Housing and Monetary Policy in the Business Cycle: What do Housing Rents have to say?*

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Abstract

In this paper we unveil a feedback loop between monetary policy, housing tenure choice (own vs rent) and measured inflation and quantify its consequences. This feedback loop is explained in three parts: i) Housing rents respond positively to contractionary monetary policy shocks; ii) This effect of interest rates on housing rents gives rise to an important and systematic inflation mismeasurement problem because, directly and indirectly, housing rents weigh approximately 30% in the CPI and 13% in the PCE; iii) When interest rates are set according to a Taylor rule, the systematic mismeasurement of inflation gives rise to a feedback loop by which the monetary authority keeps setting interest rates too high (low) because inflation is apparently too high (low). To rationalize i) and quantify the importance of iii) we propose a standard New Keynesian model augmented with an endogenous housing tenure choice mechanism. Using a calibrated version of the model, we do a counterfactual exercise and estimate that, when the monetary authority targets the implied consumer price index net of housing rents instead of the implied consumer price index, the loss function of monetary policy is 14.5% lower and the welfare in terms of consumption equivalent variation is 0.9% higher. Finally, analysing the same alternative scenario for the 1983-2006 US experience, we find that the standard deviation of housing prices and nominal inflation would have been 24.8% and 19.9% lower, respectively.

JEL classification codes: E31, E43, R21.

Key Words: Housing Rents, Housing Tenure Choice, Monetary Policy, CPI, DSGE, SVAR, FAVAR, Business Cycle.

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1 Introduction

Since the 2007/2008 financial crisis the efforts to better understand the links between housing and the macroeconomy have been enormous and a large amount of new research has been produced since then. The bulk of the literature on housing and the macroeconomy has focused almost entirely on the role of house prices on different economic outcomes such as output, consumption or financial stability. Interestingly, housing rents, which are obviously related to house prices, have been, to the best of our knowledge, completely overlooked.

In this paper, we fill this gap in the literature and unveil and quantify the importance of a new link between monetary policy and the housing market that operates through the effect of monetary policy on housing rents and vice-versa. Before explaining this channel of monetary policy, we must first introduce a new stylized fact regarding the effect of monetary policy on housing rents, and highlight the importance of housing rents in the most commonly used measures of inflation, the consumer price index (CPI) and the personal consumption expenditures (PCE) price index.

New stylized fact: we show housing rents respond positively to contractionary monetary policy shocks using SVAR and FAVAR models and structural shock identification techniques on US data. Specifically, we find that when the federal funds rate is raised by 25 basis points, housing rents increase by 1.22% after five years. Our empirical findings are obtained in the context of empirical models that also include house prices, which were already known to respond negatively to contractionary monetary policy shocks (Iacoviello (2005), Del Negro and Otrok (2007)). Hence, it is surprising that housing rents increase when income, other sale prices and housing prices fall after that same unexpected increase in interest rates.

One possible explanation for these two apparently conflicting results, house prices declining while house rents increase in response to a contractionary monetary policy shock, is the effect that monetary policy may have on housing tenure decisions (own vs. rent). If for some reason the prices of houses and rents do not adjust quickly enough to its new long-run nominal level after a contractionary monetary policy shock, the relative costs of owning vs. renting will change, and this will lead to some people switching from one type of tenure to the other. In support of this interpretation, we show that after a contractionary monetary policy shock rental vacancy rates, homeownership rates and housing starts decline while homeowner vacancy rates increase.

Importance of housing rents in the CPI or PCE: since the adoption of the owner equivalent rent (OER) estimate in 1983 as a measure of shelter costs faced by homeowners that live in their own house, that the direct and indirect weight of housing rents in the CPI has been over 20%, and currently surpassing 30%. In the case of PCE, which uses the same information coming from the housing rental market, the current weight of shelter in the overall index is lower than in the case of CPI and is just slightly above 13% of the total index. [1] The reason why housing rents have such a large weight on total CPI and total PCE is because in the estimation of the OER the Bureau of Labor Statistics (BLS) uses information from the housing rental market to impute rental prices to houses that are owner-occupied (see BLS CPI methodology (2009) for more details on this procedure). Reflective of this is the fact that the correlation between the year-on-year growth rates of housing rent and OER is around 0.85. Hence, the shelter component of CPI and PCE is almost entirely driven by the housing rental market.

The new channel of monetary policy that we claim to unveil is as follows: when the monetary authority increases (decreases) interest rates, *real* housing rents increase (decrease). This creates a measurement issue in tracking underlying nominal inflation and leads to a downward (upward) biased estimate of inflation when CPI or PCE are used. Because directly and indirectly, housing rents have a fairly large weight on CPI and PCE, this bias may be sufficiently large and lead the monetary policy authority to keep setting interest rates too high (low) in its attempt to achieve a certain inflation target. This feedback can add unnecessary variation to the underlying inflation rate and housing prices, and generate large welfare costs and losses to a monetary policy whose objective is to minimize inflation and output gap variance.

To formalize and quantify the importance of this mechanism we add an endogenous housing tenure choice mechanism and heterogeneous agents to a standard New Keynesian model (Clarida, Gali and Gertler (1999)). By including housing rents, we can introduce a theoretical CPI in the model that is constructed based on a weighted basked of housing rents and composite consumption good. We calibrate the model to match key features of the U.S. economy assuming the monetary authority reacts to CPI, and show that it fits remarkably well some of the data moments that are not targeted by the calibration exercise. Moreover, with our model, we are able to endogenously generate a price puzzle without having to assume that there is a cost channel of monetary policy. [2]

With the calibrated model we do a counterfactual exercise where we compare both aggregates

[1] If we excluded the food and energy components from CPI and PCE, that is, if our reference was not total CPI or total PCE but core CPI and core PCE, the current weights of shelter in core CPI would be over 40% and over 17% in the case of core PCE.

[2] In a companion paper, Dias and Duarte (2015), we explore this result further, and show that to a large extent the price puzzle can be explained by the response of shelter to monetary shocks. In addition, we also show that inflation is much less persistent than what analyses based on overall CPI or PCE suggest.

and price dynamics of the calibrated model, the benchmark case, whereby we assume the interest rate Taylor rule takes CPI as input, to an alternative setting where the Taylor rule takes a rents-free consumer price index as input. Our counterfactual exercises reveal that: 1) targeting a measure of inflation that excludes housing rents leads to a 0.9% welfare gain in consumption equivalent variation and to a 14.5% fall in the loss function of monetary policy whose objective is to minimize inflation and output gap variance; 2) we estimate that this mechanism can explain 37.5% of the increase in house prices above trend[3] that occurred between 2002 and 2007; 3) under the alternative scenario, we find that the standard deviation of housing prices and nominal inflation would have been 24.8% and 19.9% lower for the 1984-2006 US experience, respectively.

In this paper, we do not argue for the exclusion of housing rents from the CPI in every circumstance. Housing rents are an important item on measuring households cost of living since households spend around 30% of their income with shelter, and hence should be part of the consumer price index. In general, price indexes trends capture well the evolution of the nominal state of the economy. However, when relative prices of some specific goods change suddenly, these price indexes are affected regardless of how underlying monetary inflation behaves. Vining and Elwertowski (1976) make this point very clearly. This is one of the reasons economists have built core versions of the price indexes. When studying the effects of monetary policy on the monetary inflation, it is important to remove housing rents, thus creating a different core index, because their relative price is strongly affected and they have a large weight in price indexes. When these two facts are added together, serious biases can be introduced when tracking the nominal state of the economy.

Our contribution adds to three distinct strands of literature, namely the literature looking at housing and the business cycle, the literature about problems of the CPI, or similar price indexes, as a measure of inflation, and literature about housing tenure choice. The two papers about housing and the business cycle that are closest to our contribution are Iacoviello (2005) and Leamer (2007). In Iacoviello (2005), the author makes the point that housing market generate amplifications of the business cycle dynamics because housing prices are used as collateral and they co-move with the economy activity. In our paper, we abstract from the housing prices financial channel and focus on explaining how housing rents can also lead to business cycle amplifications through mismeasure-

[3]The trend was computed using an HP filter. It is worth noting our model is a business cycle model and has nothing to say with respect to housing prices trend. Although the trend of housing prices was substantial between 2002 and 2006, we can still analyse by how much housing prices were above trend for the same period and compare this housing prices business cycle dynamics for the two different scenarios.

ment in the CPI coupled with a Taylor rule. In Leamer (2007), the author argues that "housing is the business cycle" and proposes that the monetary authority should not only target inflation and GDP, but also housing starts. In this paper we incorporate this suggestion indirectly because by better controlling (true) inflation, the monetary authority is also indirectly controlling the incentives for investment in housing.

In the case of the literature on the problems of CPI as measure of inflation, we add to the literature on measures of core inflation – the issue we highlight is due to a change in relative prices – but also to the literature on the biases of the CPI as measure of inflation. In the case of core inflation, the list of contribution is very long and therefore the best reference is a survey paper like Clark (2001) which summarizes the main contributions in this area. In the case of biases of the CPI as measures of inflation, the starting point of this literature is Boskin et al. (1998). In this paper, the authors estimate that due to different sources, the CPI is biased upwards by more than 1 percentage point. Moreover, specifically analysing how shelter is computed in the CPI, Gordon and vanGoethem (2007) argue rental shelter housing has been biased downward for its entire history since 1914, while Díaz and Luengo-Prado (2008) show that the rental equivalence approach overestimates the cost of housing services. An important distinction of our paper to this literature is that we show a dynamic bias in the CPI instead of a static one.

To the best of our knowledge, the first model of housing tenure choice was developed by Henderson and Ioannides (1983). However, their analysis is in a partial equilibrium setting. More recently, Chambers, Garriga, and Schlagenhauf (2009) have expanded the structure of the rental and housing markets and were able to show mortgage innovations in the U.S. account for most changes in homeownership rate. Sommer, Sullivan and Verbrugge (2013) take Chambers, Garriga, and Schlagenhauf (2009) structure and are the first to consider a model where both housing rents and housing prices are determined in equilibrium. However, Sommer, Sullivan and Verbruggeb (2013) analysis is for steady state and transitional dynamics. In our paper, at the cost of extremely simplify the structure on the housing and rental market, we are able to endogeneize housing rents and housing prices in the business cycle.

The remainder of the paper is organized as follows. In section 2 we provide our main empirical findings which show the effect of monetary policy on housing rents and housing tenure choice. Section 3 builds the monetary model and section 4 calibrates the model to the US experience and discusses the model solution. Section 5 shows the counter factual exercise with the calibrated model. Finally, section 6 draws the main conclusions of the paper.

2 Empirical Findings

2.1 Evidence on the effect of monetary policy on housing rents and prices

In this section we describe the data used and show the impulse responses of the variables of interest to a contractionary monetary policy shock[4] using SVAR and FAVAR. The monetary contractionary shock is defined here as an unexpected increase in the federal funds rate.

Our main finding is that housing *rents* respond positively to a contractionary monetary policy shock. This response is surprising as housing *prices*, most other sale prices and output respond negatively to the same shock Moreover, the response is large in magnitude. In our benchmark SVAR, we find that a permanent increase of the federal funds rate by 25 basis points increases housing rents by 1.22% after five years.

2.1.1 SVAR

A. *SVAR Data and Identification*

The data used in the SVAR covers the 1975-2006 period for the US. The starting period was selected based on when housing prices data became available. We exclude the period of the great recession because the standard monetary transmission mechanism was lost during the period. Hence, interest rate Taylor rule behaviour was no longer a good description of monetary policy in the neighbouring period of the great recession. For this reason, we excluded the period from our analysis.

All data was collected from FRED database. We used six aggregate time series for the US in our SVAR analysis: real gross domestic product (GDPC1), all-transactions house price index (USSTHPI), rent of primary residence in CPI (CUS-R0000SEHA), GDP deflator (GDPDEF), M1 money stock (M1) and finally federal funds rate (FF). Real housing prices and rents were computed deflating the housing price index and rents with the GDP deflator. All series were transformed to be covariance stationary using log-difference with the exception of federal funds rate. This transformation also allows for an easier interpretation of the impulse-response functions.

The SVAR is an appropriate empirical strategy to analyze the dynamic impact of monetary policy on housing rents as it allows one to identify a monetary policy shock with a small set of assumptions. In our benchmark SVAR, we use the standard Cholesky identification following Christiano,

[4]For impulse responses to other shocks see Figures section in the appendix.

Eichenbaum and Evans (1998) whereby the order follows GDP, Inflation, Housing rents, housing prices, federal funds rate and M1. Hence, monetary policy instruments are ordered last and have no contemporaneous effect on the remaining variables of the system.

However, the ordering of the variables in the system is always a cause of concern. In this particular case, matters become worse because how can one order housing prices and rents? However, our main results are robust to different orderings in the Cholesky decomposition. In addition, our results are also robust to a different identification strategy by pure-sign restriction following Uhlig (2005). In the pure-sign restriction we restrict the response of inflation to be negative, M1 to also be negative and federal funds rate to be positive for four periods while the remaining responses are left unrestricted.

B. *SVAR Results*

Our main finding is housing rents increase after a monetary contractionary policy shock. In addition, we show housing prices decrease in response to the same shock. While the result on housing prices confirms previous findings in the literature like in Iacoviello (2005) and Del Negro and Otrok (JME, 2007), the housing rents positive response is novel and surprising.

In Figure 1, we show the responses of our six variable benchmark SVAR to a positive standard deviation shock in the federal funds rate. All the responses are in percentage points on the level of each variable. Housing rents responds positively after six quarters forward. The initial sluggish response of housing rents could be the result of stickiness, as housing rents contracts are usually annual.

The effect of the monetary policy contractionary shock on housing rents is long lasting, reaching an approximately 0.4% positive response after twenty quarters, five years. The response is large in magnitude and although not reported here, the response is also significant at a 95% credible set. If we calculate the accumulated effect on housing rents, we find that a permanent increase of the federal funds rate by 25 basis points increases housing rents by 1.22% after five years.

The positive response of housing rents happens while output, price level and housing prices are decreasing. In particular, we find the usual u-shape response of output to a contractionray monetary policy shock and that housing prices respond in a larger magnitude than rents in the opposite direction. The negative effect we find of monetary policy on housing rents confirms previous literature findings, like Del Negro and Otrok (JME, 2007).

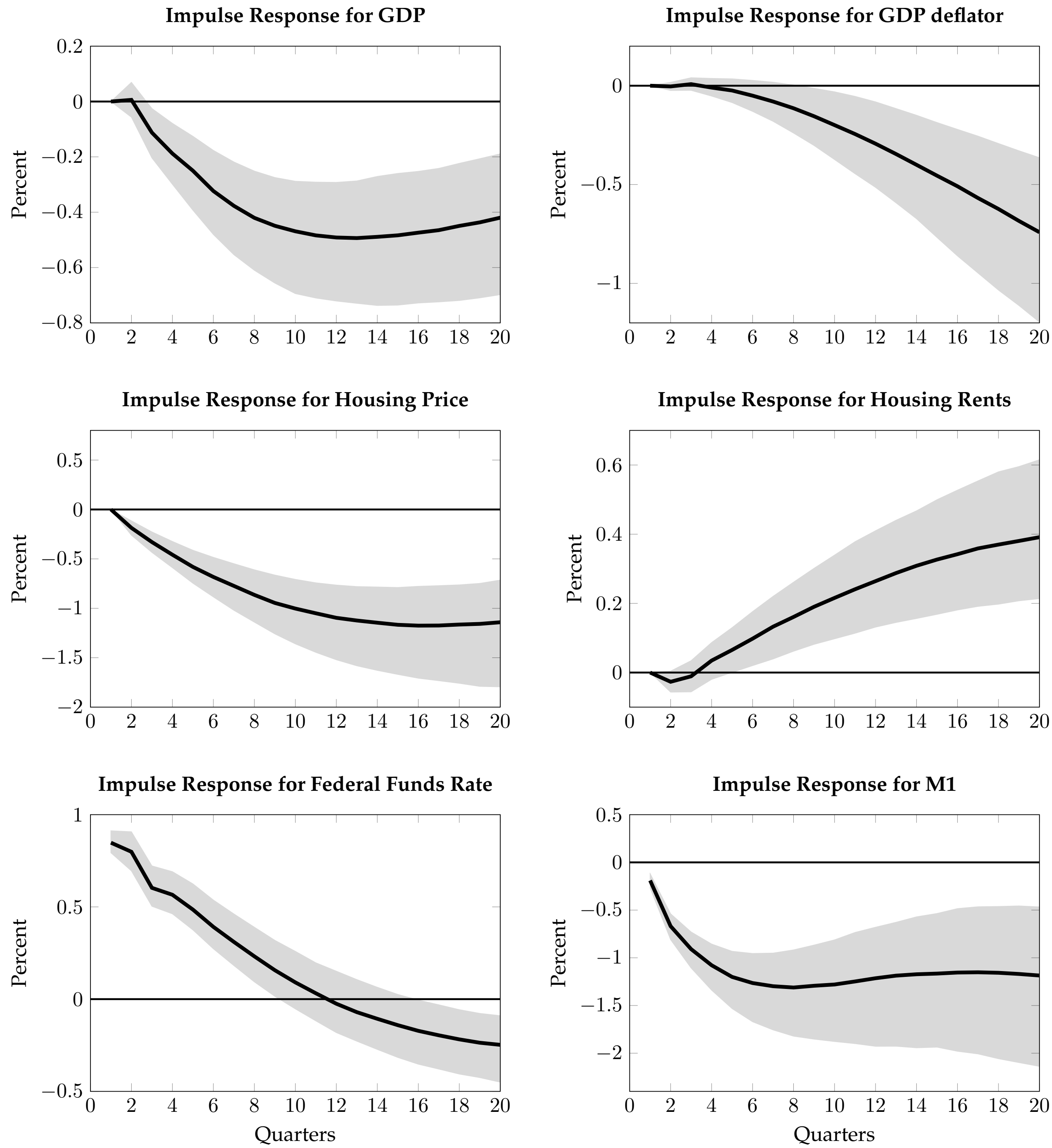


Figure 1: Recursive identification Impulse Responses and confidence bands of the SVAR system to a standard deviation shock in the federal funds rate. Confidence bands represent the 68% credible set of point estimate impulse responses.

One might worry about the specific order selected in the Cholesky decomposition to identify the SVAR. Hence, as a robustness check we estimate the SVAR with different orders and with an agnostic identifications strategy following Uhlig (2005). The results for the pure-sign restriction are reported in Figure 2. In the pure-sign identification we restrict the response of inflation and M1 be negative and federal funds rate to be positive for four periods while the remaining responses are left unrestricted.

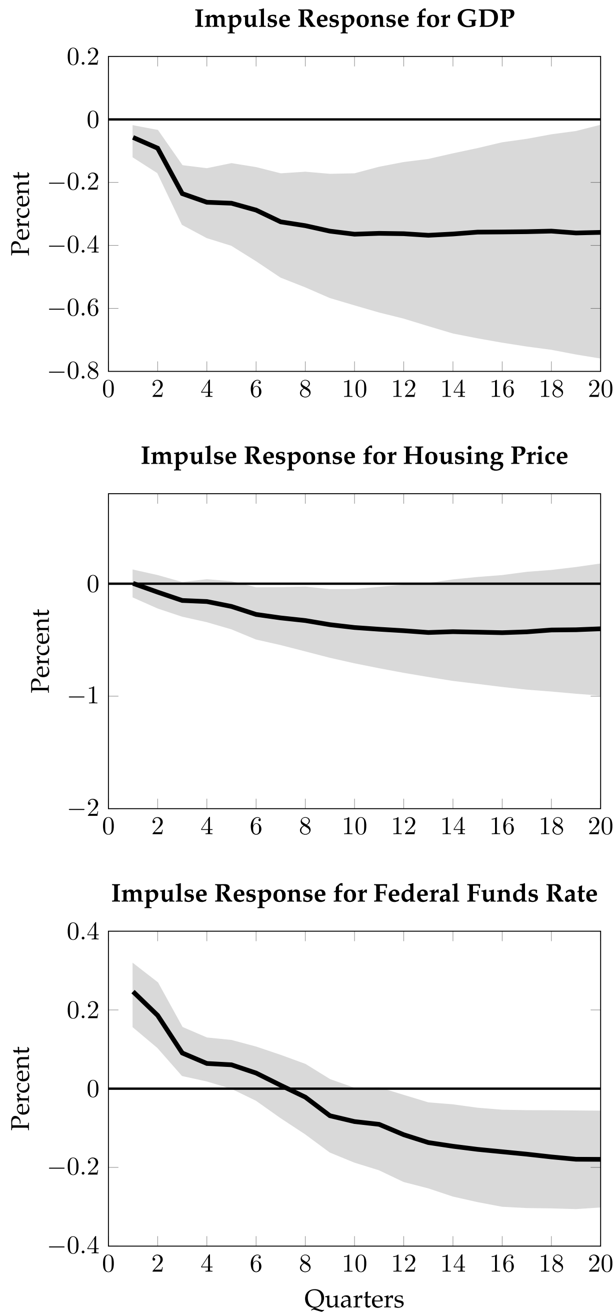


Figure 2: Pure-Sign Restriction with $k = 4$ Impulse Responses and confidence bands of the SVAR system to a standard deviation shock in federal funds. Confidence bands represent the 68% credible set of point estimate impulse responses. Here House Prices and Rents are left unrestricted.

The impulse-responses to the contractionary monetary policy shock using the pure-sign restriction are qualitatively the same as what we found in the SVAR with the Cholesky decomposition. In particular, we also find housing rents increase while housing prices fall. However, the responses are larger in magnitude in the pure-sign restriction. Here, the standard deviation shock in the federal funds rate is approximately 0.24%, which is close to what is reported in Uhlig (2005), while the standard deviation in the benchmark SVAR was 0.86%. After accounting for the standardization of the impulse-response functions (dividing the responses by the standard deviation) we find that the response of housing rents to a 1% increase in the federal funds rate is 0.46% and 0.83% in the Cholesky decomposition and pure-sign restriction, respectively.

2.1.2 FAVAR

A. *FAVAR Data and Identification*

The FAVAR methodology provides a solution to the limited information problem of the SVAR, and shows that the added information it exploits, help in properly identifying the monetary transmission mechanism. We use quarterly data on 114 time series , that include a broad measures of prices, production, housing and business activity[5] like in Stevanovic (2015) plus our variables of interest over the 1959Q1- 2006 Q4. All data are assumed stationary or transformed to be covariance stationary[6].

We follow Bernanke, Boivin, and Eliasz (2005) and first use principal components analysis to construct three factors that provide information about the underlying state of the economy. Secondly, we treat the Federal funds rate (FFYF) as an observed factor and estimate a SVAR with four variables: the federal funds rate plus the three factors we estimated using principal components.

The FAVAR naturally allows to overcome some of our missing data. We replace the missing values with the mean of each variable and use principal components to estimate the factors with the full dataset. There is no clear way on how one should proceed since not including the full sample period when data is available to most of the variables can create bias. In our case, the factors estimation will not be negatively affected by the missing data since it amounts to only 1.6% of the total data. At the same time, the benefits of adding more information on all other series are rather large. Hence, we decided to estimate the full sample. In any case, the results are robust if we use 1983-2006 period.

[5]We thank Dalibor Stevanocic for kindly providing us with the dataset

[6]The principal components analysis requires the data is all in a similar scale and is stationary

Another interesting feature of the FAVAR is that we can recover the impulse-responses functions to any of the data series we are interested in, through the effect of the shock on each factor. This is made possible by the principal components analyses that decomposes all series by how much they are explained by factors and by what is unknown. Hence, using the loading factor coefficients we can then recover the effect of a contractionary monetary policy shock in any variable of interest.

B. *FAVAR Results*

The FAVAR results confirm our SVAR findings while arguably having a better identification of the contractionary monetary policy shock. In Figure 3, we present the impulse-response functions of the variables that constituted the benchmark SVAR to allow an easier comparison between the two results. Housing rents respond positively to an unexpected increase in the federal funds rate, while all other sale prices, housing prices and output are falling. Here, the u-shape of output response is clear and this confirms the neutrality of monetary policy in the long-run.

Housing rents response is initially less sluggish than in the benchmark SVAR but it still only starts increasing at a higher pace after three to four quarters. Housing prices again respond in a faster fashion than housing rents. The magnitude of responses is hard to infer directly from the scale reported in Figure 3 since all variables were standardized in order to use the FAVAR methodology. Since, we use the FAVAR just as more of a robustness exercise, we are more interested in the qualitative behaviour of the impulse-response functions.

To put in a nutshell, our main empirical findings on the effect of monetary policy on housing rents are housing rents increase after a contractionary monetary policy shock. This result is surprising and motivates the question on what market mechanism is behind such price dynamics.

We suggest the effect of monetary policy on housing tenure choice, that is, the choice between owning and renting, can rationalize our empirical findings. in the presence of nominal or financial frictions, when nominal interest rates increases, the real interest rate increases as well and the real cost of owning relative to renting increases. Given everything else equal, this may make some people that are close to be indifferent to prefer to rent instead of buying. If housing supply remains constant or decreases, this change in consumption behavior leads to an increase of housing rents relative to all other goods in the economy while all other prices and income fall. We test if the implications at the aggregate level of such a mechanism are present in the next section.

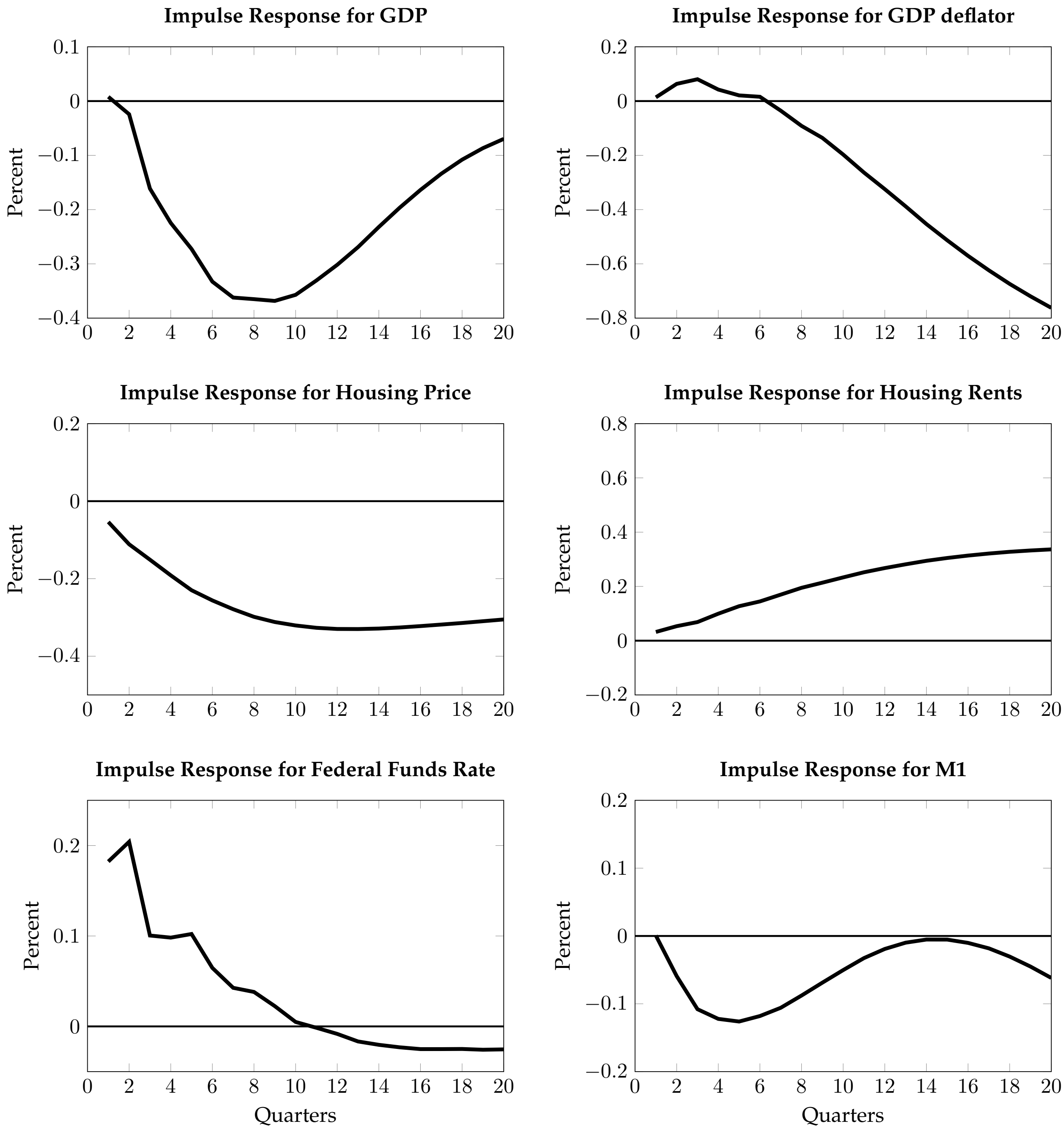


Figure 3: FAVAR impulse-responses of variables that constituted the benchmark SVAR to a standard deviation shock in the federal funds rate.

2.2 Evidence on the effect of monetary policy on housing tenure choice

In order to test if the housing tenure choice mechanism is present we show what are the effects of monetary policy on homeownership rate, homeowner vacancy rate, rental vacancy rate. Again, we use SVARs and FAVARs to address this question.

In the SVAR, we add these three variables to the benchmark system and re-estimate the model. By adding all of theses variables, we quickly loose a large number of degrees of freedom which highlights some of the limitations of SVARs. In addition, how to order these additional variables is hard to answer. The results are presented in Figure 4. The responses of rental vacancy rate and homeownership rate turn out to be non-significant. Moreover, although housing rents behave similar to what we find in the benchmark case, the same cannot be said about housing prices. With the extended SVAR, housing prices are also not significant. The FAVAR methodology allows one to overcome these limitations.

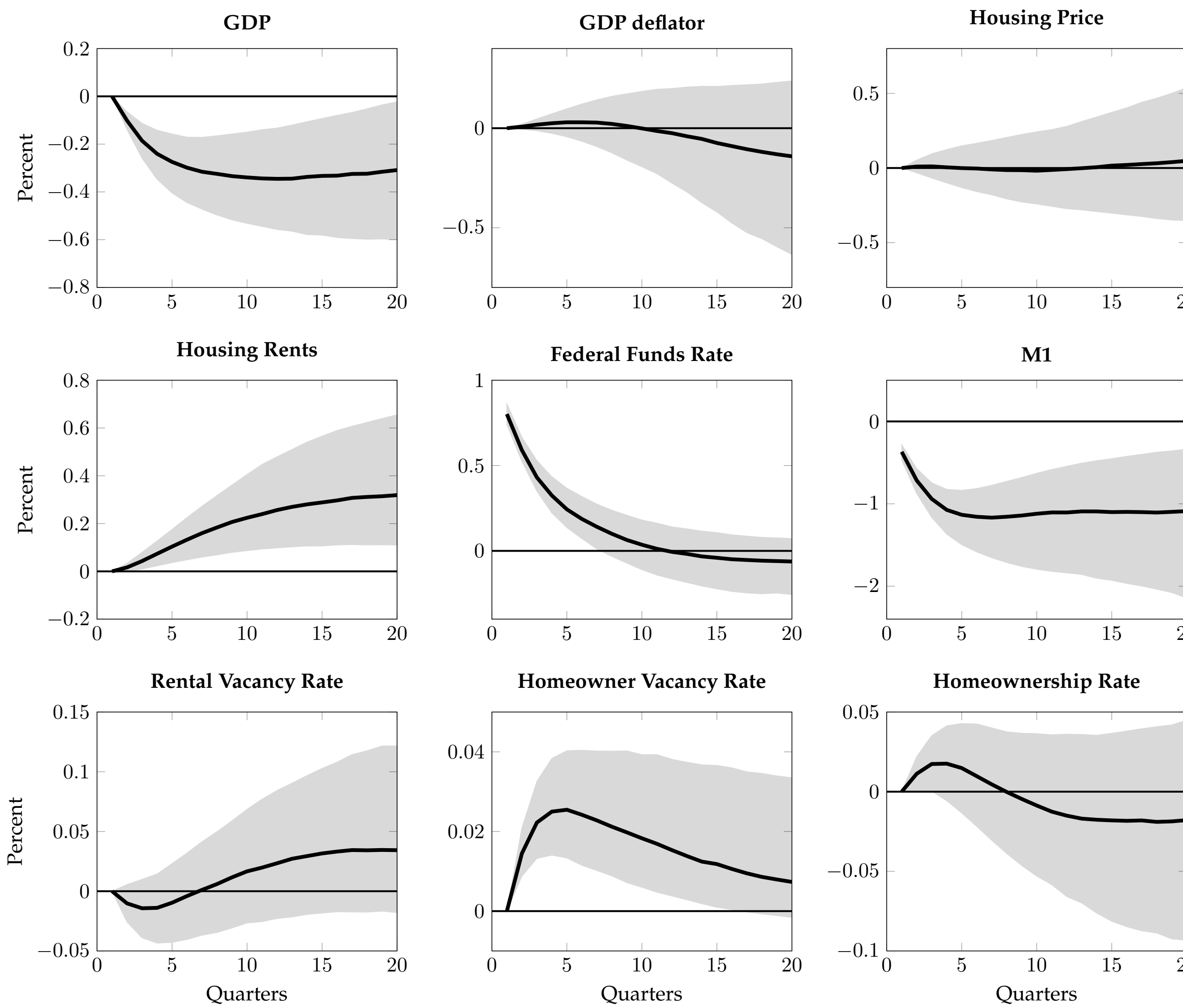


Figure 4: Recursive identification Impulse Responses and confidence bands of the extended SVAR system to a standard deviation shock in the federal funds rate. Confidence bands represent the 68% credible set of point estimate impulse responses.

In Figure 5, we present the response-functions on variables that are related to the housing tenure choice plus some other variables of interest that are commonly reported in other studies that use FAVARs. All the results confirm the effect of monetary policy on housing tenure choice. Although, confidence intervals are not reported here yet, a preliminary one step bootstrap confirmed that all of the responses are significant at a 68% confidence level.

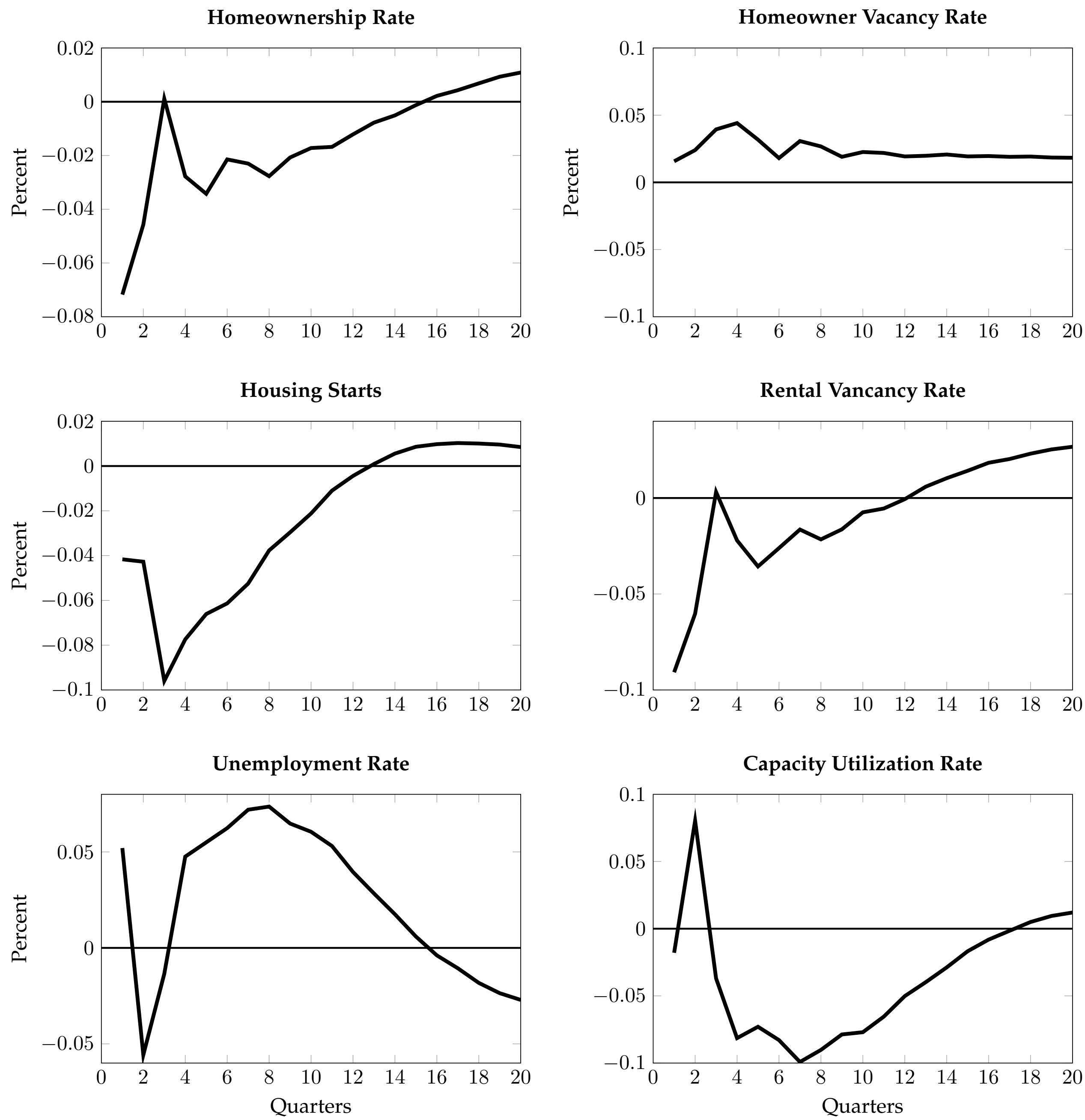


Figure 5: FAVAR impulse-responses of housing variables, unemployment rate and capacity utilization rate to a standard deviation shock in the federal funds rate.

We find homeownership rate decreases, which confirms at the aggregate level that more households decide to rent instead of own a house after an unexpected increase in interest rates. Moreover, we also finds the rental vacancy rate decreases, suggesting that there is a demand pressure on housing rents and that supply does not seem to keep up making vacancies decrease over total supply of housing rental. At the same time, the opposite is true to homeowner vacancy rate. Finally, similar to previous literature Bernanke, Boivin, and Eliasz (2005), we also find that housing starts decrease, suggesting that housing prices are not falling because of an increase in supply but rather from a strong decrease in housing demand.

3 New Keynesian Model with Housing Tenure Choice

We extend Clarida, Gali and Gertler (1999) model with endogenous tenure choice decision, housing prices and housing rents. The inclusion of housing tenure choice in a standard New Keynesian model with Taylor rule allow us to derive implications of monetary policy shocks to both housing prices and rents as well as on homeownership rate. Moreover, by including housing rents, we can introduce a theoretical CPI in the model that is constructed on housing rents and composite consumption good. By assuming that a central bank reacts to an imperfect measure of inflation like CPI, we show how different feedback between inflation and monetary policy is created in a Taylor rule that responds to CPI instead of inflation. In our model, housing rents increase when interest rates increase. Hence, central banks over reacts to inflation shocks when they observe an imperfect measure of inflation like a consumer price index. This effect is worse the larger the share of housing rents in the consumer price index.

Consider an economy where there is a continuum of households with measure one that live infinitely and that from time to time make a discrete decision on weather to own or rent a house when they go to the housing market. There is a fixed probability of re-optimizing on whether to rent or own a house. This probability is assumed to be the same across all agents, both renters and home owners. Therefore, a constant mass of households are going to re-optimize every period. Given, that the mass of households has measure one, the amount of households that re-optimize is just the probability of re-optimizing. This idea is close in spirit to Calvo (1983) pricing where every period a fixed share of firms are allowed to re-optimize.

Households are heterogeneous with respect to their preference on the housing services coming from owning a house. Some agents prefer more than others to live in a house they own instead of a rented one. This assumption is commonly assumed in the tenure choice literature. The heterogeneity is needed in order to generate households that rent and households that own their house. There are alternative ways to introduce heterogeneity in this model that give the same qualitative implications on the dynamics of the model. Two examples are different households expectations about future housing prices and heterogeneity in maintenance costs when owning a house. These alternatives complicate the solution without affecting the results.

We assume that in the initial period of the world only a share of the households are endowed with housing stock. Moreover, the households that receive housing stock will have initial high debt so that the initial income is the same across all households. In other words, in the initial period, some households have housing stock to sell but high debt, and others have no initial housing stock and no debt. This assumption helps isolating the effects coming from heterogeneity in the housing market and it makes the model trackable. The interaction of income distribution and housing distribution would make the model more complicated to solve as we need to keep track of both distributions over time.

The set of assumptions made in this paper reduces the dimensionality problem while allowing us to capture the main dynamics of household heterogeneity in the housing market and how this heterogeneity affects the price dynamics in the housing market. Given income is the same and that decisions, besides the discrete choice, are not affected by the heterogeneity in households preferences, we can go from infinite types ex-ante to only two types ex-post. A household type that rents and other that owns the housing stock. However, the quantity of each type is still endogenous and that is the main difference to standard models in the literature.

Following Iacoviello (2005) we assume there is a fixed stock of housing in this economy. Moreover we assume the shares of the the total stock that is devoted to rent and owning are also fixed. By doing so, we abstract from the supply side when we analyse the price dynamics. There are two main reason that makes one more comfortable with such assumption. First, empirical evidence on the supply side of housing shows the supply of housing decreases when interest rates increase, which would make the impact of interest rate on housing prices and rents stronger. The second reason is we are mainly interested in the dynamics of repeated sales of housing stock. Our main interest lies on studying how the price of the same housing stock fluctuates over the business cycle.

The stock of houses for owning is owned by the households that bought that housing stock. In this economy, there exists landlords that own the housing stock for rent and rent it to the households. Landlords take care of maintenance costs and include them in housing rents that are charged to any agent type. Hence, households do not face any maintenance cost when renting a house. We assume all agents have fixed equal shares of the landlords firms and thus receive the same amount of profits coming from renting housing.

In our environment, households go on their respective housing market every period. That is, if you are a renter you go to the housing rental market and decide on how much to rent every period. And if you are a owner, you sell the stock you had from previous period and decide on how much to buy again. However, sometimes the households are going to re-optimize and decide on whether he wants to rent or own a house. There are many reasons why come household would do so, but we abstract from this exercise. Here, we just assume households do not re-optimize every period.

The production side of the economy is similar to Clarida Gali and Gertler (1999). There is a continuum of intermediate monopolistic firms who produce using labor only and sell their product to be used as an input by the final good firms, and are subject to sticky prices. . Final good firms produce using intermediate goods varieties only. The monopolistic intermediate firms on the consumption sector are the source of nominal rigidity while housing prices and rents are assumed to be flexible. Finally, there is a monetary authority that obeys a Taylor rule when setting interest rates.

A. *Households*

Households decide on how much to consume of the composite consumption good and housing services, and finally on how much to borrow with nominal bonds. Households supply labor ineslastically and receive a nominal wage W_t for their total labor. On the one hand. if the household decides to own a house, he pays Q_t for each unit of housing services[7]. On the other hand, if the household decides to rent a house, he pays R_t. Finally, households receive/pay gross nominal interest I_t on their nominal bonds. The households have to choose between renting and owning a house. Once they decide to rent or own they are stuck with that decision until they can re-optimize again. Therefore, to make this choice, they compare how much utility they receive from each alternative, and choose the one that yields the highest discounted utility to them. The utility is both discounted by time preference of consumption and the probability of re- optimizing. Let V denote the indirect utility function, the agent will choose to rent or own depending on which choice gives him the highest level of utility.

$$\max_{rent,own}(V^*_{rent}, V^*_{own})$$

[7]We assume for simplicity that each unit of housing stock provides exactly one unit of housing services.

When households decide to rent, note that there is no heterogeneity and hence their decision is the same among the households who decide to rent. Their problem can be described as:

$$\max_{\hat{c}_t,\hat{h}_t,\hat{b}_{t+1},N_t} E_0 \sum_{t=0}^{\infty}(\gamma\beta)^t(\ln \hat{c}_t + \alpha \ln \hat{h}_t - \exp(\tau_t)\frac{N_t^{1+\eta}}{1+\eta})$$

s.t.

$$\begin{aligned} &\hat{c}_t + L_t\hat{h}_t + \hat{b}_t = a_t \\ &a_t = W_tN_t + \Pi_t + O(owned_{t-1})(\frac{I_t}{\pi_t}b_{t-1} + Q_th_{t-1}) \\ &\text{given} \quad h_0, b_0 \end{aligned} \tag{1}$$

Where τ is an exogenous preference shock to leisure and a_t stands for the household net worth. The indicator function O takes the value one if he households owned a house in the previous period. If he did, he is going to have a debt associated with that purchase that offsets the value of the house. Hence, we assume that the net worth of the agents who are considering renting is the same regardless of whether the household owned a house or not in the previous period. Also, when renting, households do not own the housing stock and hence cannot sell the housing stock in the next period. In our model, we implicitly assume that landlords take care of any type of maintenance.

Solving for the first order conditions of this maximization problem we get the following Euler equations:

$$\hat{c}_t^{-1} = \gamma\beta E_t[\frac{I_{t+1}}{\pi_{t+1}}\hat{c}_{t+1}^{-1}] \tag{2}$$

$$\frac{\alpha}{\hat{h}_t} = \frac{L_t}{\hat{c}_t} \tag{3}$$

$$\exp(\tau_t)N_t^{\eta}\hat{c}_t = W_t \tag{4}$$

Equation (2), the first Euler equation represents the typical dynamic trade-off between consumption now and future consumption. This trade-off is a direct result from the savings decision. The second Euler equation (3) represents the new feature of our model, and it shows the trade-off between consumption of the composite final good and housing services. Finally, the third Euler equation (4) represents the trade-off between leisure and consumption.

When the households decide to own a house, their problem is to:

$$\max_{c_t,h_t,b_t,N_t} E_0 \sum_{t=0}^{\infty} (\gamma\beta)^t (\ln c_t + \alpha \ln h_t - \exp(\tau_t)\frac{N_t^{1+\eta}}{1+\eta} - \rho^i)$$

s.t.

$$\begin{aligned} & c_t + Q_t h_t + b_t = a_t \\ & a_t = W_t N_t + \Pi_t + I(owned_{t-1})(\frac{I_t}{\pi_t} b_{t-1} + Q_t h_{t-1}) \\ & \text{given} \quad h_0, \ b_0 \end{aligned} \tag{5}$$

Solving for the first order conditions of this maximization problem we get the following Euler equations:

$$\hat{c}_t^{-1} = \gamma\beta E_t[\frac{I_{t+1}}{\pi_{t+1}} c_{t+1}^{-1}] \tag{6}$$

$$\frac{\alpha}{h_t} = \frac{1}{c_t}\left(Q_t - \frac{Q_{t+1}}{I_{t+1}/\pi_{t+1}}\right) \tag{7}$$

$$\exp(\tau_t) N_t^{\eta} c_t = W_t \tag{8}$$

Given the optimal decisions coming from both tenure choices, households will choose the one that gives him more utility. Moreover, assuming the net worth is the same and given our log utility function, the only difference between the tenure decisions is going to be the amount of housing services and consumption. Hence we have households will rent if:

$$V_{rent}^* = E_0 \sum_{t=0}^{\infty} (\gamma\beta)^t (\ln \hat{c}_t^* + \alpha \ln \hat{h}_t^*) > E_0 \sum_{t=0}^{\infty} (\gamma\beta)^t (\ln c_t^* + \alpha \ln h_t^* - \rho^i) = V_{own}^*$$

Hence, using (3) and (6) and simplifying we have that the indifferent household is given by the following equality:

$$E_0 \sum_{t=0}^{\infty} (\gamma\beta)^t L_t \hat{h}_t^{1+\alpha} = E_0 \sum_{t=0}^{\infty} (\gamma\beta)^t \left(\left(Q_t - \frac{Q_{t+1}}{I_{t+1}/\pi_{t+1}}\right) h_t^{1+\alpha} - \bar{\rho}_t\right) \tag{9}$$

$$\bar{\rho}_t = (1-\gamma\beta) E_0 \sum_{t=0}^{\infty} (\gamma\beta)^t \left(\left(Q_t - \frac{Q_{t+1}}{I_{t+1}/\pi_{t+1}}\right) h_t^{1+\alpha} - L_t \hat{h}_t^{1+\alpha}\right) \tag{10}$$

The household that is indifferent between renting and owning pins down how many households are going to rent and own a house in equilibrium. Households that prefer to own a house at a level $\rho_i < \bar{\rho}$, will decide to own a house while households they have $\rho_i > \bar{\rho}$ will rent. Note that the cutoff rule $\bar{\rho}$ is endogenous and depends on prices and allocations.

B. *Firms*

The firm problem in our model is standard in the New Keynesian framework. We use a continuum of intermediate monopolistic firms together with Calvo pricing mechanism that use only labor input in production.

Each household buys their consumption good from final good firms. The final good firms buy Y_{it} from the intermediate sector for P_{it} and sell their production to the households for P_t. The technology of production of the final good firms is given by:

$$Y_t = \left(\int_0^1 {Y_{it}}^{1-\frac{1}{\epsilon}} dk \right)^{\frac{\epsilon}{\epsilon-1}}, \quad \epsilon > 1 \tag{11}$$

Individual demand for each intermediate firms product is given by:

$$Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\epsilon} Y_t \tag{12}$$

Equations (11) and (12) imply that:

Intermediate firms demand labor and their production technology is given by:

$$Y_{it} = A_t N_t(k) \tag{13}$$

In our model nominal rigidity is imposed like in Calvo (1983) whereby a fraction of firms, $1-\theta$, is allowed to reset price each period. The problem is symmetric and so all firms that can re-optimize choose P_t^* to solve:

$$\max_{P_t^*} E_0 \sum_{\tau=0}^{\infty} \theta^\tau \left\{ \nu_{t+\tau} (P_t^* Y_{i,t+\tau} - \Phi_{t+\tau} | Y_{t+\tau|t} \right\} \tag{14}$$

Where $\Phi_{t+\tau}$ is the marginal cost at a specific level of production. The profits of the intermediate firms are transfers to the households. The details of the derivations of P^* in a nonlinear fashion can be found in Christiano (2011).

As a fraction of prices stays unchanged, the aggregate price level evolution is;

$$P_t = (\theta P_{t-1}^{1-\epsilon} + (1-\theta) P_t^{*1-\epsilon})^{1/(1-\epsilon)} \tag{15}$$

If we do a first order approximation around the steady state on Equation (15) together with the solution to (14), we get the forward-looking Phillips curve. In our case, we will do a second order approximation because agents use welfare when deciding to own or rent. Hence, we a second order approximation around steady state in order to have an accurate solution of the model.

C. *Consumer Price Index*

With the explicit introduction of housing rents, we can formalize the implied consumer price index in our model economy. The consumer price index in going to be a weighted average of nominal prices of housing and non-housing goods. We assume the weight a of 0.3 on housing shelter that is the same as in the data CPI. Hence we have CPI inflation is given by:

$$CPI_t = a\frac{P_t}{P_{t-1}} + (1-a)\frac{P_t}{P_{t-1}}\frac{L_t}{L_{t-1}} \tag{16}$$

The consumption good real price is 1 and hence the price variation is given by monetary inflation. However, housing rents nominal change of prices is a composition of monetary inflation and real housing rents inflation. From equation (16) it is clear that CPI gives a guidance on how monetary inflation behaves in trend if real prices behave like some white noise. However, if real prices change strongly and persistently in opposite directions, CPI becomes noisy as a measure of monetary inflation. This model provides a formal way to start thinking about how monetary inflation should be measured, and goes in the direction of providing insights to the points raised in Vining and Elwertowski (1976).

D. *Central Bank*

The central bank implements a Taylor-type of interest rate rule. Hence, central bank reacts to output gap and inflation gap according to:

$$I_t = (I_{t-1})^{\phi_I}(CPI_{t-1}^{1+\phi_\pi}(Y_{t-1}/Y)^{\phi_Y} r)^{1-\phi_I} e_{I,t} \tag{17}$$

We assume all agents in the economy measure well monetary inflation and know the central bank targets the implied CPI with housing rents. In the counterfactual section we show how this economy differs from one where the central bank reacts to a CPI that is rents-free.

E. *Exougenous Shocks*

In our model economy τ_t has follows an AR(1) process:

$$\tau_t = \rho_\tau \tau_{t-1} + e_{\tau,t} \tag{18}$$

Hence, there are two kinds of shocks: a preference on leisure shock $e_{\tau,t}$ and a monetary policy shock $e_{I,t}$. Both shocks follow a normal distribution $e_{\tau,t} \sim N(0, \sigma_\tau)$ and $e_{I,t} \sim N(0, \sigma_I)$, respectively.

F. *Market Clearing*

The market clearing conditions in our economy are the following:

Goods Market

$$\gamma \int_0^{\bar{\rho}_{t-1}} c_t di + (1-\gamma) \int_0^{\bar{\rho}_t} c_t di + \gamma \int_{\bar{\rho}_{t-1}}^1 \hat{c}_t di + (1-\gamma) \int_{\bar{\rho}_t}^1 \hat{c}_t di = W_t + \Pi_t \quad \forall t \tag{19}$$

Labor Market

$$\int_0^1 N_{jt} dj = N_t \quad \forall t \tag{20}$$

Homeowners housing market

$$\gamma \int_0^{\bar{\rho}_{t-1}} h_t di + (1-\gamma) \int_0^{\bar{\rho}_t} h_t di = H^O \quad \forall t \tag{21}$$

Rental housing market

$$\gamma \int_{\bar{\rho}_{t-1}}^1 \hat{h}_t di + (1-\gamma) \int_{\bar{\rho}_t}^1 \hat{h}_t di = H^R \quad \forall t \tag{22}$$

Nominal Bonds Market

$$\gamma \int_0^{\bar{\rho}_{t-1}} b_t di + (1-\gamma) \int_0^{\bar{\rho}_t} b_t di + \gamma \int_{\bar{\rho}_{t-1}}^1 \hat{b}_t di + (1-\gamma) \int_{\bar{\rho}_t}^1 \hat{b}_t di = 0 \quad \forall t \tag{23}$$

G. *Equilibrium*

Definition. *The Rational Expectations Competitive Equilibrium is a sequence household choices* $\{c_t, \hat{c}_t, h_t, \hat{h}_t, b_{t+1}, \hat{b}_{t+1}, N_t\}_{t=0}^{\infty}$*, a sequence of housing tenure choice (rent vs own)* $\{o^i\}_{t=0}^{\infty}$*, profits and transfers* $\{\Pi_t\}_{t=0}^{\infty}$ *,a cut-off preference level that makes the households indifferent between renting and owning* $\{\bar{\rho}_t\}_{t=0}^{\infty}$ *and a sequence of prices* $\{W_t, Q_t, L_t, P_t, P_t^* CPI_t, I_t\}_{t=0}^{\infty}$ *such that:*

1) Given prices and profits, $\{c_t, h_t, b_{t+1}, N_t\}_{t=0}^{\infty}$ *solves the households problem when owning and* $\{\hat{c}_t, \hat{h}_t, \hat{b}_{t+1}, N_t\}_{t=0}^{\infty}$ *solves the households problem when renting.*

2) Given prices and allocations, $\{\bar{\rho}_t\}_{t=0}^{\infty}$ *solves equation (10).*

3) Given prices and allocations, $\{P_t^*\}_{t=0}^{\infty}$ *solves (10) and profits* $\{\Pi_t\}_{t=0}^{\infty}$ *are the associated indirect function (14) with optimal price* $\{P_t^*\}_{t=0}^{\infty}$*.*

4) Given allocations, $\{W_t, Q_t, L_t\}_{t=0}^{\infty}$ *solve market clearing (19), (20), (21), (22) and (23).*

5) Given prices and allocations, $\{P_t\}_{t=0}^{\infty}$ *solves equation (15),* $\{CPI_t\}_{t=0}^{\infty}$ *solves equation (16) and*$\{I_t\}_{t=0}^{\infty}$ *solves equation (17).*

4 Calibration and Solution

We calibrate the model to match long-term moments of the US economy. All parameter values are taken form previous literature on New Keynesian models like Iacoviello (2005), Clarida, Gali and Gertler (1999) and Christiano, Eichenbaum and Evans (2005). In Table 1 we show the parameters values. The inter-temporal discount factor was selected to match the US steady state annual interest rate approximately.

The parameter that governs the labor supply aversion with a value of 0.01 implies a practically flat labor supply. This is higher than what microeconometric studies suggest, but it is consistent with the weak observed response of real wages to macroeconomic disturbances and moreover can be motivated by the changes in labor supply coming from the extensive margin. That is the amount

Description	Parameter	Value
Preferences		
Discount Factor	$\gamma\beta$	0.99
Weight on housing services	α	0.10
Labor Supply Aversion	η	0.01
Sticky Prices		
Steady State Markup	X	1.20
Probability of fixed price	θ	0.75
CPI		
Housing Rents Share in CPI	a	0.30
Taylor Rule		
Interest Rate Smoothing	ϕ_I	0.80
Reaction to Inflation Gap	ϕ_π	1.50
Reaction to Output Gap	ϕ_Y	0.10
Exogenous Shocks		
Persistence of Leisure Preference Shock	ρ_τ	0.90
Leisure Preference Shock Std. Dev.	σ_τ	0.010
Interest Rate Shock Std. Dev.	σ_I	0.007

Table 1: Benchmark model calibrated parameters. All parameters are selected from previous literature on standard New Keynesian models like Clarida, Gali and Gertler (1999), Christiano, Eichenbaum and Evans (2005), and Iacoviello (2005).

of individuals that change from unemployed to employed, even though hours works do not change much for individuals at work.

The preference parameter on housing services is justified by Iacoviello (2005). Our preferences are the same the exception that we do not model explicitly money. However, money has a insignificant impact on utility function in Iacoviello (2005), which is typically the case in money in the utility models. The markup is taken from Christiano, Eichenbaum and Evans (2005). The housing rents share in CPI is around 30%. The Taylor rule parameters are taken from Clarida, Gali and Gertler (1999) and are similar to those used by Iacoviello (2005). These parameters imply a Taylor rule that describes well monetary policy post Volcker period. Finally, the shock on monetary policy was calibrated to match the initial response of interest rates of the benchmark SVAR.

The model is solved using a perturbation method with a second order approximation around the steady state. The second order approximation in our model is crucial because agents compare lifetime utility function when deciding on whether to own or rent a house. It is well known that first order approximations give inaccurate solutions to welfare analysis because they miss second moments. Hence, with the second order approximation and small shocks we are able to accurately solve the model.

Although our model is highly stylised, Table 2 shows the models performs remarkably well in matching long term moments like ownership rate and price to rent ratio, as well as business cycle moments. Although the source of heterogeneity in our model comes only from preferences and the housing supply side is introduced in a very simple way, the homeownership rate we get from our model is close to the data. Our preferences heterogeneity is in some sense a reduce form approach to what drives the homeownership rate. For the fundamentals behind the homeownership rate and the price to rent ratio see Chambers, Garriga, and Schlagenhauf (2009), Sommer, Sullivan and Verbrugge (2013) and Miao, Wang and Zha (2014). Moreover, the price to rent ratio is also similar to the average price to rent ratio found in the data, which suggest supply dynamics do not seem to be important in matching long term housing tenure choices dynamics.

Moments	Model	Data
Steady State		
Homeownership rate	0.70	0.64
Price-Rent Ratio	23.29	18.80
Business Cycle		
CPI Std. Dev.	0.025	0.015
Output Std. Dev.	0.099	0.014
Housing Prices Std. Dev.	0.103	0.054
Housing Rents Std. Dev.	0.0083	0.0069

Table 2: Model *versus* Data comparison of moments that were not targeted

Besides housing prices standard deviation , the model business cycles standard deviation matches well the data. The model predicts housing prices that almost doubles that of the data. One reason can be the missing housing market fundamentals in the model and another reason might be the lack of stickiness in housing rents. Housing rents are very sticky in reality and in our model they are assume flexible. Given how our mechanism for homeownership works, if rents do not respond as strongly specially when decreasing (housing rents stickiness is not symmetric), housing prices will not change as abruptly and this will dampen housing prices volatility.

With the model calibrated we show the theoretical impulse-response functions in Figure 6. The tenure choice mechanism enables the New Keynesian model to opposite responses of housing prices and housing rents in response to a monetary monetary contractionary shock. Housing prices decrease and housing rents increase after nominal interest rates increase. This result is puzzling if one thinks of housing as an asset only. However, housing is also a consumption good and utility considerations are hence important in determining prices. If houses are just assets, one would expect housing prices are nothing but the present value of all future housing rents. Hence, changes in interest rates would have to change both housing prices and rents in the same direction. However, housing is not just an asset and households buy housing stock not just to rent it but also to consume it. Hence, there is a dichotomy between rents and housing prices.

Moreover, with heterogeneous agents, households have different valuations for the same housing stock. When interest rate increase, more agents prefer to rent instead of owning creating a change in housing demand in the extensive margin. We can see in Figure 6 that indeed this is the case looking at how homeownership rate decreases after interest rates rise.

The consideration of housing rents allows us to introduce a theoretical consumer price index. We can see in Figure 6 that CPI increases in spite of the fact monetary inflation decreases. This is the result of rising rents that is sufficiently large to overcome the drop in monetary inflation. CPI then decreases since housing rents start decreasing. Interestingly, when CPI is targeted by the Taylor rule, monetary inflation first decreases and then increases above steady state. Since, the monetary authority overshoots interest rates households cut consumption sharply. As a response to the drop in demand, firms first cut down employment and decrease prices to maintain the fixed markup. However, households and firms know the monetary authority is targeting CPI, and once CPI behaves normally, they know the interest rates are going to quickly drop making them increase consumption. Firms again increase employment and prices increase given the higher wages. The employment and output responses can be found in the appendix of this paper in Figure 10.

Looking at Figure 7, we can see that the model impulse responses matches well the SVAR impulse response functions. Housing rents increase while housing prices and output fall. Moreover, we are able to match the "price puzzle" that commonly appears in the SVAR literature on monetary policy. Hence, looking at a theoretical measure that allows to construct a price index similar to a CPI, there is no puzzle in a rising CPI while nominal inflation is decreasing. This happens because the rise in housing rents out weights the decrease in nominal inflation. We explore this insight in Dias and Duarte (2015) and show that the price puzzle is largely explained by housing rents. Our

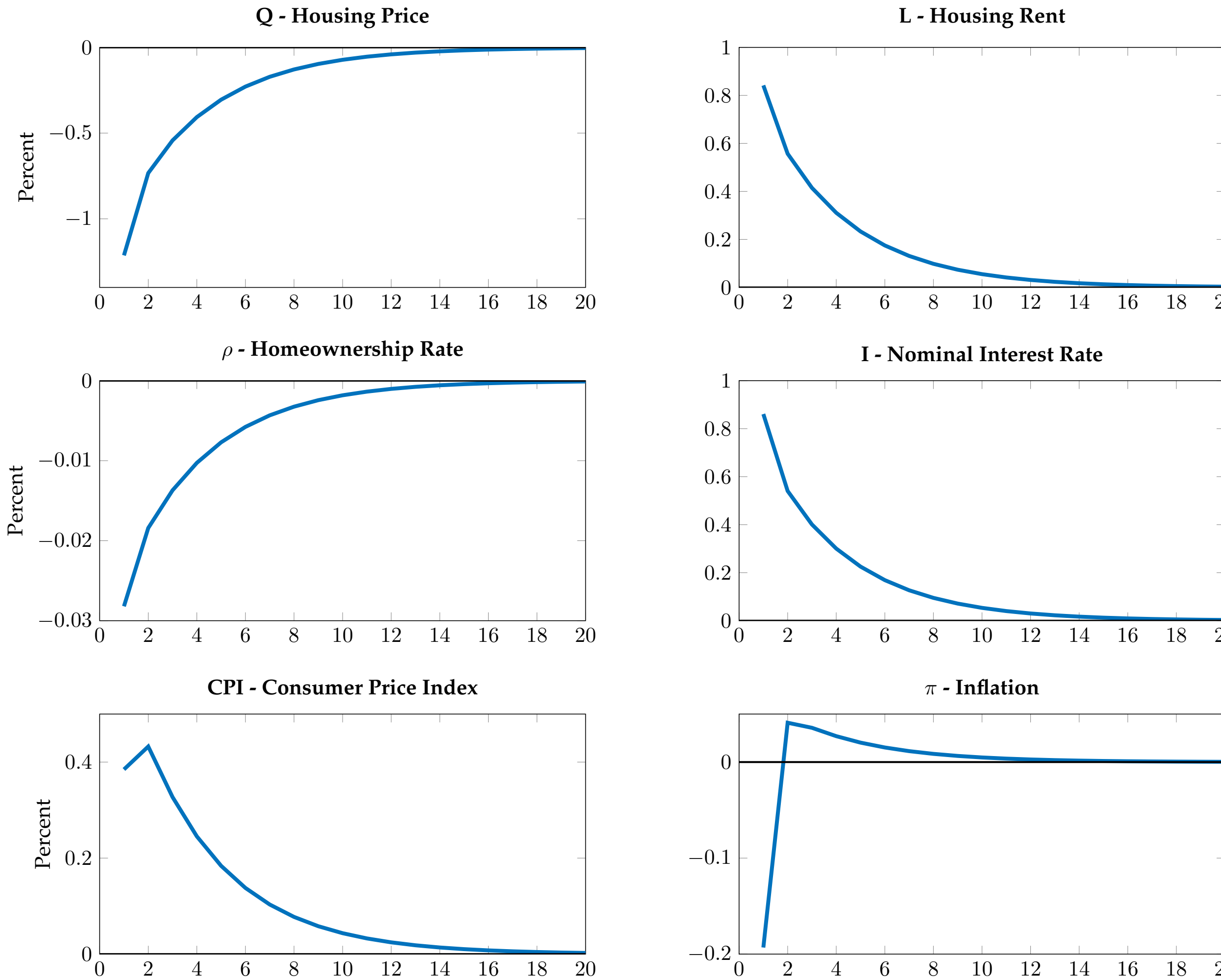


Figure 6: Impulse-Response functions for main variables of interest for the benchmark model where the Taylor rule targets CPI. Each graph shows percentage-point response of one of the model's variables to a one-standard-deviation shock in monetary policy.

results suggest a mechanism that can generate the price puzzle different from the so called channel cost of monetary policy (Barth and Ramey (2001)) and Christiano, Eichenbaum and Evans (2005). To test this hypothesis, Rabanal (2006) estimates a New Keynesian model of the business cycle and tests the conditions under which a cost channel of monetary policy could generate a positive response of prices to a contractionary monetary policy shock. This author finds that, demand side effects always dominate supply side effects in prices and therefore there is no evidence that the cost channel of monetary policy could explain the price puzzle. Our results provide some insights on the type of demand shocks that drive the response of prices.

The fit is particularly not good in the first periods. This is mainly due to the identification assumption of the SVAR. We are faced with a trade-off, we either make an identification ordering

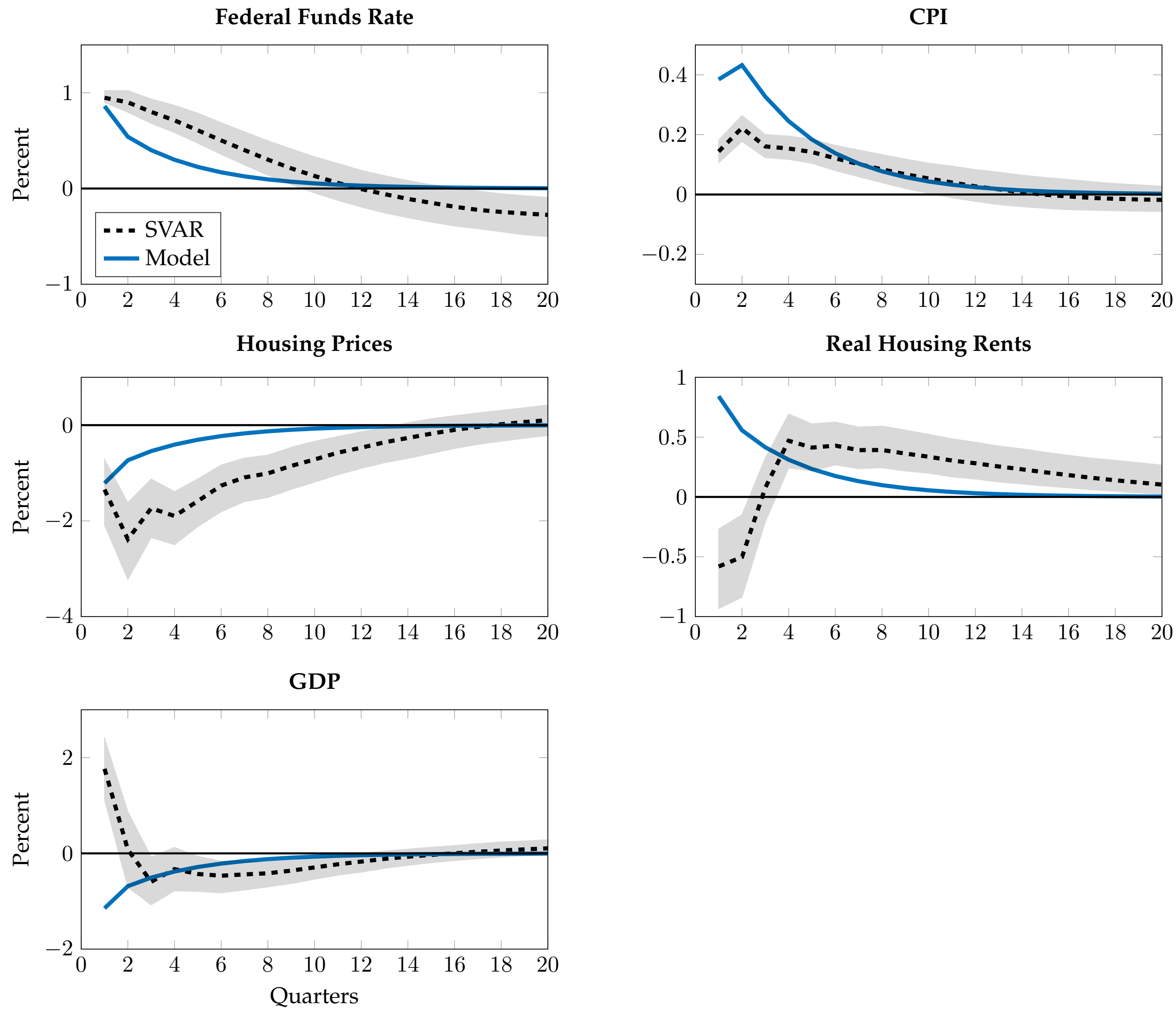


Figure 7: Impulse-Response functions for main variables of interest for the benchmark model where the Taylor rule targets CPI *versus* SVAR with Choleski identification that is consistent with the model. Each graph shows percentage-point response of one of the model's variables to a one-standard-deviation shock in monetary policy.

that is consistent with the timing assumptions of the model, or we get a better identification. This trade-off was also faced by Iacoviello (2005). We decided to follow Iacoviello (2005) and opted for the former one by sacrificing some identification to make the SVAR more consistent with the model. Hence, given that in the model all variables respond contemporaneously to shocks in interest rates, we order the federal funds rate first in the SVAR. Besides, the initial periods, the economy behaves similarly to the SVAR. Finally, it is worth noting that rents are flexible in the model while in reality rents are very sticky as shown by the SVAR response of housing rents. If our model had rents being stick like the data, our theoretical CPI would be able to be always positive like in the data. For more details on the price puzzle see Dias and Duarte (2015).

5 Counterfactual - CPI *versus* CPI net of rents

Here, we ask the question on how the dynamics of the model in the benchmark case compare to the alternative setting, where the monetary authority targets a rents-free consumer price index. Note that the rents-free price index is just the usual monetary inflation studied in most of the standard New Keynesian models.

We show in Figure 8 the impulse responses of the two different cases. In the alternative case, where the monetary authority targets the rents-free CPI, interest rates will be lower than in the benchmark as a response to the same shock. This happens because when the monetary authority targets the consumer price index with housing rents, CPI will be initially above the target, and hence interest rates will be set too high to bring CPI to the target. The increase in CPI is in turn driven by rising housing rents. Although the differences are small in a response to a single shock, these differences can become rather large when accumulating different shocks to the economy over time. Moreover, if rents were sticky, CPI distortions would be much larger in later periods. Real interest rate is similar with the exception of the first period.

When interest rate Taylor rules use the CPI as an input, interest rates will be set too high based on rising rents instead of nominal inflation and will add unnecessary variation to the underlying inflation rate. This generates large welfare costs and losses to a monetary policy whose objective is to minimize inflation and output gap variance. Table 3 reports the welfare analysis. We simulate the model with monetary policy shocks for one thousand periods. We find that targeting a measure of inflation that excludes housing rents leads to a 0.9% welfare gain in consumption equivalent variation and to a 14.5% fall in the loss function of monetary policy in comparison to the case that the monetary authority targets a measure of inflation that includes housing rents. Households are affected differently. Owners are affect more in consumption equivalent variation because housing prices are more volatile to interest rate shocks than housing rents.

Finally, using the same counterfactual, we answer how prices dynamics might have been different for the U.S. experience between 1984 and 2006. With two shocks, we assume that only housing prices and CPI are observable. Then, using the Kalman filter with the calibrated parameters we are able to recover the monetary policy and preference shocks for the 1984-2006 by matching ob-

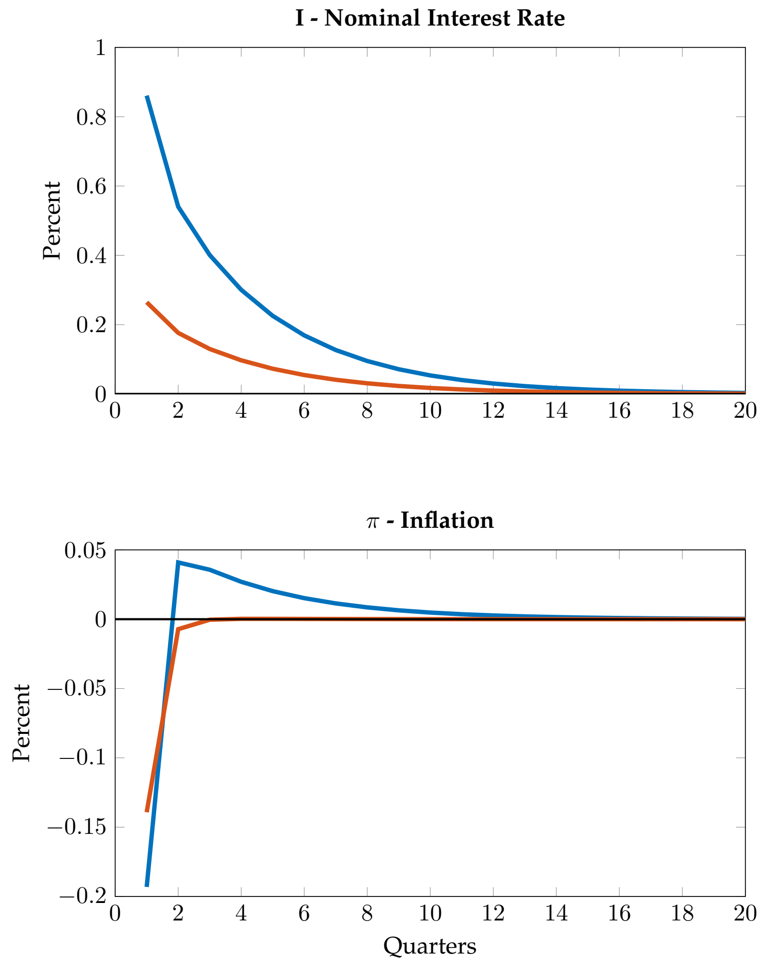


Figure 8: Impulse-Response functions for main variables of interest for the benchmark model where the Taylor rule targets CPI *versus* alternative setting when Taylor rule targets nominal inflation π. Each graph shows percentage-point response of one of the model's variables to a one-standard-deviation shock in monetary policy.

served series of housing prices and CPI for the same time period. Figure 9 shows the graphs for housing prices and CPI. We can see that the benchmark model replicates the dynamics of housing prices quite well. We then simulate the model with the same shocks and show how the price dynamics would differ if the monetary authority reacted to a rents-free consumer price index. First, we find that under the alternative scenario , the standard deviation of housing prices would have been 24.8% lower for the 1984-2006 US experience. Secondly, we estimate that this mechanism can explain 37.5% of the increase in house prices above trend from 2002 to 2006.

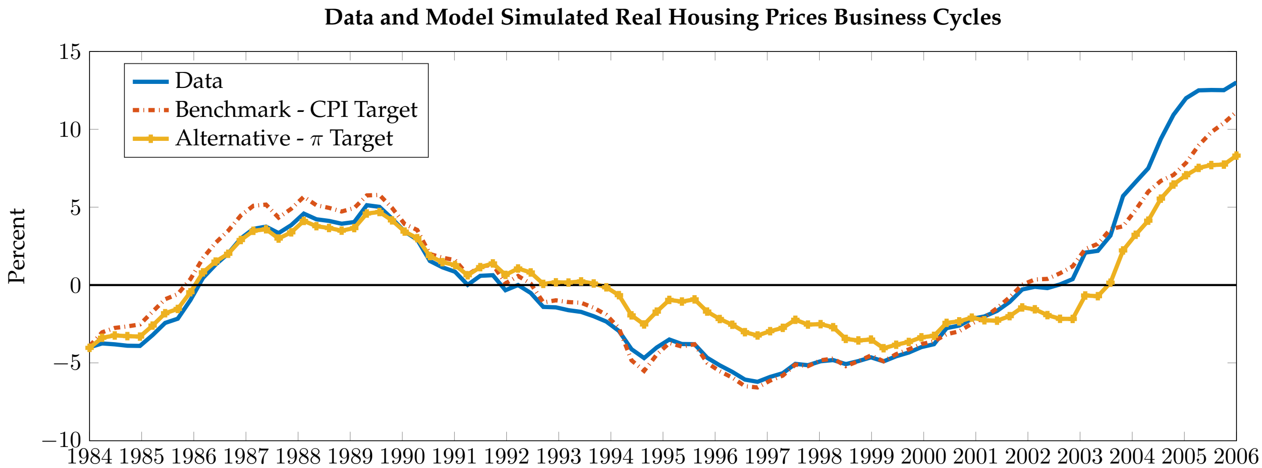
From the second graph in Figure 9 we observe that CPI gives indeed a poor estimate of monetary inflation. Moreover, this mismeasurement is dynamic and changes over time depending on how housing rents behave. When the monetary authority increases (decreases) interest rates, *real*

	Benchmark Model (Target CPI)	Alternative Model (Target π)	$\Delta\%$
Welfare			
Utility	0.2610	0.2703	+3.56%
Owner	0.4920	0.5010	+1.84%
Renter	−0.1462	−0.1379	+5.65%
Consumption Equivalent Variation	1.3563	1.3690	+0.93%
Owner	1.6355	1.6504	+0.91%
Renter	0.8640	0.8712	+0.83%
Monetary Policy Loss Function	0.063	0.054	−14.55%

Table 3: Welfare Analysis and Monetary Policy Function. All the numbers reported are the result of simulating the model for 1000 periods, with the initial value set at the steady state. The monetary policy function is the quadratic function $\sum_{t=0}^{\infty} \beta^t(\pi_t^2 + \lambda(y_t - y_{tn}))$ computed with $\lambda = 0.003$.

housing rents increase (decrease). This creates a measurement issue in tracking underlying nominal inflation and leads to a downward (upward) estimate of inflation when CPI are used. Because directly and indirectly, housing rents have a fairly large weight on CPI, this mismeasurement may be sufficiently large and lead the monetary policy authority to keep setting interest rates too high (low) in its attempt to achieve a certain inflation target.

It is worth noting that the monetary authority has been targeting PCE instead of CPI. However, the weight on housing rents is still large, and is particularly high when looking at core PCE. The hazardous effects of the mismeasurment would be smaller than in the CPI and hence one can think of the CPI as an upper bound to the implications on monetary inflation. Next, when we compare the benchmark with the alternative scenario, we find that the standard deviation of nominal inflation would have been 19.9% lower. In the alternative case, the CPI seems to track better monetary inflation than in the benchmark case. Finally, it is interesting to note how nominal inflation looked uncontrolled before the recent financial crisis. This might be the result of apparently low inflation measures through CPI because of falling housing rents. When the CPI increases, the benchmark monetary inflation quickly comes back to target while the alternative monetary inflation falls but not as much. This might be explained by the low reaction of interest rates to shocks in the alternative model. We do also see a drop in monetary inflation, but not as big as in the benchmark case. This smaller drop can be explained by the fact that the shocks are identified observing CPI using the



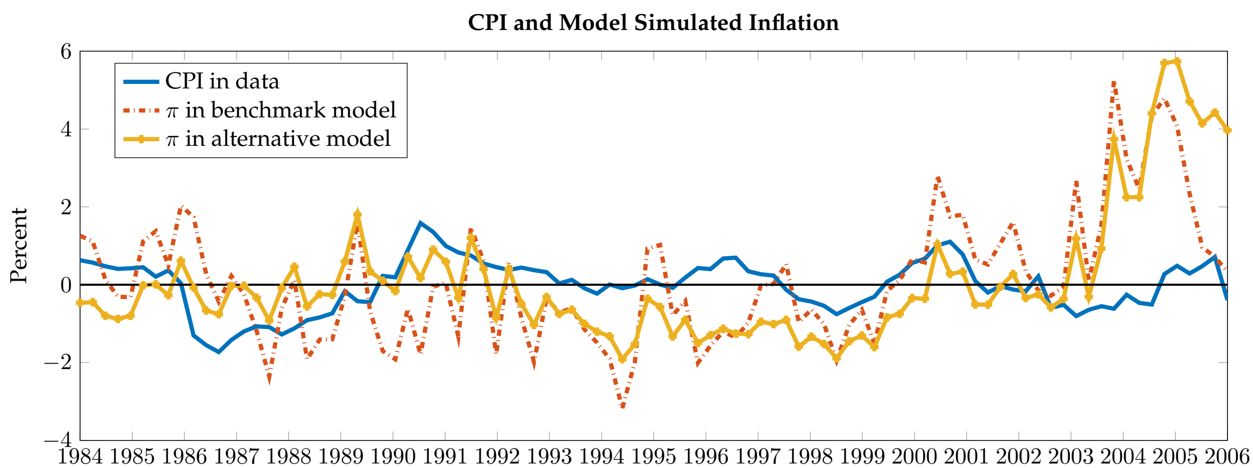


Figure 9: Housing Prices Business cycle on top and CPI business cycle for data from 1984 to 2006 with simulated data form the benchmark and simulated model. All business cycles are computed using a HP filter. In the model, by assuming we only observe housing prices and CPI we extract the implied monetary policy and preference shocks using Kalman Filter. We use the recovered shocks to simulate the model.

benchmark case.

6 Conclusion

In this paper we unveil a new channel through which housing reveals its importance in the economy by investigating the interaction between monetary policy and housing rents. Using SVARs and FAVARs, we first show housing rents respond positively to a contractionary monetary policy shock. Secondly, recognizing housing rents directly and indirectly account for about 30% of CPI, we show our first finding brings new insights on inflation measurement and strong implications to the way monetary policy is conducted. We propose and calibrate a DSGE model that endogeneizes housing tenure choice and is both able to explain the empirical findings and provide answers for monetary policy experiments.

Counterfactual exercises reveal that when the Taylor rule uses the CPI as an input, interest rates will be set too high based on rising rents instead of currency inflation. This generates large welfare costs, adds unnecessary variation to the underlying monetary inflation rate and losses to a monetary policy whose objective is to minimize inflation and output gap variance. Finally, by simulating the model we find monetary policy based on CPI explains a large proportion of the housing price business cycle boom that preceded the 2008 financial crisis.

We do not make the case for the exclusion of housing rents from the consumer price indexes in every circumstance. Housing rents are an important item on measuring households cost of living since households spend around 30% of their income with shelter, and hence should be included. In general, price indexes trends capture well the evolution of the nominal state of the economy. However, when relative prices of some specific goods change suddenly, the consumer prices indexes are affected regardless of how underlying monetary inflation behaves. Given that we show housing rents relative price is strongly affected by monetary policy and that housing rents have a large weight in the consumer price indexes, care should be in place when interpreting the response of consumer price indexes to monetary policy shocks as purely monetary inflation.

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Appendix

A - Figures

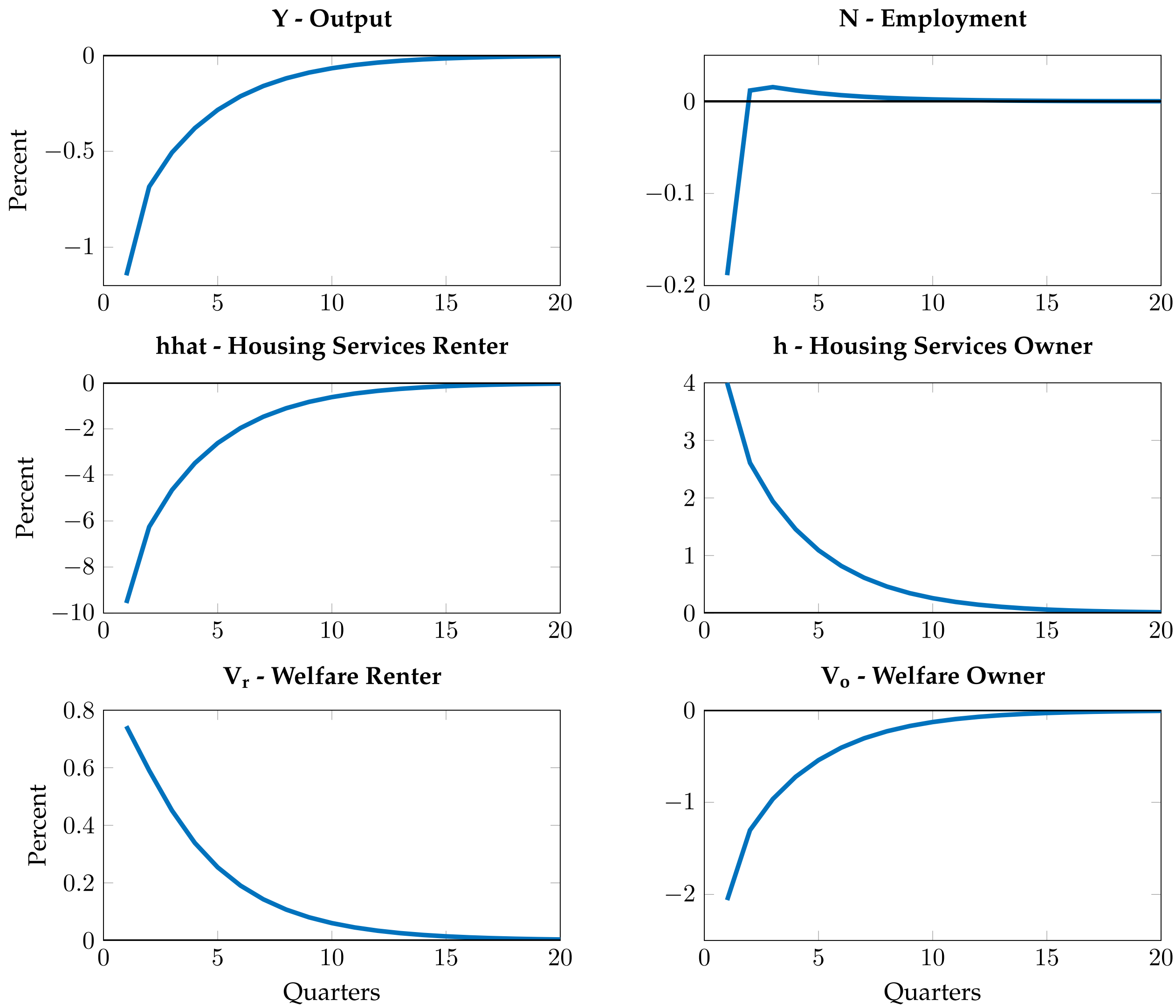
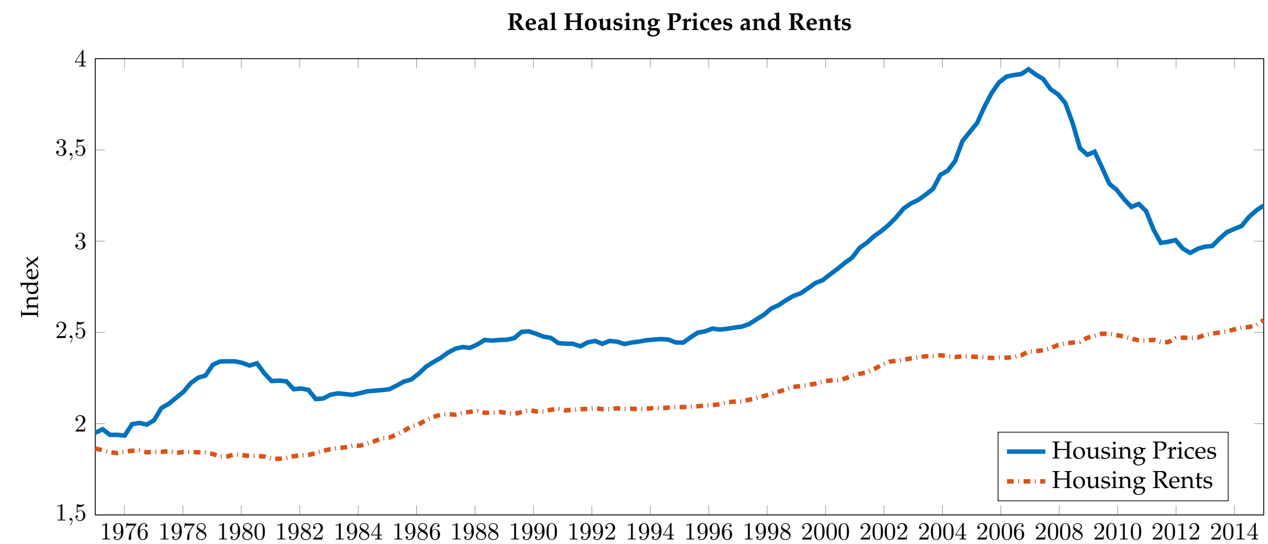


Figure 10: Impulse-Response functions for other variables of interest for the benchmark model where the Taylor rule targets CPI. Each graph shows percentage-point response of one of the model's variables to a one-standard-deviation shock in monetary policy.



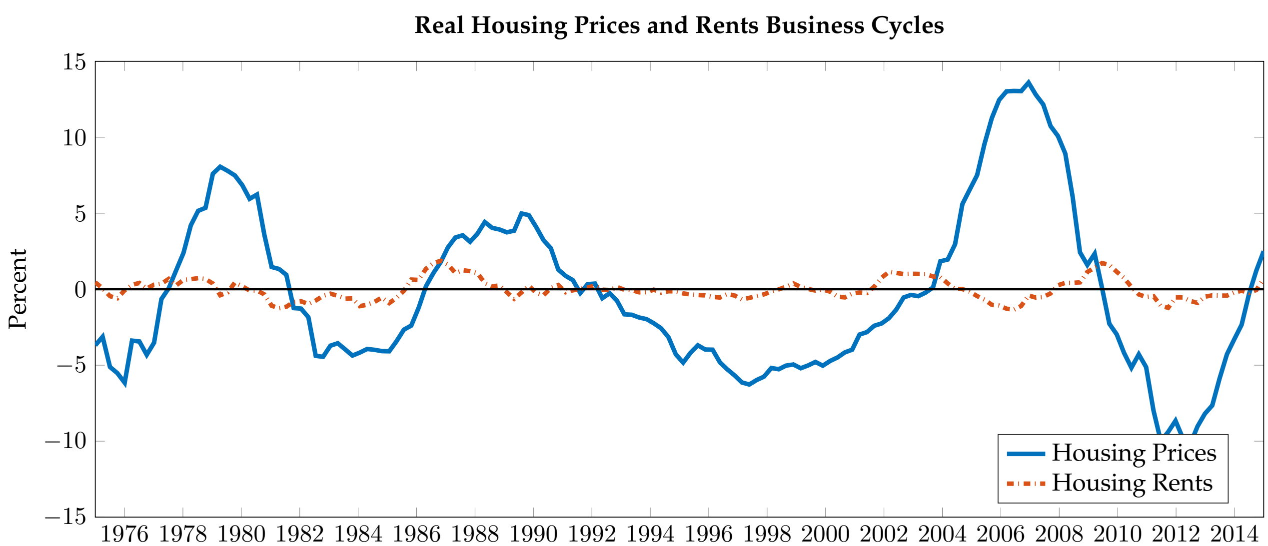


Figure 11: Real Housing Prices and Rents from 1975 to 2015 and business cycles extracted with a HP filter with parameter lambda set to 36000 and 1600 from housing prices and housing rents, respectively. The higher lambda for housing prices is justified by the fact that they have long cycles and are more volatile than output.