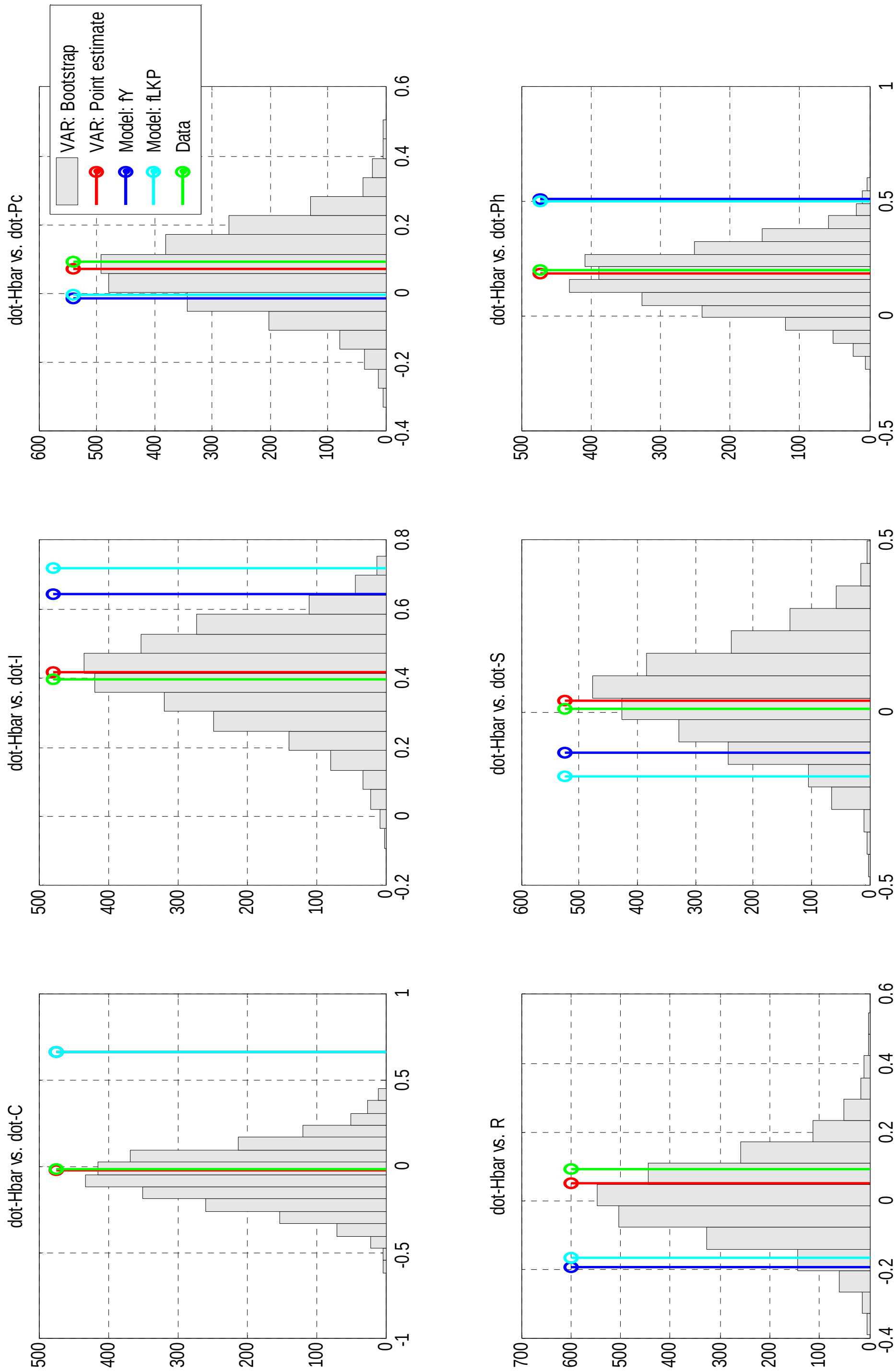
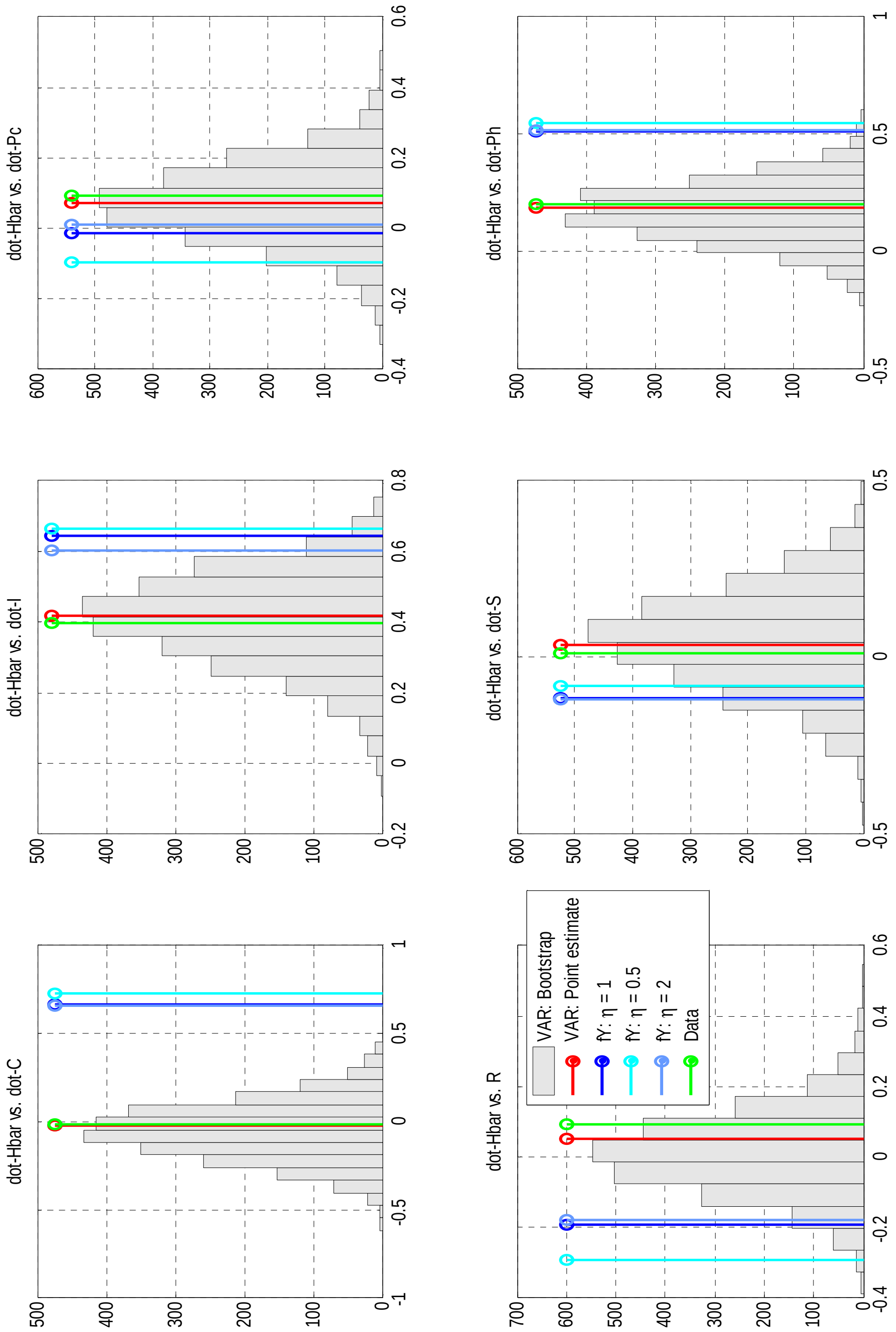


Figure B.18: Correlation of New Houses with Selected Variables (Various Values of* η*)



CNB WORKING PAPER SERIES		
12/2014	Jan Brůha Jiří Polanský	*The housing sector over business cycles: Empirical analysis and DSGE modelling*
11/2014	Tomáš Adam Miroslav Plašil	*The impact of financial variables on Czech macroeconomic developments: An empirical investigation*
10/2014	Kamil Galuščák Gábor Kátay	*Labour force participation and tax-benefit systems: A cross-country comparative perspective*
9/2014	Jaromír Tonner Jan Brůha	*The Czech housing market through the lens of a DSGE model containing collateral-constrained households*
8/2014	Michal Franta David Havrlant Marek Rusnák	*Forecasting Czech GDP using mixed-frequency data models*
7/2014	Tomáš Adam Soňa Benecká Jakub Matějů	*Risk aversion, financial stress and their non-linear impact on exchange rates*
6/2014	Tomáš Havránek Roman Horváth Zuzana Iršová Marek Rusnák	*Cross-country heterogeneity in intertemporal substitution*
5/2014	Ruslan Aliyev Dana Hájková Ivana Kubicová	*The impact of monetary policy on financing of Czech firms*
4/2014	Jakub Matějů	*Explaining the strength and efficiency of monetary policy transmission: A panel of impulse responses from a Time-varying Parameter Model*
3/2014	Soňa Benecká Luboš Komárek	*International reserves: Facing model uncertainty*
2/2014	Kamil Galuščák Petr Hlaváč Petr Jakubík	*Stress testing the private household sector using microdata*
1/2014	Martin Pospíšil Jiří Schwarz	*Bankruptcy, investment, and financial constraints: Evidence from a post-transition economy*
15/2013	Jaromír Baxa Miroslav Plašil Bořek Vašíček	*Inflation and the steeplechase between economic activity variables*
14/2013	Narcisa Kadlčáková Luboš Komárek Zlatuše Komárková Michal Hlaváček	*Identification of asset price misalignments on financial markets with extreme value theory*
13/2013	Giovanni Calice RongHui Miao Filip Štěrba Bořek Vašíček	*Short-term determinants of the idiosyncratic sovereign risk premium: A regime-dependent analysis for European credit default swaps*
12/2013	Michal Skořepa Luboš Komárek	*Sources of asymmetric shocks: The exchange rate or other culprits?*
11/2013	Alexis Derviz	*Collateral composition, diversification risk, and systemically important merchant banks*
10/2013	Tomáš Konečný Oxana Babecká	*Evaluating the links between the financial and real sectors in a small open economy: The case of the Czech Republic*

	Kucharčuková	
9/2013	Michal Franta	*The effect of non-linearity between credit conditions and economic activity on density forecasts*
8/2013	Jan Babecký Tomáš Havránek	*Structural reforms and economic growth: A meta-analysis*
7/2013	Michal Andrle Jan Brůha Serhat Solmaz	*Inflation and output comovement in the Euro Area: Love at second sight?*
6/2013	Marek Rusnák	*Nowcasting Czech GDP in real time*
5/2013	Tomáš Havránek Roman Horváth Petra Valičková	*Financial development and economic growth: A meta-analysis*
4/2013	Peter Tóth	*Currency shocks to export sales of importers: A heterogeneous firms model and Czech micro estimates*
3/2013	Aleš Bulíř Jaromír Hurník Kateřina Šmídková	*Inflation reports and models: How well do central banks really write?*
2/2013	František Brázdik	*Expected regime change: Transition toward nominal exchange rate stability*
1/2013	Adam Geršl Jitka Lešanovská	*Explaining the Czech interbank market risk premium*
15/2012	Róbert Ambriško Jan Babecký Jakub Ryšánek Vilém Valenta	*Assessing the impact of fiscal measures on the Czech economy*
14/2012	Václav Hausenblas Ivana Kubicová Jitka Lešanovská	*Contagion risk in the Czech financial system: A network analysis and simulation approach*
13/2012	Michal Franta	*Macroeconomic effects of fiscal policy in the Czech Republic: Evidence based on various identification approaches in a VAR framework*
12/2012	Konstantin Belyaev Aelita Belyaeva Tomáš Konečný Jakub Seidler Martin Vojtek	*Macroeconomic factors as drivers of LGD prediction: Empirical evidence from the Czech Republic*
11/2012	Adam Geršl Petr Jakubík Tomáš Konečný Jakub Seidler	*Dynamic stress testing: The framework for testing banking sector resilience used by the Czech National Bank*
10/2012	Tomáš Havránek Marek Rusnák	*Transmission lags of monetary policy: A meta-analysis*
9/2012	Volha Audzei František Brázdik	*Monetary policy and exchange rate dynamics: The exchange rate as a shock absorber*
8/2012	Alexis Derviz Jakub Seidler	*Coordination incentives in cross-border macroprudential regulation*
7/2012	Peter Claeys Bořek Vašíček	*Measuring sovereign bond spillover in Europe and the impact of rating news*

6/2012	Michal Franta Jan Libich Petr Stehlík	*Tracking monetary-fiscal interactions across time and space*
5/2012	Roman Horváth Jakub Seidler Laurent Weill	*Bank capital and liquidity creation: Granger causality evidence*
4/2012	Jaromír Baxa Miroslav Plašil Bořek Vašíček	*Changes in inflation dynamics under inflation targeting? Evidence from Central European countries*
3/2012	Soňa Benecká Tomáš Holub Narcisa Liliana Kadlčáková Ivana Kubicová	*Does central bank financial strength matter for inflation? An empirical analysis*
2/2012	Adam Geršl Petr Jakubík Dorota Kowalczyk Steven Ongena José-Luis Peydró Alcalde	*Monetary conditions and banks' behaviour in the Czech Republic*
1/2012	Jan Babecký Kamil Dybczak	*Real wage flexibility in the European Union: New evidence from the labour cost data*
15/2011	Jan Babecký Kamil Galuščák Lubomír Lízal	*Firm-level labour demand: Adjustment in good times and during the crisis*
14/2011	Vlastimil Čadek Helena Rottová Branislav Saxa	*Hedging behaviour of Czech exporting firms*
13/2011	Michal Franta Roman Horváth Marek Rusnák	*Evaluating changes in the monetary transmission mechanism in the Czech Republic*
12/2011	Jakub Ryšánek Jaromír Tonner Osvald Vašíček	*Monetary policy implications of financial frictions in the Czech Republic*
11/2011	Zlatuše Komárková Adam Geršl Luboš Komárek	*Models for stress testing Czech banks´ liquidity risk*
10/2011	Michal Franta Jozef Baruník Roman Horváth Kateřina Šmídková	*Are Bayesian fan charts useful for central banks? Uncertainty, forecasting, and financial stability stress tests*
9/2011	Kamil Galuščák Lubomír Lízal	*The impact of capital measurement error correction on firm-level production function estimation*
8/2011	Jan Babecký Tomáš Havránek Jakub Matějů Marek Rusnák Kateřina Šmídková Bořek Vašíček	*Early warning indicators of economic crises: Evidence from a panel of 40 developed countries*
7/2011	Tomáš Havránek Zuzana Iršová	*Determinants of horizontal spillovers from FDI: Evidence from a large meta-analysis*

6/2011	Roman Horváth Jakub Matějů	*How are inflation targets set?*
5/2011	Bořek Vašíček	*Is monetary policy in the new EU member states asymmetric?*
4/2011	Alexis Derviz	*Financial frictions, bubbles, and macroprudential policies*
3/2011	Jaromír Baxa Roman Horváth Bořek Vašíček	*Time-varying monetary-policy rules and financial stress: Does financial instability matter for monetary policy?*
2/2011	Marek Rusnák Tomáš Havránek Roman Horváth	*How to solve the price puzzle? A meta-analysis*
1/2011	Jan Babecký Aleš Bulíř Kateřina Šmídková	*Sustainable real exchange rates in the new EU member states: What did the Great Recession change?*
15/2010	Ke Pang Pierre L. Siklos	*Financial frictions and credit spreads*
14/2010	Filip Novotný Marie Raková	*Assessment of consensus forecasts accuracy: The Czech National Bank perspective*
13/2010	Jan Filáček Branislav Saxa	*Central bank forecasts as a coordination device*
12/2010	Kateřina Arnoštová David Havrlant Luboš Růžička Peter Tóth	*Short-term forecasting of Czech quarterly GDP using monthly indicators*
11/2010	Roman Horváth Kateřina Šmídková Jan Zápal	*Central banks´ voting records and future policy*
10/2010	Alena Bičáková Zuzana Prelcová Renata Pašaličová	*Who borrows and who may not repay?*
9/2010	Luboš Komárek Jan Babecký Zlatuše Komárková	*Financial integration at times of financial instability*
8/2010	Kamil Dybczak Peter Tóth David Voňka	*Effects of price shocks to consumer demand. Estimating the QUAIDS demand system on Czech Household Budget Survey data*
7/2010	Jan Babecký Philip Du Caju Theodora Kosma Martina Lawless Julián Messina Tairi Rõõm	*The margins of labour cost adjustment: Survey evidence from European firms*
6/2010	Tomáš Havránek Roman Horváth Jakub Matějů	*Do financial variables help predict macroeconomic environment? The case of the Czech Republic*
5/2010	Roman Horváth Luboš Komárek Filip Rozsypal	*Does money help predict inflation? An empirical assessment for Central Europe*
4/2010	Oxana Babecká Kucharčuková	*A gravity approach to modelling international trade in South-Eastern Europe and the Commonwealth of Independent States:*

	Jan Babecký Martin Raiser	*The role of geography, policy and institutions*
3/2010	Tomáš Havránek Zuzana Iršová	*Which foreigners are worth wooing? A Meta-analysis of vertical spillovers from FDI*
2/2010	Jaromír Baxa Roman Horváth Bořek Vašíček	*How does monetary policy change? Evidence on inflation targeting countries*
1/2010	Adam Geršl Petr Jakubík	*Relationship lending in the Czech Republic*
15/2009	David N. DeJong Roman Liesenfeld Guilherme V. Moura Jean-Francois Richard Hariharan Dharmarajan	*Efficient likelihood evaluation of state-space representations*
14/2009	Charles W. Calomiris	*Banking crises and the rules of the game*
13/2009	Jakub Seidler Petr Jakubík	*The Merton approach to estimating loss given default: Application to the Czech Republic*
12/2009	Michal Hlaváček Luboš Komárek	*Housing price bubbles and their determinants in the Czech Republic and its regions*
11/2009	Kamil Dybczak Kamil Galuščák	*Changes in the Czech wage structure: Does immigration matter?*
10/2009	Jiří Böhm Petr Král Branislav Saxa	*Perception is always right: The CNB´s monetary policy in the media*
9/2009	Alexis Derviz Marie Raková	*Funding costs and loan pricing by multinational bank affiliates*
8/2009	Roman Horváth Anca Maria Podpiera	*Heterogeneity in bank pricing policies: The Czech evidence*
7/2009	David Kocourek Filip Pertold	*The impact of early retirement incentives on labour market participation: Evidence from a parametric change in the Czech Republic*
6/2009	Nauro F. Campos Roman Horváth	*Reform redux: Measurement, determinants and reversals*
5/2009	Kamil Galuščák Mary Keeney Daphne Nicolitsas Frank Smets Pawel Strzelecki Matija Vodopivec	*The determination of wages of newly hired employees: Survey evidence on internal versus external factors*
4/2009	Jan Babecký Philip Du Caju Theodora Kosma Martina Lawless Julián Messina Tairi Rõõm	*Downward nominal and real wage rigidity: Survey evidence from European firms*
3/2009	Jiri Podpiera Laurent Weill	*Measuring excessive risk-taking in banking*
2/2009	Michal Andrle Tibor Hlédik	*Implementing the new structural model of the Czech National Bank*

	Ondra Kameník Jan Vlček	
1/2009	Kamil Dybczak Jan Babecký	*The impact of population ageing on the Czech economy*
14/2008	Gabriel Fagan Vitor Gaspar	*Macroeconomic adjustment to monetary union*
13/2008	Giuseppe Bertola Anna Lo Prete	*Openness, financial markets, and policies: Cross-country and dynamic patterns*
12/2008	Jan Babecký Kamil Dybczak Kamil Galuščák	*Survey on wage and price formation of Czech firms*
11/2008	Dana Hájková	*The measurement of capital services in the Czech Republic*
10/2008	Michal Franta	*Time aggregation bias in discrete time models of aggregate duration data*
9/2008	Petr Jakubík Christian Schmieder	*Stress testing credit risk: Is the Czech Republic different from Germany?*
8/2008	Sofia Bauducco Aleš Bulíř Martin Čihák	*Monetary policy rules with financial instability*
7/2008	Jan Brůha Jiří Podpiera	*The origins of global imbalances*
6/2008	Jiří Podpiera Marie Raková	*The price effects of an emerging retail market*
5/2008	Kamil Dybczak David Voňka Nico van der Windt	*The effect of oil price shocks on the Czech economy*
4/2008	Magdalena M. Borys Roman Horváth	*The effects of monetary policy in the Czech Republic: An empirical study*
3/2008	Martin Cincibuch Tomáš Holub Jaromír Hurník	*Central bank losses and economic convergence*
2/2008	Jiří Podpiera	*Policy rate decisions and unbiased parameter estimation in conventionally estimated monetary policy rules*
1/2008	Balázs Égert Doubravko Mihaljek	*Determinants of house prices in Central and Eastern Europe*
17/2007	Pedro Portugal	*U.S. unemployment duration: Has long become longer or short become shorter?*
16/2007	Yuliya Rychalovská	*Welfare-based optimal monetary policy in a two-sector small open economy*
15/2007	Juraj Antal František Brázdik	*The effects of anticipated future change in the monetary policy regime*
14/2007	Aleš Bulíř Kateřina Šmídková Viktor Kotlán David Navrátil	*Inflation targeting and communication: Should the public read inflation reports or tea leaves?*
13/2007	Martin Cinncibuch Martina Horníková	*Measuring the financial markets' perception of EMU enlargement: The role of ambiguity aversion*
12/2007	Oxana Babetskaia-Kukharchuk	*Transmission of exchange rate shocks into domestic inflation: The case of the Czech Republic*

11/2007	Jan Filáček	*Why and how to assess inflation target fulfilment*
10/2007	Michal Franta Branislav Saxa Kateřina Šmídková	*Inflation persistence in new EU member states: Is it different than in the Euro area members?*
9/2007	Kamil Galuščák Jan Pavel	*Unemployment and inactivity traps in the Czech Republic: Incentive effects of policies*
8/2007	Adam Geršl Ieva Rubene Tina Zumer	*Foreign direct investment and productivity spillovers: Updated evidence from Central and Eastern Europe*
7/2007	Ian Babetskii Luboš Komárek Zlatuše Komárková	*Financial integration of stock markets among new EU member states and the euro area*
6/2007	Anca Pruteanu-Podpiera Laurent Weill Franziska Schobert	*Market power and efficiency in the Czech banking sector*
5/2007	Jiří Podpiera Laurent Weill	*Bad luck or bad management? Emerging banking market experience*
4/2007	Roman Horváth	*The time-varying policy neutral rate in real time: A predictor for future inflation?*
3/2007	Jan Brůha Jiří Podpiera Stanislav Polák	*The convergence of a transition economy: The case of the Czech Republic*
2/2007	Ian Babetskii Nauro F. Campos	*Does reform work? An econometric examination of the reform-growth puzzle*
1/2007	Ian Babetskii Fabrizio Coricelli Roman Horváth	*Measuring and explaining inflation persistence: Disaggregate evidence on the Czech Republic*
13/2006	Frederic S. Mishkin Klaus Schmidt-Hebbel	*Does inflation targeting make a difference?*
12/2006	Richard Disney Sarah Bridges John Gathergood	*Housing wealth and household indebtedness: Is there a household 'financial accelerator'?*
11/2006	Michel Juillard Ondřej Kameník Michael Kumhof Douglas Laxton	*Measures of potential output from an estimated DSGE model of the United States*
10/2006	Jiří Podpiera Marie Raková	*Degree of competition and export-production relative prices when the exchange rate changes: Evidence from a panel of Czech exporting companies*
9/2006	Alexis Derviz Jiří Podpiera	*Cross-border lending contagion in multinational banks*
8/2006	Aleš Bulíř Jaromír Hurník	*The Maastricht inflation criterion: "Saints" and "Sinners"*
7/2006	Alena Bičáková Jiří Slačálek Michal Slavík	*Fiscal implications of personal tax adjustments in the Czech Republic*
6/2006	Martin Fukač Adrian Pagan	*Issues in adopting DSGE models for use in the policy process*

5/2006	Martin Fukač	*New Keynesian model dynamics under heterogeneous expectations and adaptive learning*
4/2006	Kamil Dybczak Vladislav Flek Dana Hájková Jaromír Hurník	*Supply-side performance and structure in the Czech Republic (1995–2005)*
3/2006	Aleš Krejdl	*Fiscal sustainability – definition, indicators and assessment of Czech public finance sustainability*
2/2006	Kamil Dybczak	*Generational accounts in the Czech Republic*
1/2006	Ian Babetskii	*Aggregate wage flexibility in selected new EU member states*
14/2005	Stephen G. Cecchetti	*The brave new world of central banking: The policy challenges posed by asset price booms and busts*
13/2005	Robert F. Engle Jose Gonzalo Rangel	*The spline GARCH model for unconditional volatility and its global macroeconomic causes*
12/2005	Jaromír Beneš Tibor Hlédik Michael Kumhof David Vávra	*An economy in transition and DSGE: What the Czech national bank's new projection model needs*
11/2005	Marek Hlaváček Michael Koňák Josef Čada	*The application of structured feedforward neural networks to the modelling of daily series of currency in circulation*
10/2005	Ondřej Kameník	*Solving SDGE models: A new algorithm for the sylvester equation*
9/2005	Roman Šustek	*Plant-level nonconvexities and the monetary transmission mechanism*
8/2005	Roman Horváth	*Exchange rate variability, pressures and optimum currency area criteria: Implications for the central and eastern European countries*
7/2005	Balázs Égert Luboš Komárek	*Foreign exchange interventions and interest rate policy in the Czech Republic: Hand in glove?*
6/2005	Anca Podpiera Jiří Podpiera	*Deteriorating cost efficiency in commercial banks signals an increasing risk of failure*
5/2005	Luboš Komárek Martin Melecký	*The behavioural equilibrium exchange rate of the Czech koruna*
4/2005	Kateřina Arnoštová Jaromír Hurník	*The monetary transmission mechanism in the Czech Republic (evidence from VAR analysis)*
3/2005	Vladimír Benáček Jiří Podpiera Ladislav Prokop	*Determining factors of Czech foreign trade: A cross-section time series perspective*
2/2005	Kamil Galuščák Daniel Münich	*Structural and cyclical unemployment: What can we derive from the matching function?*
1/2005	Ivan Babouček Martin Jančar	*Effects of macroeconomic shocks to the quality of the aggregate loan portfolio*
10/2004	Aleš Bulíř Kateřina Šmídková	*Exchange rates in the new EU accession countries: What have we learned from the forerunners*
9/2004	Martin Cincibuch Jiří Podpiera	*Beyond Balassa-Samuelson: Real appreciation in tradables in transition countries*
8/2004	Jaromír Beneš	*Eigenvalue decomposition of time series with application to the*

	David Vávra	*Czech business cycle*
7/2004	Vladislav Flek, ed.	*Anatomy of the Czech labour market: From over-employment to under-employment in ten years?*
6/2004	Narcisa Kadlčáková Joerg Keplinger	*Credit risk and bank lending in the Czech Republic*
5/2004	Petr Král	*Identification and measurement of relationships concerning inflow of FDI: The case of the Czech Republic*
4/2004	Jiří Podpiera	*Consumers, consumer prices and the Czech business cycle identification*
3/2004	Anca Pruteanu	*The role of banks in the Czech monetary policy transmission mechanism*
2/2004	Ian Babetskii	*EU enlargement and endogeneity of some OCA criteria: Evidence from the CEECs*
1/2004	Alexis Derviz Jiří Podpiera	*Predicting bank CAMELS and S&P ratings: The case of the Czech Republic*

CNB Research and Policy Notes

3/2014	Michal Franta Tomáš Holub Petr Král Ivana Kubicová Kateřina Šmídková Bořek Vašíček	*The exchange rate as an instrument at zero interest rates: The case of the Czech Republic*
2/2014	František Brázdik Zuzana Humplová František Kopřiva	*Evaluating a structural model forecast: Decomposition approach*
1/2014	Michal Skořepa Jakub Seidler	*Capital buffers based on banks' domestic systemic importance: Selected issues*
2/2013	Jan Brůha Tibor Hlédik Tomáš Holub Jiří Polanský Jaromír Tonner	*Incorporating judgments and dealing with data uncertainty in forecasting at the Czech National Bank*
1/2013	Oxana Babecká Kucharčuková Michal Franta Dana Hájková Petr Král Ivana Kubicová Anca Podpiera Branislav Saxa	*What we know about monetary policy transmission in the Czech Republic: Collection of empirical results*
3/2012	Jan Frait Zlatuše Komárková	*Macroprudential policy and its instruments in a small EU economy*
2/2012	Zlatuše Komárková Marcela Gronychová	*Models for stress testing in the insurance sector*

1/2012	Róbert Ambriško Vítězslav Augusta Dana Hájková Petr Král Pavla Netušilová Milan Říkovský Pavel Soukup	*Fiscal discretion in the Czech Republic in 2001-2011: Has it been stabilizing?*
3/2011	František Brázdik Michal Hlaváček Aleš Maršál	*Survey of research on financial sector modelling within DSGE models: What central banks can learn from it*
2/2011	Adam Geršl Jakub Seidler	*Credit growth and capital buffers: Empirical evidence from Central and Eastern European countries*
1/2011	Jiří Böhm Jan Filáček Ivana Kubicová Romana Zamazalová	*Price-level targeting – A real alternative to inflation targeting?*
1/2008	Nicos Christodoulakis	*Ten years of EMU: Convergence, divergence and new policy priorities*
2/2007	Carl E. Walsh	*Inflation targeting and the role of real objectives*
1/2007	Vojtěch Benda Luboš Růžička	*Short-term forecasting methods based on the LEI approach: The case of the Czech Republic*
2/2006	Garry J. Schinasi	*Private finance and public policy*
1/2006	Ondřej Schneider	*The EU budget dispute – A blessing in disguise?*
5/2005	Jan Stráský	*Optimal forward-looking policy rules in the quarterly projection model of the Czech National Bank*
4/2005	Vít Bárta	*Fulfilment of the Maastricht inflation criterion by the Czech Republic: Potential costs and policy options*
3/2005	Helena Sůvová Eva Kozelková David Zeman Jaroslava Bauerová	*Eligibility of external credit assessment institutions*
2/2005	Martin Čihák Jaroslav Heřmánek	*Stress testing the Czech banking system: Where are we? Where are we going?*
1/2005	David Navrátil Viktor Kotlán	*The CNB's policy decisions – Are they priced in by the markets?*
4/2004	Aleš Bulíř	*External and fiscal sustainability of the Czech economy: A quick look through the IMF's night-vision goggles*
3/2004	Martin Čihák	*Designing stress tests for the Czech banking system*
2/2004	Martin Čihák	*Stress testing: A review of key concepts*
1/2004	Tomáš Holub	*Foreign exchange interventions under inflation targeting: The Czech experience*

CNB ECONOMIC RESEARCH BULLETIN

November 2014	*Macroprudential research: Selected issues*
April 2014	*Stress-testing analyses of the Czech financial system*

November 2013	*Macroeconomic effects of fiscal policy*
April 2013	*Transmission of monetary policy*
November 2012	*Financial stability and monetary policy*
April 2012	*Macroeconomic forecasting: Methods, accuracy and coordination*
November 2011	*Macro-financial linkages: Theory and applications*
April 2011	*Monetary policy analysis in a central bank*
November 2010	*Wage adjustment in Europe*
May 2010	*Ten years of economic research in the CNB*
November 2009	*Financial and global stability issues*
May 2009	*Evaluation of the fulfilment of the CNB's inflation targets 1998–2007*
December 2008	*Inflation targeting and DSGE models*
April 2008	*Ten years of inflation targeting*
December 2007	*Fiscal policy and its sustainability*
August 2007	*Financial stability in a transforming economy*
November 2006	*ERM II and euro adoption*
August 2006	*Research priorities and central banks*
November 2005	*Financial stability*
May 2005	*Potential output*
October 2004	*Fiscal issues*
May 2004	*Inflation targeting*
December 2003	*Equilibrium exchange rate*

Czech National Bank
Economic Research Department
Na Příkopě 28, 115 03 Praha 1
Czech Republic
phone: +420 2 244 12 321
fax: +420 2 244 14 278
http://www.cnb.cz
e-mail: research@cnb.cz
ISSN 1803-7070