House Prices, Aggregate Markups and Monetary Policy

Pablo Lara Hinojos*– CUNY Graduate Center

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Abstract

I study the empirical relationship between house prices, aggregate markups and inflation in a Vector Autoregressive (VAR) setting. I find that following a positive housing price shock, both markups and inflation increase, which is the aggregate counterpart of the findings of recent studies that find a positive relationship between house prices, retail prices and markups at the local level. To rationalize these empirical results I develop a New Keynesian model with a housing sector in which the evolution of markups depends both on the evolution of house prices, which are endogenous; and an exogenous shock. The presence of endogenous markups changes the dynamics of the interest rate, inflation, markups and output only after a housing price shock. The responses of these variables to other structural shocks are the same as those of a model with purely exogenous markups, which suggests that the optimal monetary policy response to house prices should not be too different from the response to other shocks. Consequently, the standard Taylor rule that reacts to the output gap and to inflation approximates the optimal policy even if the Central Bank believes markups are exogenous.

JEL Codes: E12, E31, E32, E50.

1 Introduction

There is recent evidence that indicates that house prices may impact the consumption of households and the dynamics of retail prices at the local level. Stroebel and Vavra (2019) find that housing

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prices have an effect on local retail prices. Specifically, by using detailed micro data, the authors estimate an elasticity of between 15% and 20% from housing prices to local retail prices across housing booms and busts. The authors also document that this phenomenon occurs only in zip codes with a high proportion of homeowners, and not in zip codes with a majority of renters. After analyzing different possible explanations [1], they conclude that the effect is due to changes in natural markups [2].

Building on the work of Stroebel and Vavra (2019), I study the effect of house prices on aggregate inflation and aggregate markups. To do so, I build a quarterly series for aggregate markups following the methodology of De Loecker, Eeckhout, and Unger (2020) and using Compustat data. With this series, I then estimate a non-structural Vector Autoregression (VAR) that includes the interest rate, the inflation rate, real aggregate house prices aggregate markups, and output as endogenous variables. From the Impulse Response Functions (IRFs) of the VAR, I find that aggregate house prices and aggregate markups indeed exhibit a positive comovement. To the best of my knowledge, this is the first paper to document this result. In total, I find three stylized facts[3]. First, after a housing price shock, aggregate markups and inflation increase. This is the aggregate counterpart of the findings of Stroebel and Vavra (2019). Second, after a positive markup shock, output decreases and house prices rise. Third, after an increase in output, both house prices and markups expand as well.

To rationalize these empirical results, I extend the NKM of Iacoviello (2005), which includes a housing sector. I include a positive link between house prices and aggregate markups explicitly. That is, in the law of motion of aggregate markups, I add a term that changes positively with house prices. The degree of responsiveness from markups to house prices depends on an elasticity parameter that is estimated to match the data. The model features three types of agents: households, which can be either *constrained* or *unconstrained*; entrepreneurs; and retailers. Households demand money, a consumption good, and housing. They also supply labor to entrepreneurs. Entrepreneurs combine

[1]Such as: an increase in local rents for retailers, an increase in local labor costs, a change in store or product quality, changes in income gentrification, or store entry and exit.

[2]Natural markups are taken to be the result of producers competing monopolistically on the production of varieties and the final good being a CES-composite, or Dixit-Stiglitz-composite, of them. In this setting, the optimal pricing function is $p_t^* = \mathcal{M}mc_t$. Where $\mathcal{M}$ is the natural markup, and $\mathcal{M} = \frac{\varepsilon}{\varepsilon-1}$, with ε being the elasticity of substitution between varieties.

[3]For a more in-depth analysis, see Lara Hinojos (2020), In which I also carry out some robustness exercises and show that these results remain under different specifications.

housing services (i.e. commercial real estate), capital, and labor from both types of households, to produce an intermediate good, under perfect competition. Retailers use this intermediate good and differentiate it into distinct varieties which they sell monopolistically. The final good is a Dixit-Stiglitz aggregate of these varieties with shocks to the elasticity of substitution and therefore to markups [4]. Retailers face Calvo-type rigidities and they are the source of both the price persistence[5] and the natural markups in the model. The model is closed off by including a central bank that conducts monetary policy following a Taylor rule.

I discipline the model by minimizing the distance between the empirical IRFs and the model-implied IRFs. The model with endogenous natural markups that react to house prices is able to qualitatively replicate the stylized facts described above. In particular, the model is able to generate the increase in both inflation and natural markups that occurs after a housing price boom. It is also able to replicate the increase in house prices and natural markups that occurs after a positive output shock. After a natural markup shock, the model replicates the fall in output that follows. However, one shortcoming of the model is that housing prices decrease following a natural markup shock, while the data suggests that they should increase slightly.

In order to show how necessary endogenous markups are to generate the three empirical facts that I document, I compare my benchmark model against a model in which natural markups vary across time, but do so exogenously. Specifically, I re-compute the responses of the model after each structural shock, while holding the elasticity of markups with respect to house prices equal to zero. Therefore, this *restricted model* differs from the benchmark model only in the sense that aggregate markups are now exogenous. I find that the model with exogenous markups is unable to replicate the empirical facts described above. In particular, since markups do not react to changes in house prices, they do not increase after a house price shock. This also dampens the inflation increase after such a shock and therefore the monetary response. However, the difference between these two models is not economically significant. Similarly, there is nearly no change across both models in the behavior of the rest of the variables after each one of the other structural shocks.

[4] While the typical Dixit-Stiglitz assumes a constant value for the elasticity of substitution parameter ε in $\frac{\varepsilon}{\varepsilon-1}$, there are various papers that relax this assumption and assume that this parameter or, more precisely, the whole ratio varies exogenously following and autoregressive process. See for instance Christiano, Motto, and Rostagno (2014). In the context of the Dixit-Stiglitz constant elasticity of substitution technology, altering one or the other generates the same results, mechanically.

[5] This is done exactly in the same manner as Bernanke, Gertler, and Gilchrist (1999).

I complement this result by performing an analysis of the optimal monetary policy. In this context, optimality means that the Central Bank minimizes a convex combination of inflation and output volatility. This exercise suggests that the Central Bank does not gain much from reacting to house prices, as is common in the monetary literature[6]. This is because, by reacting to inflation and the output gap, the Central Bank can implement essentially the same combination of output and inflation volatility as if it were reacting to asset prices. Additionally, and by a similar argument, this analysis also indicates that the policy implications of aggregate markups reacting to house prices are limited, at best. That is, the combination of inflation and output volatility that arises from the Central Bank erroneously using a model with exogenous markups as the true version, is not significantly different from the optimal combinations achieved by using the "correct" model. All of these results indicate that the relationship between markups and inflation should not imply separate policy concerns at the aggregate level. Reacting to inflation and to the output gap can approximate the optimal monetary policy in all the cases analyzed.

Related Literature. This paper is related to various main strands of literature. First, it builds on the work of Stroebel and Vavra (2019), which in turn is related to other papers that study the relationship between housing wealth and household consumption, such as Mian, Rao, and Sufi (2013) or Aguiar, Hurst, and Karabarbounis (2013), to name a few of them. However, most of these papers follow a more micro approach to this relationship.

Second, from an empirical standpoint, it is related to recent papers that attempt to measure aggregate markups. In this literature, two papers stand out, namely De Loecker et al. (2020) and Hall (2018). Both attempt to measure aggregate markups using the production function approach, but the first paper uses micro-data from Compustat to compute them; while the second one uses aggregate data to do so. This paper is mainly related to De Loecker et al. (2020) since I use the same methodology on firm-level quarterly data to obtain a quarterly series for aggregate markups.

Third, from a theoretical standpoint, this paper is generally related to the wide selection of New Keynesian models (NKMs), which are the standard tool to study inflation dynamics and the role of monetary policy in an aggregate setting. In particular, this paper is related to two main groups of NKMs. Given that I am interested in the effects of house prices on aggregate markups

[6] See for example Iacoviello (2005), who obtains the same result from a similar exercise.

and inflation dynamics, the model requires a housing sector. In that sense, it is closely related to Iacoviello (2005) and Iacoviello and Neri (2010), as it is an extension of the former. Alternatively, it is also related to a group of medium-scale models that include time-varying markups, albeit with exogenous dynamics. Some examples of these models are Christiano et al. (2014) or Justiniano, Primiceri, and Tambalotti (2010, 2011).

Finally, and more broadly related to the topic of aggregate markups and their macroeconomic effects, the work of Edmond, Midrigan, and Xu (2018) is relevant for this paper. Their results, which arise from a model with heterogeneous firms and endogenous markups, show that the main effect of markups is akin to a general tax for the whole economy and that this is the main driver of efficiency losses from markups, accounting for at least two thirds of the total losses under different versions of the model. They also find that markups generate losses through misallocation, but this effect is limited at best. It is also related to (Furceri, Lee, & Tavares, 2021) who attempt to measure how firm markups and market power can affect their responses to monetary policy.

2 Empirical Evidence

The first step in understanding the aggregate implications of the effect of house prices on natural markups found at the micro level by Stroebel and Vavra (2019) is to verify whether or not this relationship holds when employing aggregate data. To this purpose, in Lara Hinojos (2020) I estimate a VAR which includes the nominal interest rate, the inflation rate, real aggregate house prices, aggregate markups, and real output. I then analyze the impulse response functions (IRFs) from this system to measure the joint behavior of the variables in the system. A first obstacle in this strategy is the lack of an aggregate quarterly series for markups. To circumvent this problem, I follow the methodology of De Loecker et al. (2020), using quarterly data from Compustat to compute an aggregate quarterly measure for natural markups.

The results of this exercise give rise to the following three stylized facts:

1. After a shock to housing prices (q), inflation (π) and markups ($\mathcal{M}$) increase significantly.

2. After a shock to markups ($\mathcal{M}$), output (Y) decreases significantly and house prices (q) rise weakly.

3. After a shock to output (Y), markups ($\mathcal{M}$) increase significantly and house prices (q) do so weakly.

This section discusses briefly the empirical results from this exercise. A more detailed analysis can be found in Lara Hinojos (2020). Where I also perform various robustness exercises and find that the stylized facts above hold for different specifications and sample periods[7].

2.1 Aggregate Markups

While aggregate quarterly series exist for the rest of the variables in the VAR, there is not an official series for quarterly aggregate markups. There are two main measures of aggregate markups in the literature, namely Hall (2018) and De Loecker et al. (2020). Both of this methodologies allow for the estimation of yearly markups. In particular, Hall (2018) uses aggregate data to compute a yearly measure of natural markups; while De Loecker et al. (2020) uses firm-level data from Compustat to obtain an alternative measure of the aggregate markups in the economy. Given that Compustat also reports the necessary firm-level data with a quarterly frequency, I use this methodology in order to obtain a quarterly measure of aggregate markups.

Specifically, the computation of each firm's markups arises from the firm's profit maximization problem[8]. Given the solution to this problem, the optimal markup for firm i in period t is a function that depends on the total sales, the expenditures in the variable input, and the output elasticity of the variable input. The precise expression for the firm-level markup is given by:

$$\mathcal{M}_{it} = \theta_{it}^{V} \frac{P_{it}Q_{it}}{P_{it}^{v}V_{it}} \tag{1}$$

Where $P_{it}Q_{it}$ are firm's total revenues in period t; $P_{it}^{v}V_{it}$ are the firm's total expenditures in the variable input; and θ_{it}^{V} is the firm's output elasticity with respect to the variable input. That is, how much firm i's output increases when the variable input increases marginally. This term will be common across firms in the same industry-year, where industry is defined at the two-digit NAICS level.

Once each firm's markup is computed, the aggregate markup per period can be constructed as

[7] For instance, using CPI inflation instead of GDPD inflation, or excluding the period from 2008Q1 onward; or using alternative weights for the computation of the aggregate markup series.

[8] See De Loecker et al. (2020) for details.

a weighted average of each firm's individual markup. Specifically, the aggregate markup in each period is given by:

$$\mathcal{M}_t = \sum_i m_{it} \mathcal{M}_{it} \tag{2}$$

Where m_{it} is the weight given to each individual firm. These weights can vary between the share of total sales per period of each firm (Sales), the share of total costs per period (TC), or the share of the total expenditure in the variable input (COGS). Importantly, Edmond et al. (2018) argue that firms with greater market power charge higher prices, decreasing the quantity demanded for their products. A lower demand implies that the quantity sold and the inputs used to produce are also lower, while revenue might remain relatively high for those firms with greater levels of market power. This results in inflated revenue weights being allocated to larger firms, relative to the input weights. This means that choosing sales-weighted markups might be overstating the importance of larger firms and biasing the results upwards. On the other hand, there might be some issues with the measurement of total costs by firm at the quarterly level, especially regarding the expenditures in physical capital. Therefore, I choose COGS-weighted markups as the relevant series. However, as I show in Lara Hinojos (2020), the results hold when using the other two alternative measures for markups.

2.2 Aggregate House Prices and Natural Markups

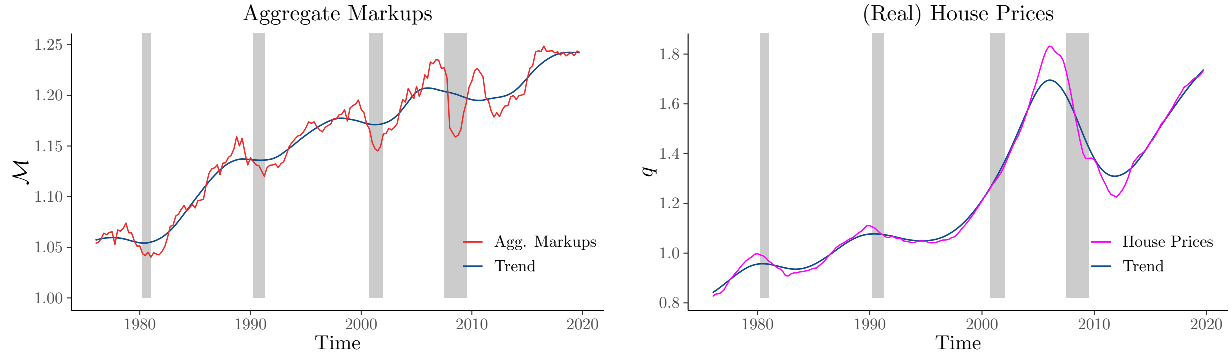
As Figure 1 shows, real house prices and aggregate markups exhibit a similar cyclical behavior, rising above their trend before a recession, and falling below it after. The graphs also shows that the two variables exhibit an overall upward trend. Both of these facts together would suggest that there is a positive co-movement of house prices and aggregate markups.

2.3 VAR

I estimate a $VAR(2)$ that contains endogenous and exogenous variables. The exact equation is given by:

$$\boldsymbol{y_t} = \boldsymbol{A_1 y_{t-1}} + \boldsymbol{A_2 y_{t-2}} + \boldsymbol{B x_t} + \boldsymbol{\varepsilon_t} \tag{3}$$

Figure 1: Aggregate Markups and Real House Prices – Series and Trends



The two graphs in the above figure show the actual series and their trend for each variable. The NBER recession periods are shaded in gray. The trend component is obtained by applying a Baxter-King filter with upper and lower limits of 32 and 2, respectively. The VAR uses the cyclical component from the natural logarithm of both series. The time period shown goes from 1976Q1 to 2019Q4. Real house prices are measured as the quarterly average of the Freddie Mac house price index deflated by the GDP Deflator.

Where $\boldsymbol{y_t} = \left(R_t, \pi_t, q_t, \mathcal{M}_t, Y_t\right)'$ is the vector of endogenous variables. Namely, the interest rate, the inflation rate, aggregate house prices, aggregate markups, and real output, respectively[9]. Since the identification of the structural shock depends on a Cholesky decomposition of the variance-covariance matrix of the residuals, the above ordering of the endogenous variables implies that they are ranked from less to more endogeneity[10]. However, this ordering is not essential for the results[11].

Alternatively, $\boldsymbol{x_t}$ is a vector of the exogenous variables. These include a constant, a linear trend, the lag of the natural logarithm of a commodity price index[12], and dummies for the change of monetary policy stance in the U.S.

2.4 Empirical IRFs

I collect here the IRFs that are estimated significantly and give rise to the stylized facts presented above. Given the results of Stroebel and Vavra (2019), I am interested in the response of markups after a shock to house prices. However, the VAR allows me to understand the joint dynamics of the

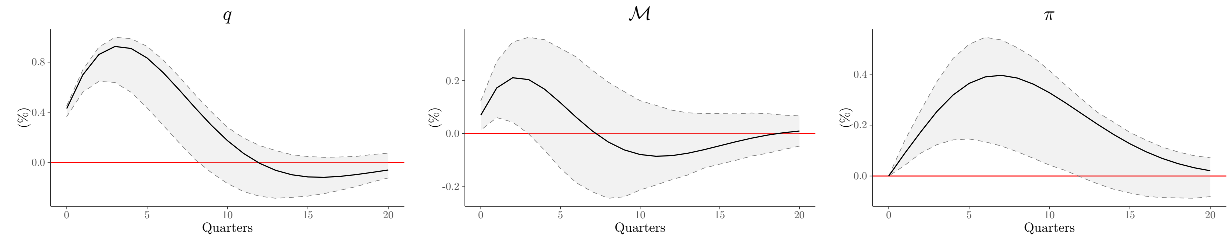
[9]The interest rate corresponds to the effective quarterly federal funds rate (on a yearly basis); the inflation rate corresponds to the quarter-on-quarter GDP Deflator inflation rate; and the cycle component of the natural logarithm of Freddie Mac's house price index (deflated by the GDPD), the series for aggregate markups, and real output.

[10]This assumes a lower triangular Cholesky decomposition.

[11]In Lara Hinojos (2020) I show that the results hold after employing Generalized Impulse Response Functions as developed in Pesaran and Shin (1998), which are invariant to different orderings of the VAR.

[12]This is done to alleviate possible concerns of a *price puzzle* emerging, as described in Sims (1992).

Figure 2: Fact 1 – Shock to house prices.



The figure shows the responses of markups ($\mathcal{M}$) and inflation (π) after a one-standard-deviation orthogonal shock to house prices (q). The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.

whole system. For the full responses, see Appendix A [13].

Each IRF collects the response of all the variables after each shock with magnitude equal to one standard deviation [14]. By construction, the Cholesky decomposition guarantees that each one of these shocks can be interpreted as an orthogonal structural shock. The confidence intervals for each IRF are computed by running a bootstrap of the IRFs with 1,000 runs.

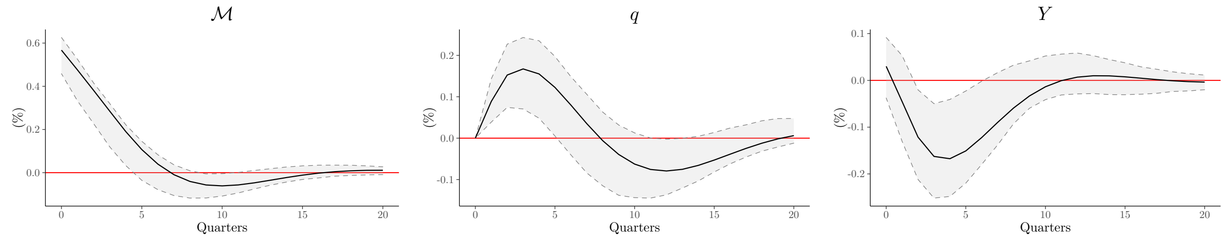
House Prices Shock

Fact 1 results from the responses to a housing shock. Figure 2 shows the response the variables in the VAR after such a shock. It is possible to observe that the shock to q behaves in a hump-shaped manner, and so do the responses from π and $\mathcal{M}$. This fact would be consistent with the findings of Stroebel and Vavra (2019), who find that after an increase in house prices, both markups and retail prices rise as well. That is, the dynamics of house prices shape the dynamics of both inflation and aggregate markups. Such a response could be explained by the same mechanism discussed in their paper. Namely, after a positive housing price shock, there is both a *wealth effect* and a *relaxation of the collateral constraints* for households. This in turn, may decrease price sensitivity, which leads producers to optimally increase their markups in response. The increase in markups then leads to an increase in inflation. As house prices return to their trend, so do markups and inflation.

[13] Most of the stylized facts described here hold under various robustness checks. In particular, the positive relationship between house prices and aggregate markups holds under different specifications of the VAR, when employing generalized impulse response functions, local projections, vector error-correction models, and when considering different sample periods. For more detail see Lara Hinojos (2020).

[14] The standard deviation of each variable is measured by the square root of diagonal entries of the variance-covariance matrix of the residuals.

Figure 3: Fact 2 – Shock to markups.



The figure shows the responses of house prices (q) and real output (Y) after a one-standard-deviation orthogonal shock to aggregate markups ($\mathcal{M}$). The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.

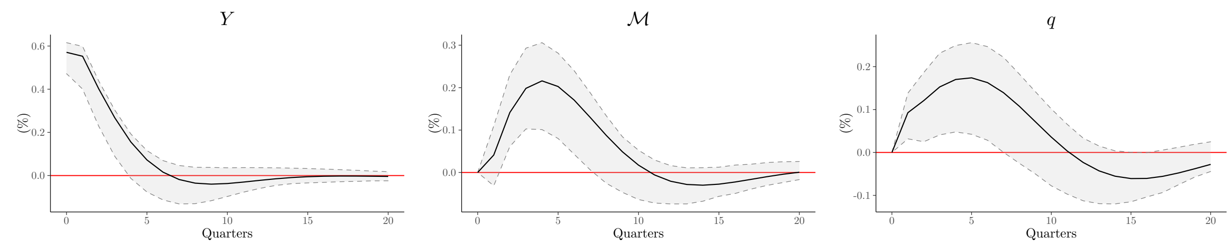
Markups Shock

Fact 2 emerges from the responses of the system after an orthogonal shock to markups. Figure 3 shows the responses of the VAR to this shock. Output (Y) rises non-significantly above its trend upon impact; but after 4 to 5 periods, it significantly falls below trend. House prices (q) rise above trend after the shock. Such behavior could be explained by looking at the cyclical behavior of both variables: aggregate markups tend to increase above their trend before a recession, as shown in Figure 1, which means they act as a lead indicator of economic activity. House prices also rise above their trend before a recession, so this could explain the apparent positive co-movement between these two variables.

Output Shock

Fact 3 follows from the responses of the VAR to a shock to real output. These responses plotted in Figure 4, which shows that after a positive shock to output (Y), both house prices (q) and markups ($\mathcal{M}$) increase. There are a few possible explanations consistent with this behavior. Firstly, if input increases due to a rise in Total Factor Productivity (TFP), then consumption goods become relatively more abundant than housing, which causes the relative price of housing (q) to increase. This increase in house prices then causes the wealth effect and the relaxation of collateral constraints described before, which decreases the price sensibility of households and drives firms to increase their markups, even as prices should be falling. On the other hand, a positive shock to output can be interpreted as a positive income shock which increases both the demand for housing, and house

Figure 4: Fact 3 – Shock to real output.



The figure shows the responses of natural markups ($\mathcal{M}$) and house prices (q) after a one-standard-deviation orthogonal shock to real output (Y). The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.

prices as a response, as well as the markups that firms can charge. On the other hand, there is a rising literature that shows that larger, more productive firms are able to establish higher markups[15], if the TFP shock affects these firms more intensely, their market power would increase and so would aggregate markups.

In order to rationalize these results, I extend the model in Iacoviello (2005) to account for the relationship between house prices and natural markups found by Stroebel and Vavra (2019).

3 Model

The environment of the model is characterized as a discrete-time, infinite-horizon economy. It is populated by entrepreneurs, retailers, and two types of households: *patient* and *impatient*. Both entrepreneurs and households are infinitely lived and of measure one. Entrepreneurs produce a homogeneous good using labor hired from both types of households, physical capital, and housing. Households consume, work, and demand real estate and money. Each retailer buys the homogeneous good and transforms it into a specific variety. These varieties are then aggregated together to produce the final good. Retailers compete monopolistically and are the source of nominal rigidities. The model is closed off by including a central bank that adjusts the money supply to induce a particular interest rate Taylor rule.

Each one of these agents solves an optimization problem subject to specific constraints.

[15]See Edmond et al. (2018), for instance.

3.1 Patient Households

Patient households choose consumption c'_t, housing h'_t, labor L'_t and real money balances M'_t/P_t, to solve:

$$\begin{aligned} \max_{c'_t,h'_t,L'_t,M'_t} \quad & \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[ln\, c'_t + \boldsymbol{j}_t ln\, h'_t - \frac{(L'_t)^{\eta'}}{\eta'} + \chi ln \left(\frac{M'_t}{P_t} \right) \right] \right\} \\ \text{s.t.} \quad & c'_t + q_t(h'_t - h'_{t-1}) + R_{t-1}\frac{b'_{t-1}}{\pi_t} = b'_t + w'_t L'_t + F_t + T'_t - \frac{\Delta M'_t}{P_t} - \xi_{h',t} \end{aligned} \tag{4}$$

In words, households maximize their lifetime utility subject to their flow of funds. Where q_t is the real price of housing; $\boldsymbol{j}_t$ is a housing-demand shifter; b'_t are real bond holdings; R_{t-1} is the nominal interest rate on bonds between $t-1$ and t; w'_t is the real wage; F_t are lump-sum profits received from the retailers; and $T'_t - \frac{\Delta M'_t}{P_t}$ are net transfers from the central bank financed by printing money. On the other hand $\pi_t = \frac{P_t}{P_{t-1}}$ denotes the gross inflation rate. Also, $\xi_{h',t} \equiv \frac{\psi_h}{2}\left(\frac{\Delta h'_t}{h'_{t-1}}\right)^2 q_t h'_{t-1}$ is a housing adjustment cost.

Solving this problem implies the following First Order Conditions:

$(w.r.t \;\; c'_t)$

$$\frac{1}{c'_t} = \beta \mathbb{E}_t \left\{ \frac{R_t}{c'_{t+1}} \right\} \tag{5}$$

$(w.r.t \;\; L'_t)$

$$w'_t = (L'_t)^{\eta - 1} c'_t \tag{6}$$

$(w.r.t \;\; h'_t)$

$$\frac{q_t}{c'_t} = \frac{\boldsymbol{j}_t}{h'_t} + \beta \mathbb{E}_t \left\{ \frac{q_{t+1}}{c'_{t+1}} \right\} \tag{7}$$

Where I omit the term related to housing adjustment costs, since they are excluded from the analysis in what follows. For patient households, the discount factor is large enough so they do not face financial constraints. This will not be the case for impatient households.

3.2 Impatient Households

Impatient households have a lower discount factor, relative to patient households. This implies that they discount the future more heavily. They choose consumption c''_t, housing h''_t, labor L''_t, and real money balances M''_t/P_t to solve:

$$\max_{c''_t,h''_t,L''_t,M''_t} \quad \mathbb{E}_0\left\{\sum_{t=0}^{\infty}(\beta'')^t\left[ln\, c''_t+\boldsymbol{j}_t ln\, h''_t-\frac{(L''_t)^{\eta''}}{\eta''}+\chi ln\left(\frac{M''_t}{P_t}\right)\right]\right\}$$

$$\text{s.t.} \quad c'_t+q_t(h''_t-h''_{t-1})+R_{t-1}\frac{b'_{t-1}}{\pi_t}=b''_t+w''_tL''_t+F_t+T''_t-\frac{\Delta M''_t}{P_t}-\xi_{h'',t} \tag{8}$$

$$b''_t\le m''\mathbb{E}_t\left\{\frac{q_{t+1}h''_t\pi_{t+1}}{R_t}\right\}$$

Where $\beta''<\beta$ reflects the fact that impatient households discount the future more heavily than patient ones; $\boldsymbol{j}_t$ is a housing demand shifter[16]; and $\xi_{h',t}\equiv\frac{\psi_h}{2}\left(\frac{\Delta h'_t}{h''_{t-1}}\right)^2 q_th''_{t-1}$ are housing adjustment costs. The problem of the impatient households includes also a borrowing constraint. This means that, in equilibrium, impatient households are financially constrained and m'' measures how easy it is for households to collateralize their housing wealth (in other words, m'' is the loan-to-value parameter for impatient households). At $m''=0$ housing cannot be collaterized, and at $m''=1$ it is perfectly collateralizable. This constraint is analogous to the constraint that entrepreneurs face, and will be described in more detail below.

To summarize, impatient households behave similarly to patient ones. Both of them choose consumption, housing, labor and real money balances in order to maximize their lifetime utility, subject to their flow of funds. Impatient households have the additional financial constraint expressed in (8).

Letting $\aleph''_t$ denote the Lagrange multiplier associated to the impatient household's borrowing constraint, the First Order Conditions of this problem are:

$(w.r.t\ \ c''_t)$

$$\frac{1}{c''_t}=\beta''\mathbb{E}_t\left\{\frac{R_t}{\pi_{t+1}c''_{t+1}}\right\}+\aleph''_tR_t \tag{9}$$

$(w.r.t\ \ L''_t)$

$$w''_t=(L''_t)^{\eta''-1}c''_t \tag{10}$$

$(w.r.t\ \ h''_t)$

$$\frac{q_t}{c''_t}=\frac{\boldsymbol{j}_t}{h''_t}+\beta\mathbb{E}_t\left\{\frac{q_{t+1}}{c'_{t+1}}+\aleph''_tm''q_{t+1}\pi_{t+1}\right\} \tag{11}$$

[16] Which will be common across both types of households.

Where, once again, the term associated with the adjustment costs of housing has been omitted.

3.3 Entrepreneurs

Entrepreneurs sell a wholesale aggregate product, priced as P^w. Output is produced using a Cobb-Douglas technology that mixes housing, physical capital, and both types of labor. They hire labor from both types of households, and they own the physical capital. The Total Factor Productivity (TFP) term, A_t, is stochastic. Consumption and investment goods have a price of P_t, housing has a price of Q_t. Lower-case variables indicate prices divided by the price of the final consumption good P_t. Let $q = \frac{Q}{P}$, $\frac{1}{X} = \frac{P^w}{P}$ and $w = \frac{W}{P}$. Also, the entrepreneur faces a borrowing constraint à la Kiyotaki and Moore (1997). That means whenever borrowers decide to default on their debts, lenders can only repossess the assets of the borrower by paying the proportional transaction cost: $(1-m)\mathbb{E}_t\left\{q_{t+1}h_t\right\}$, with $m \in [0,1]$. This implies that the maximum amount b_t (in real terms) that a creditor can borrow is given by:

$$b_t \leq m\mathbb{E}_t\left\{\frac{q_{t+1}h_t\pi_{t+1}}{R_t}\right\}$$

Therefore, letting $\pi_t \equiv \frac{P_t}{P_{t-1}}$, the problem of the entrepreneur is:

$$\begin{aligned}
\max_{c_t,b_t,h_t,K_t,L_t',L_t''} \quad & \mathbb{E}_0\sum_{t=0}^{\infty}\gamma^t ln\, c_t \\
\text{s.t.} \quad & Y_t = A_t K_{t-1}^{\mu} h_{t-1}^{\nu}\left(L_t'\right)^{\alpha(1-\mu-\nu)}\left(L_t''\right)^{(1-\alpha)(1-\mu-\nu)} \\
& \frac{Y_t}{X_t} + b_t = c_t + q_t(h_t - h_{t-1}) + \frac{R_{t-1}}{\pi_t}b_{t-1} + w_t'L_t' + w_t''L_t'' + I_t + \xi_{K,t} + \xi_{h,t} \\
& b_t \leq m\mathbb{E}_t\left\{\frac{q_{t+1}h_t\pi_{t+1}}{R_t}\right\} \\
& I_t = K_t - (1-\delta)K_{t-1}
\end{aligned} \tag{12}$$

That is, entrepreneurs maximize their lifetime utility from consumption, subject to the technology constraint, their flow of funds, the borrowing constraint, and the law of motion for capital. The flow of funds includes, from the standpoint of sources of income, the real revenues from selling the intermediate good to retailers and the debt that they can acquire; from the standpoint of the use of resources, it includes consumption, the value of adjusting their housing demands, the real interest payments, the wage bill for both types of labor, and two adjustment costs. The first adjustment cost refers to the adjustment of physical capital, and is given by $\xi_{K,t} = \frac{\psi_K}{2\delta}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1}$, so it is a proportional cost to the stock of physical capital; and quadratic on the rate of net adjustment. The second adjustment cost is linked to commercial real estate (i.e. housing used by entrepreneurs), and it is equal to $\xi_{h,t} = \frac{\psi_H}{2\delta}\left(\frac{h_t - h_{t-1}}{h_t}\right)^2 h_{t-1}$; which is also proportional to the total housing stock, and quadratic on the rate of net adjustment. These costs can be easily removed by setting $\psi_K = 0$ or $\psi_H = 0$. In fact, once the model is taken to the data, the adjustment costs for real estate are calibrated at zero. Additionally, $\alpha \in (0, 1)$ represents the fraction of each type of labor (either coming from patient or impatient households) that is used in production.

In order to avoid entrepreneurs from accumulating wealth rapidly and self-financing in the long run, the assumption $\gamma < \beta$ (i.e. entrepreneurs discount the future more heavily than households) is needed. This allows for entrepreneurs to be constrained even in the long-run.

Letting $\aleph_t$ be the Lagrange multiplier associated to the borrowing constraint[17]; and u_t be the Lagrange multiplier associated with the law of motion of capital, the First Order Conditions of this problem are:

$(w.r.t \quad c_t)$

$$\frac{1}{c_t} = \gamma \mathbb{E}_t \left\{ \frac{R_t}{\pi_{t+1} c_{t+1}} \right\} + \aleph_t R_t \tag{13}$$

$(w.r.t \quad I_t)$

$$u_t = \frac{1}{c_t}\left[1 + \frac{\psi_K}{\delta}\left(\frac{I_t}{K_{t-1} - \delta}\right)\right] \tag{14}$$

$(w.r.t \quad K_t)$

$$u_t = \gamma \mathbb{E}_t \left\{ \frac{1}{c_{t+1}} \left(\frac{\psi_K}{\delta}\left(\frac{I_{t+1}}{K_t} - \delta\right)\frac{I_{t+1}}{K_t} - \frac{\psi_K}{2\delta}\left(\frac{I_{t+1}}{K_t} - \delta\right)^2 \right) + \frac{\mu Y_{t+1}}{c_{t+1} K_t X_{t+1}} + u_{t+1}(1-\delta) \right\} \tag{15}$$

$(w.r.t \quad h_t)$

$$\frac{q_t}{c_t} = \mathbb{E}_t \left\{ \frac{\gamma}{c_{t+1}} \left(\nu \frac{Y_{t+1}}{X_{t+1} h_t} + q_{t+1} \right) + \aleph_t m \pi_{t+1} q_{t+1} \right\} + \mathbb{E}_t \left\{ \frac{d\xi_{h,t}}{dh_t} + \frac{d\xi_{h,t+1}}{dh_t} \right\} \tag{16}$$

With:

[17] In Iacoviello (2005), this is called λ_t, but I use $\aleph_t$ instead to avoid any confusion with the natural markups.

$$\frac{d\xi_{h,t}}{dh_t} + \frac{d\xi_{h,t+1}}{dh_t} = \frac{\psi_H}{\delta}(h_t - h_{t-1}) - \frac{\psi_H}{\delta}\left(\frac{h_{t+1}}{h_t} - 1\right)\frac{1}{h_t} + \frac{\psi_H}{2\delta}\left(\frac{h_{t+1}}{h_t} - 1\right)^2$$

However, once the model is calibrated, $\psi_H = 0$ is chosen, so these terms disappear.

$(w.r.t \quad L'_t)$

$$w'_t = \alpha(1-\mu-\nu)\frac{Y_t}{X_t L'_t} \tag{17}$$

$(w.r.t \quad L''_t)$

$$w'_t = (1-\alpha)(1-\mu-\nu)\frac{Y_t}{X_t L''_t} \tag{18}$$

The assumption of $\gamma < \beta$ guarantees that in steady state: $\aleph = \frac{(\beta-\gamma)}{c} > 0$, so that the borrowing constraint holds with equality [18]. With uncertainty, there are some necessary considerations. Because the utility function is concave, there might be a precautionary savings motive to buffer against adverse shocks. In principle, there could be a level of net worth such that whenever an entrepreneur's net worth falls below it, the precautionary savings motive dominates impatience, and entrepreneurs will borrow less than the limit. In particular, entrepreneurs might borrow below their limit after a sufficiently long streak of positive shocks. If this occurs, the model would become asymmetric around the stationary steady state and a linear approximation might not be valid. For now, it is assumed that uncertainty is "small enough" so as to prevent this from happening.

3.4 Retailers

This problem is taken directly from Bernanke et al. (1999). I also follow Justiniano et al. (2010, 2011) in the specification of the time-varying natural markups. Let $Y_t(z)$ be the quantity of output sold by retailer z, measured in units of wholesale goods, and let $P_t(z)$ be the nominal price. Total final usable goods, Y_t^f, are the following composite of individual retail goods:

$$Y_t = \left[\int_0^1 Y_t(z)^{\frac{1}{1+\lambda_{p,t}}}\, dz\right]^{1+\lambda_{p,t}}$$

Where $(1+\lambda_{p,t}) = \mathcal{M}_t$ represents the natural markup [19] which varies across time and is taken

[18] See Iacoviello (2005).

[19] In terms of demand elasticity, we have $\mathcal{M}_t = (1+\lambda_{p,t}) = \frac{\varepsilon_t}{\varepsilon_t - 1}$.

as given by the retailers. As it has already been mentioned, these natural markups will depend on the evolution of house prices, so as to incorporate the empirical findings of Stroebel and Vavra (2019).

The corresponding price index is given by:

$$P_t = \left[\int_0^1 P_t(z)^{\frac{1}{\lambda_{p,t}}} dz \right]^{\lambda_{p,t}}$$

The demand curve that each retailer faces is now given by:

$$Y_t^*(z) = \left(\frac{P_t^*(z)}{P_t} \right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_t^f$$

Where the retailer then chooses the sale price $P_t(z)$, taking as given the demand curve and the price of wholesale goods, P^w. The model has Calvo rigidities with probability of changing prices equal to $1-\theta$. Let $P_t(z)^*$ be the optimal price set by retailers who are able to change their prices, and $Y_t(z)^*$ be the demand faced by them. Retailer z must choose price $P_t(z)^*$ to solve:

$$\max_{P_t^*} \quad \sum_{k=0}^{\infty} \theta^k \mathbb{E}_{t-1} \left[\Lambda_{t,k} \frac{P_t^* - P_{t+k}^w}{P_{t+k}} Y_{t+k}^*(z) \right] \tag{19}$$

Where $P_t^w \equiv \frac{P_t}{X_t}$ is the nominal price of the wholesale good. Also, $\Lambda_{t,k} \equiv \beta^k \frac{u'(c_{t+k})}{u'(c_t)}$ is the stochastic discount factor. And $Y_{t+k}^*(z) = \left(\frac{P_t^*}{P_{t+k}} \right)^{-\frac{1+\lambda_{p,t+k}}{\lambda_{p,t+k}}} Y_{t+k}^f$ is the demand for retailer's z variety at period $t+k$ under price P_t^*.

This problem has the following First-Order Condition[20]:

$$\sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left\{ -\frac{1}{\lambda_{p,t+k}} \Lambda_{t,k} Y_{t+k}^*(z) \left(\frac{P_t^*}{P_{t+k}} - (1+\lambda_{p,t+k}) \frac{1}{X_{t+k}} \right) \right\} = 0 \tag{20}$$

This expression means that P_t^* is such that it equates the expected discounted marginal revenue to the expected discounted marginal cost.

On the other hand, since only a fraction $(1-\theta)$ of retailers can change their prices, the aggregate price index P_t evolves according to:

[20] In Iacoviello (2005) and in Bernanke et al. (1999), $\varepsilon_t = \varepsilon \, \forall t$, so that the $(\varepsilon - 1)$ element can be taken out of the expectation operator and it disappears from the equation. They also define $X \equiv \frac{\varepsilon}{\varepsilon - 1}$ as the steady state markup.

$$P_t = \left(\theta P_{t-1}^{\frac{1}{\lambda_{p,t}}} + (1-\theta) P_t^{*\,\frac{1}{\lambda_{p,t}}} \right)^{\lambda_{p,t}} \tag{21}$$

When linearizing the model and solving it, (20) together with (21) give rise to the Philips Curve.

3.5 Central Bank

The Central Bank performs lump-sum transfers to households in order to implement a Taylor-type interest rule that depends on the past nominal interest rate, inflation in the previous period and the output gap. Specifically, the rule it sets is the following:

$$R_t = (R_{t-1})^{r_R} \left(\pi_{t-1}^{1+r_\pi} \left(\frac{Y_{t-1}}{Y} \right)^{r_Y} \overline{rr} \right)^{1-r_R} e_{R,t} \tag{22}$$

Where $\overline{rr}$ and Y are steady state real interest rate an output, respectively. And where is a white noise process which natural logarithm has zero mean, and variance σ_R^2.

3.6 House Prices and Aggregate Markups

In order to incorporate the relationship between house prices and natural markups found by Stroebel and Vavra (2019), I modify the equation that governs the evolution of markups that is typically use in this type of models[21]. Specifically, the evolution of natural markups does not only contain an autoregressive component, but also a term that is positively related to the evolution of house prices. That is, natural markups evolve according to:

$$ln\left(\mathcal{M}_t\right) = (1-\rho_p)\mathcal{M} + \rho_p ln\left(\mathcal{M}_{t-1}\right) + \phi\left(ln(q_t) - ln(q_{t-1})\right) + e_{p,t} \tag{23}$$

Where $\mathcal{M}_t = 1+\lambda_t$ is the natural markup at time t, and the term without a time index represents the steady state value; $\rho_p \in (0,1)$ is the autocorrelation parameter of natural markups; q_t are house prices at time t; $\phi > 0$ is the parameter that measures the elasticity of natural markups with respect to house prices; and $e_{p,t} \sim (0, \sigma_p^2)$. In the context of Calvo rigidities, only retailers that are able to re-set their prices will increase them when natural markups increase. This is why the term for natural markups in the Phillips Curve is multiplied by the same coefficient as the changes in the

[21]See Justiniano et al. (2010, 2011).

marginal cost.

This specification has the advantage not only of being a slight modification of the usual way in which time-varying natural markups are introduced, but it also captures the effect of house prices on aggregate natural markups in the same spirit of Stroebel and Vavra (2019). That is, in terms of elasticities of natural markups with respect to house prices. The degree of this elasticity is determined by the parameter ϕ. The value for this parameter is chosen so as to minimize the distance between the model-implied impulse response functions (IRFs) and the empirical IRFs, as explained in Section 5.

3.7 Equilibrium

Without shocks, this model has a unique stationary equilibrium in which entrepreneurs and impatient households are constrained and borrow up to the limit, paying only the interest on the debt and rolling over the steady-state stock.

An equilibrium is a sequence of allocations:

$$\left\{h_t, h_t', h_t'', L_t, L_t', L_t'', c_t, c_t', c_t'', b_t, b_t', b_t'', K_t, I_t, M_t', M_t''\right\}_{t=0}^{\infty}$$

and (*shadow*)prices:

$$\left\{w_t', w_t'', R_t, P_t, P_t^*, X_t, \aleph_t, \aleph_t'', q_t, \mathcal{M}_t\right\}_{t=0}^{\infty}$$

such that:

1. *Optimality is Satisfied.* That is, the allocations solve the agents' maximization problems.
2. *Markets clear.* Meaning the labor market ($L_t = L_t' + L_t''$); the housing market ($h_t + h_t' + h_t'' = H$); the bond market ($b_t + b_t' + b_t'' = 0$); and the goods market ($c_t + c_t' + c_t'' + I_t = Y_t$) all clear.

Given $\left\{h_{t-1}, h_{t-1}', h_{t-1}'' R_{t-1}, b_{t-1}, b_{t-1}', b_{t-1}'' P_{t-1}\right\}_{t=0}$ and the sequence of exogenous shocks: $\{e_{R,t}, e_{u,t}, e_{A,t}, e_{p,t}, e_{j,t}\}_{t=0}^{\infty}$.

4 The Linearized Model

Log-linearizing[22] the model about a non-stochastic, zero-inflation steady state yields the following equations.

$$\hat{Y}_t = \frac{c}{Y}\hat{c}_t + \frac{c'}{Y}\hat{c}'_t + \frac{c''}{Y}\hat{c}''_t + \frac{I}{Y}\hat{I}_t \tag{A1}$$

$$\hat{c}'_t = \mathbb{E}_t\left\{\hat{c}'_{t+1}\right\} - \hat{rr}_t \tag{A2}$$

$$\hat{I}_t - \hat{K}_{t-1} = \mathbb{E}_t\left\{\gamma(\hat{I}_{t+1} - \hat{K}_t) + \frac{1-\gamma(1-\delta)}{\psi_K}(\hat{Y}_{t+1} - \hat{X}_{t+1} - \hat{K}_t) - \frac{1}{\psi_K}\Delta\hat{c}_{t+1}\right\} \tag{A3}$$

$$\hat{q}_t = \mathbb{E}_t\left\{\gamma_e\hat{q}_{t+1} + (1-\gamma_e)(\hat{Y}_{t+1} - \hat{X}_{t+1} - \hat{h}_t) - m\beta\hat{rr}_t - (1-m\beta)\Delta\hat{c}_{t+1}\right\} \tag{A4}$$

$$\hat{q}_t = \mathbb{E}_t\left\{\gamma_h\hat{q}_{t+1} - (1-\gamma_h)(\hat{h}''_t) - m''\beta\hat{rr}_t - (1-m''\beta'')(\hat{c}''_t - \omega\hat{c}''_{t+1})\right\} \tag{A5}$$

$$\hat{q}_t = \mathbb{E}_t\left\{\beta\hat{q}_{t+1} + \iota\hat{h}_t + \iota''\hat{h}''_t + \hat{c}'_t - \beta\hat{c}'_{t+1}\right\} \tag{A6}$$

$$\hat{b}_t = \mathbb{E}_t\left\{\hat{q}_{t+1} + \hat{h}_t - \hat{rr}_t\right\} \tag{A7}$$

$$\hat{b}''_t = \mathbb{E}_t\left\{\hat{q}_{t+1} + \hat{h}''_t - \hat{rr}_t\right\} \tag{A8}$$

$$\hat{Y}_t = \frac{\eta}{\eta-(1-\nu-\mu)}\left[\hat{A}_t + \nu\hat{h}_{t-1} + \mu\hat{K}_{t-1}\right] - \frac{1-\nu-\mu}{\eta-(1-\nu-\mu)}\left[\hat{X}_t + \alpha\hat{c}'_t + (1-\alpha)\hat{c}''_t\right] \tag{A9}$$

[22]For all the variables involved, the hat notation represents their percent change from their steady state value. That is, for variable x_t, $\hat{x}_t \equiv \frac{x_t - x}{x}$. Except for $\hat{\mathcal{M}}_t \equiv log(1+\mathcal{M}_t) - log(\mathcal{M})$. Where the variables without the time sub-index represent the steady state value, in both cases. Both approximations are roughly equivalent.

$$\hat{\pi}_t = \beta \mathbb{E}_t \left\{ \hat{\pi}_{t+1} \right\} - \kappa(\hat{X}_t - \hat{\mathcal{M}}_t) + \hat{u}_t \tag{A10}$$

$$\hat{K}_t = \delta \hat{I}_t + (1-\delta)\hat{K}_{t-1} \tag{A11}$$

$$\frac{b}{Y}\hat{b}_t = \frac{c}{Y}\hat{c}_t + \frac{qh}{Y}\Delta\hat{h}_t + \frac{I}{Y}\hat{I}_t + \frac{Rb}{Y}(\hat{R}_{t-1} + \hat{b}_{t-1}\hat{\pi}_t) - (1 - s' - s'')(\hat{Y}_t - \hat{X}_t) \tag{A12}$$

$$\frac{b''}{Y}\hat{b}''_t = \frac{c''}{Y}\hat{c''}_t + \frac{qh''}{Y}\Delta\hat{h}''_t + \frac{Rb}{Y}(\hat{R}_{t-1} + \hat{b}''_{t-1}\hat{\pi}_t) - s''(\hat{Y}_t - \hat{X}_t) \tag{A13}$$

$$\hat{R}_t = (1 - r_R)\Big((1 + r_\pi)\hat{\pi}_{t-1} + r_Y \hat{Y}_{t-1}\Big) + r_R \hat{R}_{t-1} + \hat{e}_{R,t} \tag{A14}$$

Where $\omega = \frac{(\beta'' - m''\beta'')}{(1-m''\beta)}$, $\iota = \frac{(1-\beta)h}{h'}$, $\iota = \frac{(1-\beta)h''}{h'}$, $\gamma_h = \beta'' + m''(\beta - \beta'')$, and $\kappa \equiv \frac{(1-\theta)(1-\theta\beta)}{\theta}$ Also, $\hat{rr}_t \equiv \hat{R}_t - \mathbb{E}_t \left\{ \hat{\pi}_{t+1} \right\}$ is the ex-ante real interest rate.

(A1) is the market-clearing condition. (A2) is the Euler equation for the patient household. (A3) is the investment schedule. The housing-consumption margin for the entrepreneur is given by (A4); while those of the impatient and patient households are described by (A5) and (A6), respectively. The borrowing constraint for entrepreneurs and for impatient households are, respectively, (A7) and (A8). (A9) describes the production function, and incorporates market clearing for the labor market. The New Keynesian Phillips Curve (NKPC) is described by (A10), which now includes the effect of natural markups on inflation. (A11) is the law of motion for capital. The flow of funds for entrepreneurs and impatient households[23] are (A12) and (A13), respectively. Finally, the Central Bank's Taylor rule is given by (A14)

These equations are the same equations found in Iacoviello (2005), except for Eq. (A10), which has the additional term $\kappa\hat{\mathcal{M}}_t$ linked to the time-variant nature of the elasticity of demand and

[23]The flow of funds for patient households is not included, because it is implied from these two by Walras' law.

natural markups, which will depend on the evolution house prices [24].

4.1 Effect of House Prices on Demand Elasticity

The log-linearized version of the evolution of natural markups is given by:

$$\hat{\mathcal{M}}_t = \rho_p \hat{\mathcal{M}}_{t-1} + \phi(\hat{q}_t - \hat{q}_{t-1}) + e_{p,t} \tag{A15}$$

Where the steady state term $(1 - \rho_p)\mathcal{M}$ disappears because the model is expressed in terms of deviations from the steady state.

4.2 Exogenous Shocks

The model is completed by describing the evolution of the other exogenous shocks, which correspond to technology and the housing demand shifter. They both follow an autoregressive structure:

$$\begin{aligned} \hat{A}_t &= \rho_A \hat{A}_{t-1} + e_{A,t} \\ \hat{\boldsymbol{j}}_t &= \rho_j \hat{\boldsymbol{j}}_{t-1} + e_{j,t} \\ \hat{u}_t &= \rho_u \hat{u}_{t-1} + e_{u,t} \end{aligned} \tag{A16}$$

With $\rho_A, \rho_j, \rho_u \in (0, 1)$; $e_{A,t} \sim (0, \sigma_A^2)$, $e_{j,t} \sim (0, \sigma_j^2)$, and $e_{u,t} \sim (0, \sigma_u^2)$.

5 Parametrization

I partition the set of parameters into three different categories [25]: calibrated parameters, Taylor rule parameters, and estimated parameters. The estimation of the parameters is done in the same manner as Iacoviello (2005), that is, by choosing the parameter values that minimize the distance between the model and the empirical Impulse Response Functions (IRFs).

5.1 Calibrated Parameters

The value of these parameters comes from the literature, or from steady-state relationships. This group of parameters includes the discount factors β, γ, and β''; the housing weight j; the technology

[24] This Phillips Curve is quite similar to the Phillips Curve in Justiniano et al. (2010, 2011). However, since this version of the model does not have inflation-indexing, it is not quite the same.

[25] This is done in the same manner as in Iacoviello (2005).

parameters ν and μ; the gross-markup in steady state is equal to the natural markup $X = (1+\lambda) = \mathcal{M}$; the labor disutility η; and the degree of price rigidity θ. In particular, the housing weight is chosen so as to guarantee a steady state value of residential housing to annual GDP of 140.8%, consistent with the evidence from the Flow of Funds accounts. Additionally, the elasticity of housing in production implies a steady state value of commercial housing to annual GDP of 63.06%, as reported in Iacoviello (2005). Importantly, the value for the steady-state markup is chosen as the average from the constructed quarterly time series from 1976 to the end of 2019.

The values for calibrated parameters are shown in Table 1.

Table 1: Calibrated Parameters

Description	Parameter	Value
Preferences: Discount factors		
Patient households	β	0.99
Entrepreneurs	γ	0.98
Impatient households	β''	0.95
Other preference parameters		
Housing services demand shifter	j	0.10
Labor supply aversion	η	1.01
Technology: Factors Productivity		
Housing share	ν	0.03
Capital share	μ	0.30
Other Technology Parameters		
Capital Adjustment Cost	ψ_K	2
Depreciation rate	δ	0.03
Housing Adjustment Cost	ψ_H, ψ_h	0
Sticky prices		
Steady-state gross markup	X	1.15
Probability fixed price	θ	0.75

5.2 Taylor rule parameters

The values for the monetary policy parameters come directly from Iacoviello (2005), with the sole exception of the standard deviation of the monetary policy shock. The values are obtained from running an OLS regression. The exact specification is:

$$R_t = \beta_0 + \beta_1 R_{t-1} + \beta_2 Y_{t-1} + \beta_3 \pi_{t-1} + D_{\text{AFTER79Q4}} + U_{t-1} + \upsilon_t$$

Where R_t is the (quarterly average) of the federal funds rate; Y_t is the cycle component[26] of the natural logarithm of quarterly real GDP; π_t is quarter-on-quarter inflation [27]; $D_{\text{AFTER79Q4}}$ is a dummy variable that equals one for every period after the fourth quarter of 1979, to account for the change in monetary policy that occurred during and after the Volcker era; and U_{t-1} is the quarterly average of the unemployment rate in period $t-1$.

This regression yields estimated values for β_1, β_2, and β_3, which are associated with R_{t-1}, Y_{t-1}, and π_{t-1}, respectively. Using the linearized version of the Taylor rule in the model, that is, Eq. (A14), we have the following relationships: $\beta_1 = r_R$, $\beta_2 = (1 - r_R)r_Y$, and $\beta_3 = (1 - r_R)(1 + r_\pi)$. So, the appropriate Taylor weights can be extracted from the above estimates.

While the standard deviation from most of the structural shocks in the model are estimated, the standard deviation of the monetary shock, σ_R, comes from the standard error of the interest rate residual from the empirical VAR that was described in the previous sections[28]. The standard deviation corresponds to the sample standard deviation of the residuals for the interest rate.

The value for this set of parameters is shown in Table 2.

Table 2: Monetary Policy Rule Parameters

Description	Parameter	Value
Taylor rule weights		
Lagged interest rate	r_R	0.933
Inflation	r_π	0.222
Output	r_Y	0.042
Standard Deviation		
Monetary shock	σ_R	0.32

[26]This cycle component is extracted by using a Baxter-King filter, as is done in the empirical VAR.
[27]Inflation is calculated as the log change of the GDP deflator.
[28]To summarize, it is a VAR system with the following variables: $(R, \pi, q, \mathcal{M}, Y)$, that is, the interest rate, inflation, house prices and output.

5.3 Estimated Parameters

The last set of parameters corresponds to those that are estimated by minimizing the distance between the empirical Impulse Response Functions (IRFs) and the model IRFs. This set is composed by the autocorrelation parameters and the standard deviation for each of the exogenous shocks. That is, the cost-push shock, the housing demand shock, the natural markup shock, the technology shock, . These parameters are: $(\rho_u, \rho_j, \rho_p, \rho_A, \sigma_u, \sigma_j, \sigma_p, \sigma_A)$. This group of parameters also includes the loan-to-value for entrepreneurs and households, m and m''; and the wage share for patient households, α. Most importantly, this group of parameters contains the elasticity of natural markups to house prices, ϕ in Eq (A15).

The empirical IRFs come from the VAR system developed in Lara Hinojos (2020), and described briefly in Section 2. This VAR system contains five variables: the interest rate, the inflation rate, house prices, and real output. The model IRFs come from the orthogonalized and Cholesky-ordered responses from the same model variables. As discussed in Ireland (2004), using econometric methods to estimate the parameters that drive the structural shocks of the model, and avoiding *stochastic singularity*[29], requires having at least the same number of disturbances as variables used in the estimation of the parameters. In this case, there are five shocks: interest rate, cost-push, natural markups, housing preference, and technology. These shocks map one-to-one with the variables included in the empirical VAR. Let $\boldsymbol{\Psi(\zeta)}$ denote the vector that collects the orthogonalized IRFs from the reduced form of the model, which are ordered in the same manner as in the empirical VAR. In addition, let $\hat{\boldsymbol{\Psi}}$ denote the $n \times 1$ [30] vector of empirical IRFs coming from the VAR. Then, the estimate of ζ, the vector of parameter solves:

$$\min(\boldsymbol{\Psi(\zeta)} - \hat{\boldsymbol{\Psi}})'\boldsymbol{\Phi}(\boldsymbol{\Psi(\zeta)} - \hat{\boldsymbol{\Psi}}) \tag{24}$$

Where $\boldsymbol{\Phi}$ is a $n \times n$ positive semi-definite weighing matrix. Under the null that the model is

[29]As discussed in Ireland (2004), this term is used in the context of Real Business Cycle models, meaning they predict that certain combination of the endogenous variables will be deterministic. If the data does not support this precise relationship between the variables of interest, the estimation of the parameters driving the dynamics of these variables in the model will yield to spurious results.

[30]Where $n = n_1^2 \times n_2 - n_3$. Additionally, n_1 is the number of variables in the VAR, n_2 is the number of elements of each IRF that are considered, and n_3 is the number of responses that are zero either by assumption or due to the Cholesky ordering. In this case, n_1, n_2 and n_3 are equal to 5, 20 and 10, respectively. So $n = 490$.

true, and the VAR fits the data, the efficient weighing matrix would be $\mathbf{\Phi} = \mathbf{\Upsilon}^{-1}$, where $\mathbf{\Upsilon}$ is the sample variance matrix from the VAR. However, following Iacoviello (2005), I use a different weighing matrix $\mathbf{\Phi} = \mathbf{\Omega}\mathbf{\Upsilon}^{-1}$ in order to add more weight to the variance and covariance structure of the IRFs that give rise to the three stylized facts described in Section 2. This affects the standard errors of the estimates, but not their consistency. The results of this estimation exercise are shown in Table 3.

Table 3: Estimated Parameters

Description	Parameter	Value	s.e.
Factor Shares and Loan-to-values			
Patient households wage share	α	0.967	(0.00)
Loan-to-value entrepreneurs	m	0.01	(0.02)
Loan-to-value imp. households	m''	0.99	(0.01)
Autocorrelation of shocks			
Cost-push (inflation)	ρ_u	0.99	(0.00)
Housing demand	ρ_j	0.99	(0.00)
Natural markups	ρ_p	0.57	(0.02)
Technology	ρ_A	0.794	(0.03)
Standard Deviation of shocks			
Cost-push (inflation)	σ_u	0.01	(0.00)
Housing demand	σ_j	1.40	(0.28)
Natural markups	σ_p	0.29	(0.02)
Technology	σ_A	0.39	(0.03)
Other			
Elasticity of markups w.r.t. house prices	ϕ	0.104	(0.01)

The results indicate that impatient households do not seem to matter as much for the aggregate economy, relative to the original estimation in Iacoviello (2005). This can be seen when looking at the share of employment of $(1-\alpha)$ and at the loan-to-value parameter (m'') for impatient households, with values of 0.01 for both parameters. This would suggest that most of the results are driven by the relaxation of the constraints for entrepreneurs.

In terms of autocorrelation of the shocks, the estimated values do not differ significantly from the estimates in Iacoviello (2005). However, the autocorrelation of natural markups is relatively low, when compared to other papers with time-varying markups[31]. This could be explained by the

[31] See, for example Justiniano et al. (2010, 2011), who estimate this parameter at around 0.90 for their model.

fact that markups react significantly to changes in house prices, so that channel may be driving the dynamics of natural markups. Regarding the standard deviations of the shocks, while the standard deviation of the cost-push shock and the housing demand shock are smaller relative to the original estimation in Iacoviello (2005)[32], the estimate for the TFP shock is similar. The fact that the standard deviation of inflation shocks is relatively small could be the result of inflation dynamics in this extended model coming from two sources: cost-push shocks and natural markups, which in turn are also affected by house prices. This means the role of cost-push shocks in explaining inflation dynamics is reduced. Additionally, it also implies that less variability in the housing demand shock is needed to generate aggregate dynamics.

Related to the behavior of natural markups, the elasticity of natural markups with respect to house prices shows that there is an amplification of housing shocks, given that the ϕ is greater than one.

6 Model IRFs

In this section I present the results of two estimation exercises. First, I show how do the model IRFs behave relative to the empirical IRFs, particularly for the IRFs that generate the stylized facts in Section 2. That is, I test how well the model fits the data. The model is able to qualitatively replicate the stylized facts. Second, in order to understand the aggregate implications of endogenous markups, I re-compute the IRFs by imposing a restriction on the parameter that measures the elasticity of natural markups with respect to house prices; that is, I set $\phi = 0$. In other words, I shut down the effect of house prices on natural markups. This effectively renders the latter exogenous. Importantly, this model with exogenous markups is not able to replicate the stylized facts described above.

6.1 Model vs Data

I first compare the model IRFs against the empirical IRFs coming from the VAR described in Section 2. For the most part, the model is able to replicate the data qualitatively well. However, in general, the hump-shaped pattern of many of the empirical responses is not attained by the

[32] With the standard deviation of the housing demand shock being roughly one fifth of the original estimation; and that of the cost-push shock being roughly one eighth of the original value.

theoretical IRFs. In this section I present the responses of the five variables in the VAR system after a one-standard deviation orthogonal shock to each one of the variables. In particular, I present the IRFs that imply the three facts presented in Section 2. That is, the IRFs after a shock to house prices, natural markups, and real output. For completeness sake, I also show the IRFs after a shock to the nominal interest rate and the inflation rate.

House Prices Shock

Figure 5 shows the responses of the system after a shock to house prices. These IRFs are the ones that give rise to Fact 1. Namely, after a housing price shock, both inflation and markups should go up. The model is able to replicate these responses qualitatively. Although, in part because of the lack of a hump-shaped pattern in the dynamics of house prices; and in part due to the amplification of housing shocks through natural markups, the responses are not exactly the same. In particular, the initial response of natural markups in the model is higher, which in turn causes an increase in inflation. As house prices decrease, natural markups fall rapidly, which also cause inflation to fall rapidly. In terms of the dynamics of the model, the increase in house prices relaxes the collateral constraints of entrepreneurs and raises the marginal product of housing (MPH), which in turns allows them to increase investment, capital, and output. The central bank raises interest rates briefly to counter the surge in inflation, however as house prices fall, so do markups and inflation as a consequence.

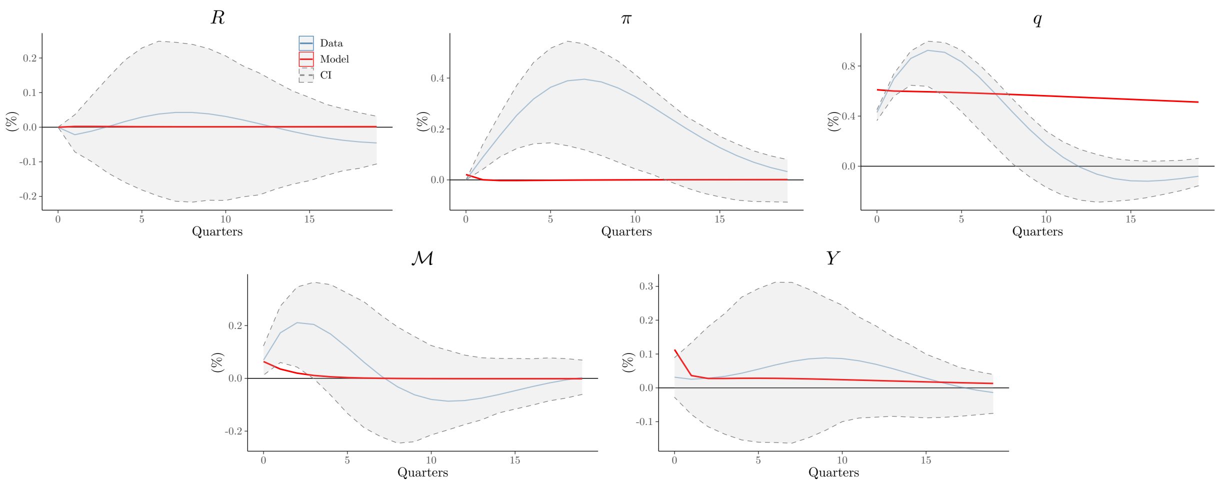
Natural Markups Shock

Fact 2 follows from the IRFs after a natural markups shock. In that sense, Figure 6 compares the empirical and the model IRFs. After a natural markups shock output falls in both the data and the model, albeit mildly in the case of the latter. Alternatively, due to the increase in interest rates, house prices fall in the model, while the data suggests a mild increase at the beginning. In this case, the model is not able to perfectly replicate the effect on house prices that a markup shock implies.

Output Shock

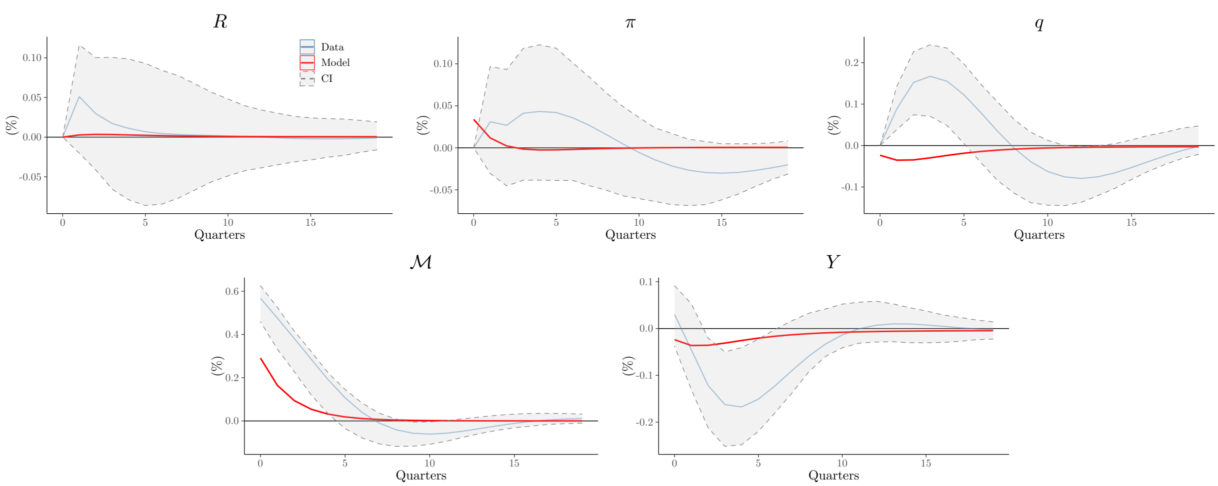
Fact 3 arises after an orthogonal shock to output. This is shown in Figure 7, for both the model and the empirical VAR. After a positive TFP shock, the marginal product of all inputs increases,

Figure 5: House Prices Shock.



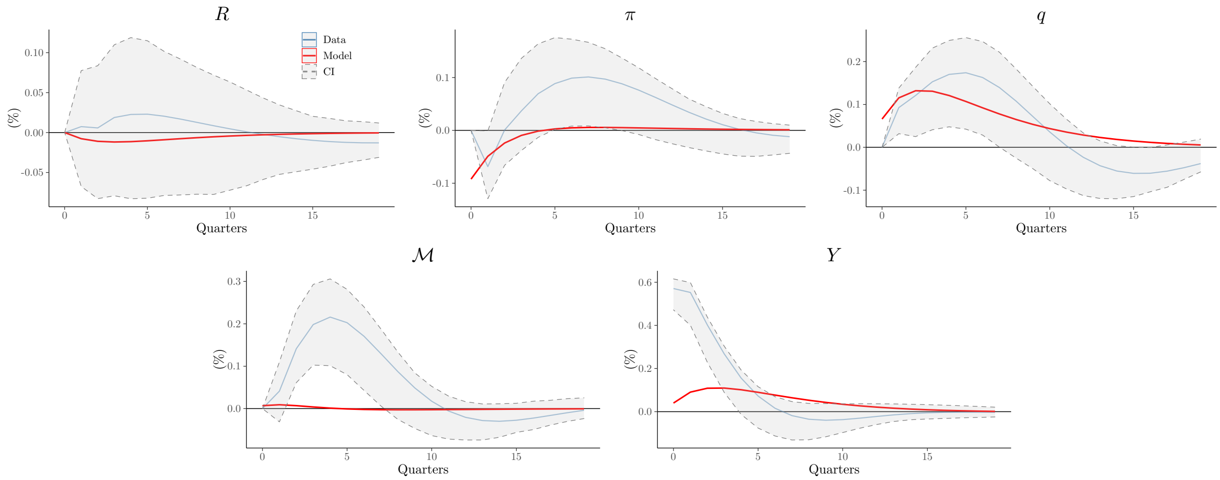
The figure shows the responses of the five variables in the VAR after a housing price (q) shock. That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to house prices. The graphs show both the model IRFs (in red) and the empirical IRFs (in blue), with their respective confidence bands (shaded).

Figure 6: Natural Markups Shock.



The figure shows the responses of the five variables in the VAR after a natural markups ($\mathcal{M}$) shock. That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to natural markups. The graphs show both the model IRFs (in red) and the empirical IRFs (in blue), with their respective confidence bands (shaded).

Figure 7: Output Shock.



The figure shows the responses of the five variables in the VAR after a real output (Y) shock. That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to output. The graphs show both the model IRFs (in red) and the empirical IRFs (in blue), with their respective confidence bands (shaded).

in particular that of housing. This increases the price of housing, which in turn raises house prices. The expansion of house prices causes natural markups to rise. However, this is not enough to raise the downward pressure on prices that the positive supply shock caused, therefore inflation decreases.

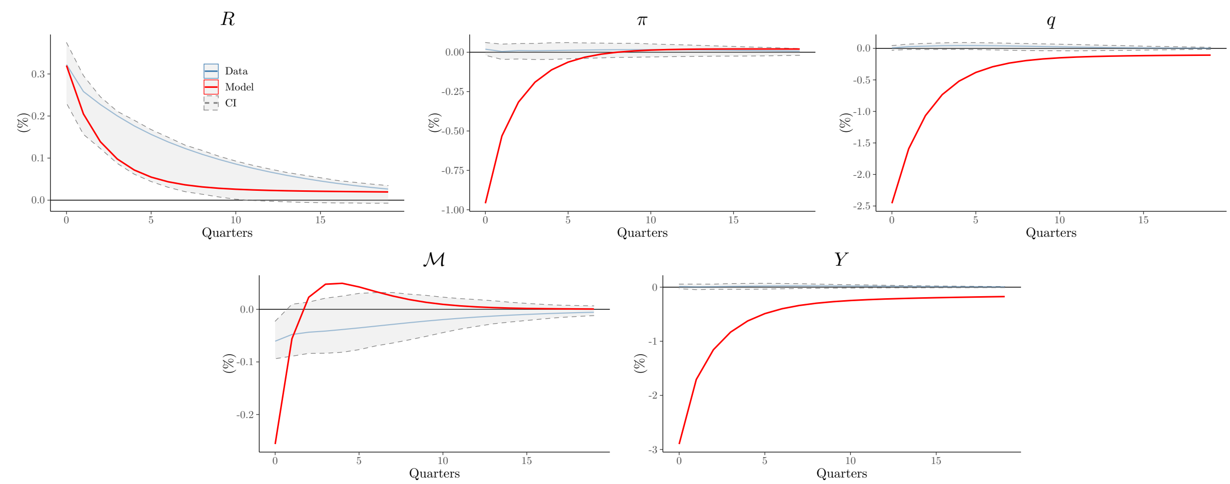
Interest Rate Shock

For the sake of completeness, I present the reaction of the model after an impulse to the nominal interest rate. That is, a monetary shock. The variables in the model behave as expected: an increase in the nominal interest rate causes real output and inflation to fall. Along with output, house prices fall, which also causes natural markups to fall, exacerbating the fall in inflation that occurs. In what concerns the empirical IRFs, none of the responses in the data are significantly different from zero. In that sense, there are no stylized facts to be extracted from them, nor do they represent a good benchmark for the model.

Inflation Shock

Figure 9 collects the responses of the variables in the VAR system after a positive inflation, or cost-push, shock. As the price for the final good increases, there is a negative income effect for impatient households, whose wage share is equal to 99%. This drives them to increase their labor supply which

Figure 8: Interest Rate Shock



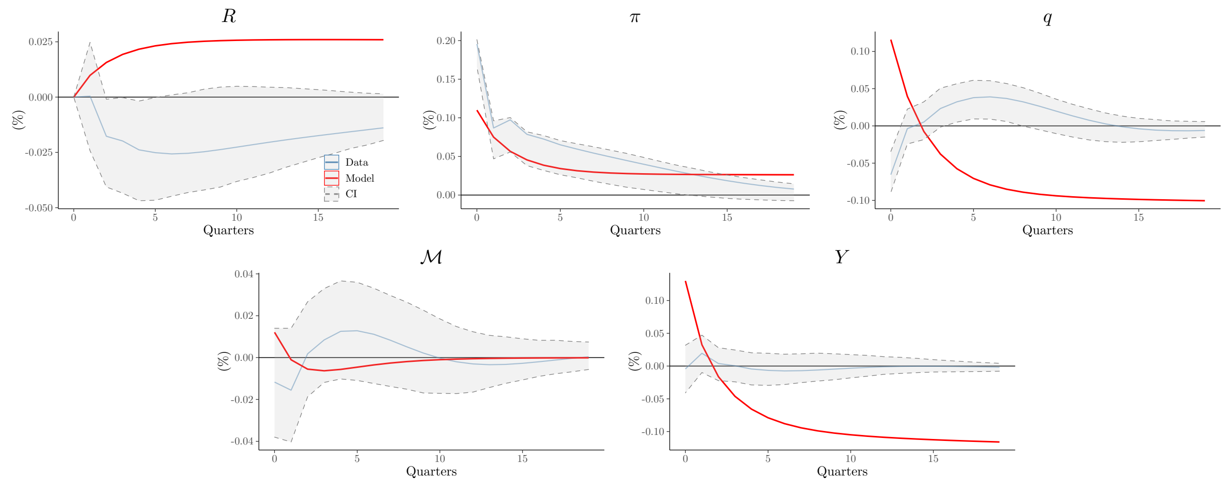
The figure shows the responses of the five variables in the VAR after a nominal interest rate shock (R) shock. That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to the nominal interest rate. The graphs show both the model IRFs (in red) and the empirical IRFs (in blue), with their respective confidence bands (shaded).

also leads to an increase in the demand for commercial real-estate and to higher output and house prices at first. The increase in house prices causes an expansion of natural markups. However, as the Central Bank reacts to the increase in inflation and output by raising the nominal interest rate, output and house prices fall, thereby bringing natural markups down. Similar to the case of an interest rate shock, the data does not show a significant response from the rest of the variables of the model, except for a small and short-lived decrease in house prices upon impact. Therefore, no stylized facts can be obtained from the data, nor can the model be properly evaluated against the data.

6.2 Importance of Endogenous Markups

In order to understand the precise effect of endogenous natural markups that react to the evolution of house prices, I force the elasticity of natural markups with respect to prices equal to be equal to zero (i.e. $\phi = 0$ in Eq. (A15)). This implies that natural markups are effectively exogenous. None of the three empirical facts documented in the same section can be replicated under this restricted model. The two models behave similarly, except after a house prices shock. This suggests that the direct effect of natural markups reacting to house prices remains limited. A possible explanation for this result is the fact that the effect of natural markups on inflation depends on the value of the

Figure 9: Inflation Shock.



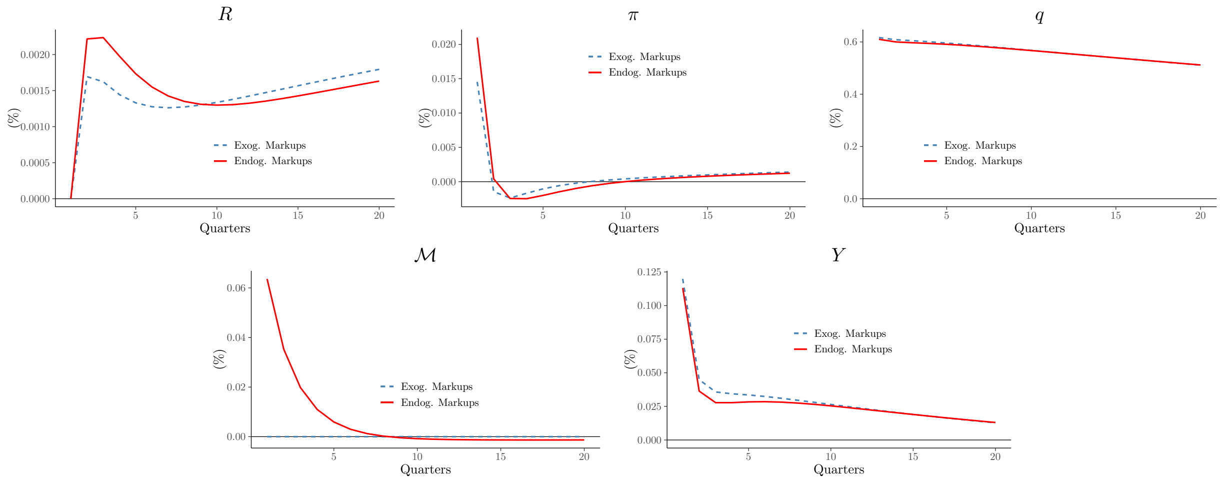
The figure shows the responses of the five variables in the VAR after an inflation shock (π) shock. That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to inflation. The graphs show both the model IRFs (in red) and the empirical IRFs (in blue), with their respective confidence bands (shaded).

parameter $\kappa \equiv \frac{(1-\theta)(1-\theta\beta)}{\theta}$, where θ is the fraction of firms that cannot change their prices. The higher θ is, the more rigid prices will be and the lower the effect of natural markups on inflation dynamics.

House Prices Shock

Fact 1 states that after a housing price shock, both markups and inflation should increase. Figure 10 collects the responses of the system after a housing price shock in both the unrestricted model, with endogenous markups, and the restricted model, with exogenous markups. By construction, the restricted model is not able to replicate the increase in natural markups that occurs after a positive housing price shock. However, the restricted model also implies a different response from inflation and monetary policy. In particular, the increase in the price of housing allows entrepreneurs to relax their collateral constraints and produce more, which lowers prices. The Central Bank reacts to this decrease by raising interest rates less abruptly, relative to the unrestricted model. However, as house prices return to their steady state value, natural markups in the unrestricted model fall, causing inflation to drop more rapidly and leading the Central Bank to decrease the interest rate more abruptly.

Figure 10: Comparison between models – House Prices Shock.



The figure shows the responses of the five variables in the VAR after a shock in house prices (q). That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to house prices in both models. The graphs show the responses from the unrestricted model with endogenous markups (in red) and the responses from the restricted model with exogenous markups (in blue and dashed).

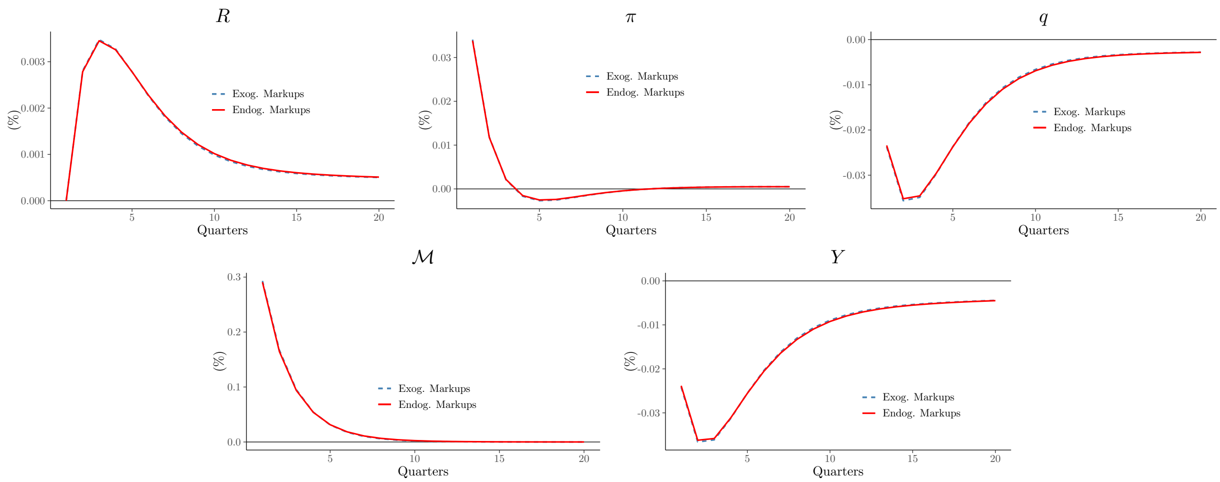
Markups Shock

A natural markup shock should induce a decrease in output and a slight increase in house prices, according to Fact 2. Neither model is able to replicate the increase in house prices that occurs after the natural markups shock. The responses of house prices, output, inflation, and interest rates is quite similar. The only difference is a slight dampening of the shocks upon impact, and a small increase in their persistence in the unrestricted model. The IRFs are shown in Figure 11.

Output Shock

Fact 3 suggests that after a positive output shock, both house prices and natural markups should increase. The responses from both models after an output shock are shown in Figure 4. After a positive TFP shock, house prices rise in both models. This is due to the fact that a higher level of TFP increases the marginal product of housing, which causes the same effect on its price. However, the model with exogenous markups is not able to replicate the increase in natural markups that occurs as a consequence of the expansion of house prices. Additionally, the positive supply shock puts downward pressure on prices in both models. However, the initial increase in house prices, and the corresponding rise in natural markups, partially offsets this decrease in prices in the model

Figure 11: Comparison between models – Markups shock.



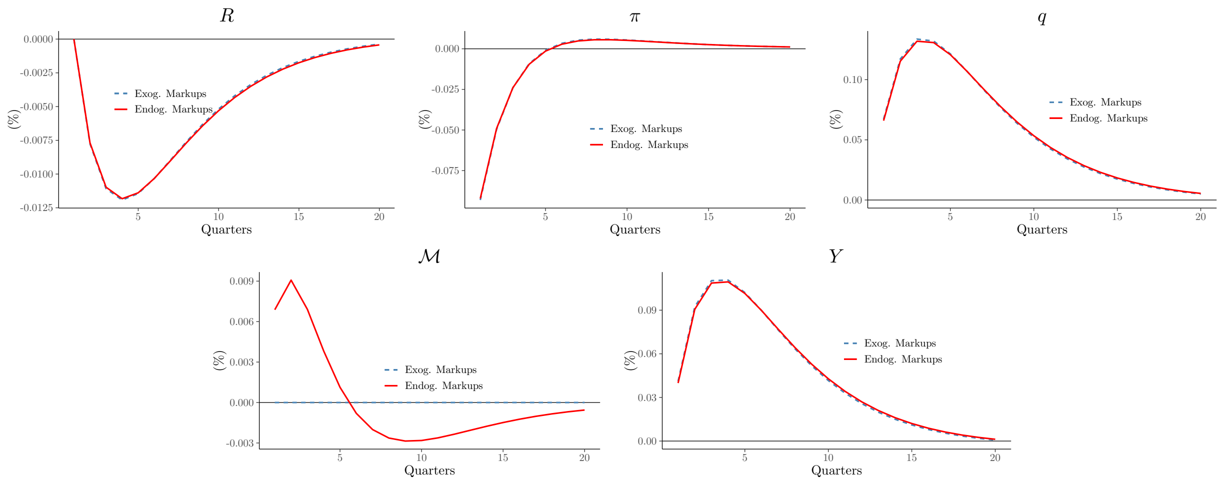
The figure shows the responses of the five variables in the VAR after a shock in natural markups ($\mathcal{M}$). That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to natural markups in both models. The graphs show the responses from the unrestricted model with endogenous markups (in red) and the responses from the restricted model with exogenous markups (in blue and dashed).

with endogenous markups. This means the Central Bank cuts interest rates more aggressively in the model with exogenous markups. However, as house prices return to their steady state values, markups decrease in the unrestricted model, which in turn decelerates inflation and allows for a milder increase in interest rates as the economy transitions back to its steady state. Despite this, the difference between models is essentially negligible.

Interest Rate Shock

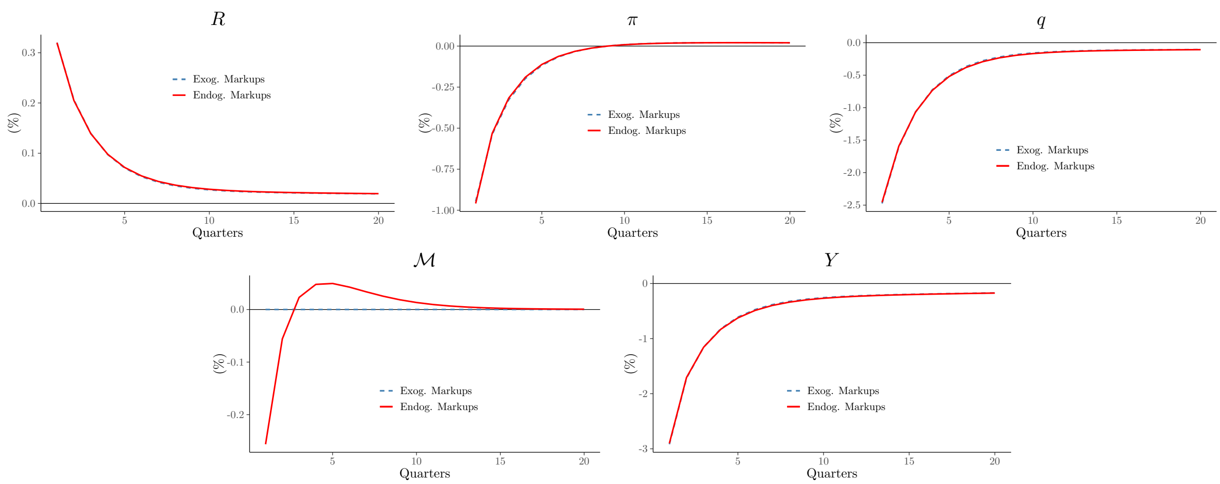
After a monetary shock, both models react in a similar fashion. The expansion of interest rates causes a contraction of aggregate prices, output, and house prices. The fall in house prices causes a contraction of natural markups in the unrestricted model, which amplifies the initial fall in inflation. However, as house prices transition back to their steady state value, natural markups increase and accelerate inflation. This forces the Central Bank to keep interest rates higher in the model with endogenous markups, which in turn causes a slower recovery. This can be seen in Figure 13. Once again, the differences between models do not seem to be economically significant.

Figure 12: Comparison between models – Output Shock.



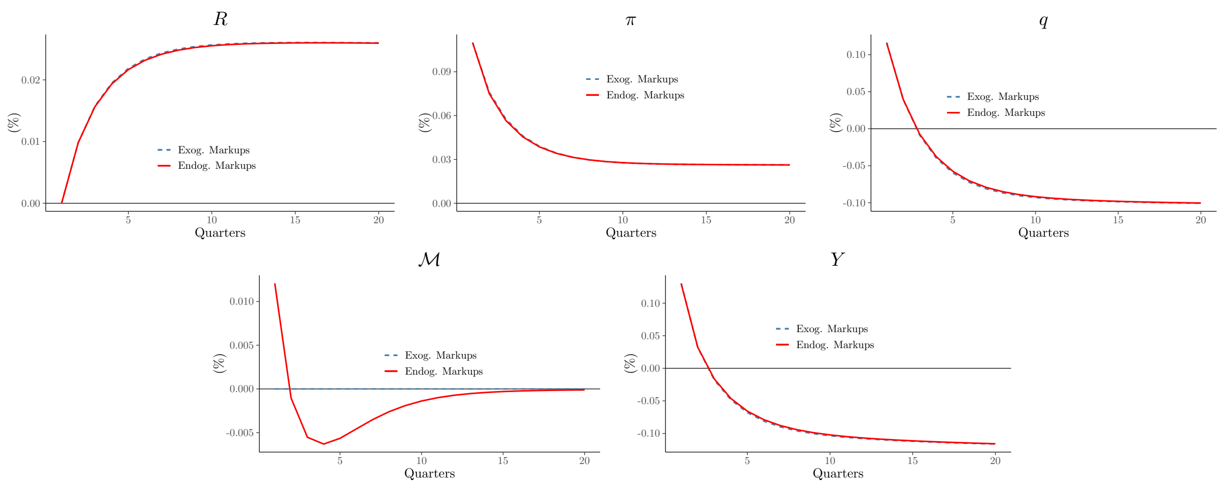
The figure shows the responses of the five variables in the VAR after a shock to real output (Y). That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to real output in both models. The graphs show the responses from the unrestricted model with endogenous markups (in red) and the responses from the restricted model with exogenous markups (in blue and dashed).

Figure 13: Comparison between models – Interest Rate Shock.



The figure shows the responses of the five variables in the VAR after a shock to the nominal interest rate(R). That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to the nominal interest rate in both models. The graphs show the responses from the unrestricted model with endogenous markups (in red) and the responses from the restricted model with exogenous markups (in blue and dashed).

Figure 14: Comparison between models – Inflation Shock.



The figure shows the responses of the five variables in the VAR after a shock to the nominal interest rate(π). That is, the figure collects the responses of the nominal interest rate (R); the inflation rate (π); house prices (q); natural markups ($\mathcal{M}$); and output (Y), after a one-standard deviation orthogonal shock to inflation in both models. The graphs show the responses from the unrestricted model with endogenous markups (in red) and the responses from the restricted model with exogenous markups (in blue and dashed).

Inflation Shock

The differences between the model with endogenous markups and the model with exogenous markups after a inflation shock are once again not economically significant. The increase in inflation triggers a monetary response from the Central Bank which depresses house prices and output. In the model with endogenous markups, this triggers a decrease in aggregate markups which causes inflation to decrease more rapidly. This allows for the interest rate to decrease more quickly. As house prices return to their steady state level, markups increase once again and accelerate inflation, which induces the central bank to maintain a higher level for interest rates. However, given that the effect of natural markups on inflation is dampened by the value of the parameter κ in the Phillips curve (i.e. Eq. (A10)), the difference between both models is not economically significant. The IRFs for both models after an inflation shock are shown in Figure 14.

7 Optimal Monetary Policy

7.1 Should the Central Bank react to asset prices?

This section analyzes the optimal policy of the Central Bank. That is, the Central Bank minimizes the loss function:

$$\omega_y \sigma_y^2 + (1 - \omega_y)\sigma_\pi^2 \tag{25}$$

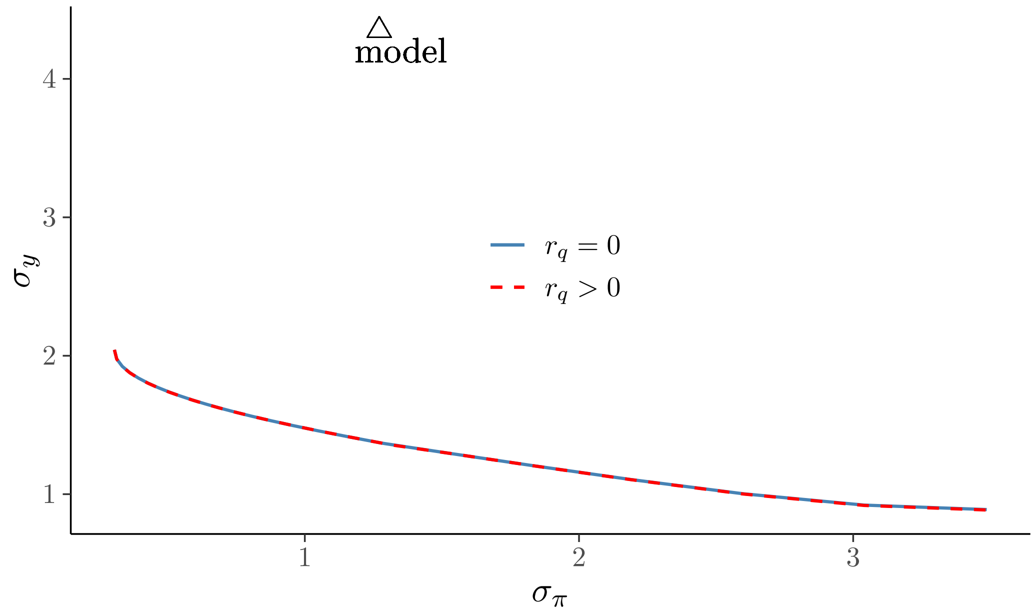
Where $\omega_y \in [0, 1]$ represents the weight that the Central Bank gives to the variance of output; $(1 - \omega_y)$ is the weight that it gives to the variance of inflation; and σ_y^2 and σ_π^2 are the variance of output and inflation, respectively.

For this analysis, I follow Iacoviello (2005), who in turn is based on Levin, Wieland, and Williams (1999). The idea is to vary the weight ω_y between $[0, 1]$ keeping the Taylor weight on the interest rate (i.e. r_R) constant at its estimated value according to the Taylor regression from Section 5, and varying the weights on inflation and output, r_π and r_Y, so as to minimize the loss function (25). Once the optimal value for these parameters is found, the standard deviation of output and inflation, σ_y and σ_π can be computed and represented in a curve that describes the set of efficient combinations for both volatilities. This curve is called the *efficient frontier*, and its downward sloping nature reflects the trade off that the Central Bank faces in trying to reduce the volatility of output and inflation.

Figure 15 shows the efficient frontiers for a model in which the weight that the Central Bank gives to asset prices is fixed at zero (i.e. $r_q = 0$) and one in which the Central Bank gives a positive weight to them (i.e. $r_q > 0$). In the latter case, this weight on house prices r_q is chosen optimally, as are r_Y and r_π. The Taylor weight on house prices rises non-monotonically with the weight given to output in the loss function, ω_y; and it oscillates between 0 and 0.118.

As can be seen in Figure 15, the difference between the two frontiers is negligible. Since each frontier shows the locus of efficient combinations of inflation and output volatilities, this suggests that the Central Bank does not gain much by reacting to asset prices. This is in line with the results of Iacoviello (2005), and those of Bernanke and Gertler (2001) and Gilchrist and Leahy (2002), who also find that there is no evidence that the Central Bank should react to asset prices.

Figure 15: Efficient Frontiers



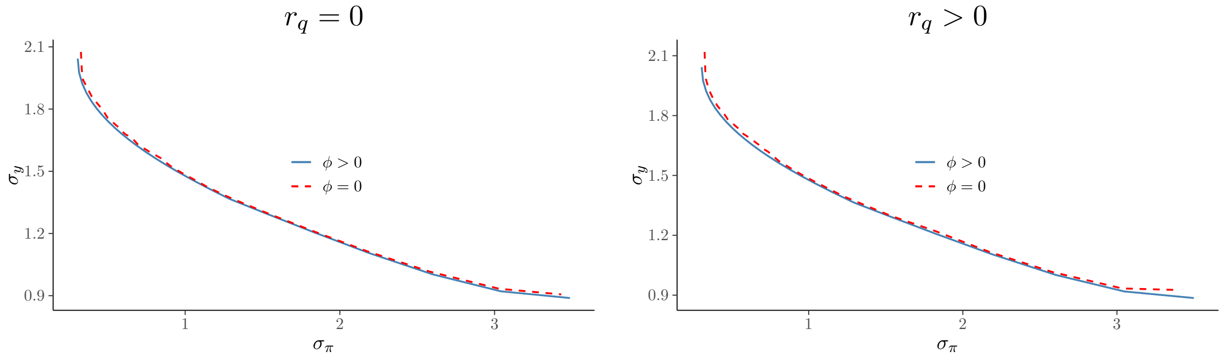
The figure shows the two efficient frontiers for a model in which the Central Bank does not react to asset prices (i.e. $r_q = 0$ in the Taylor rule), shown in blue and with a solid line; and for a model in which the Central Bank does react to asset prices (i.e. $r_q > 0$ in the Taylor rule), shown in red and with a dashed line. The downward sloping line represents the trade off that exists between output and inflation volatility. The vertical axis measures the standard deviation of output, while the horizontal axis measures the standard deviation of inflation. The two lines exhibit the locus of optimally achievable pairs of inflation and output volatility by varying the Taylor weights for output and inflation in Eq. (A14) (i.e. by varying r_y and r_p). The triangular marker shows the volatility of inflation and output achieved in the baseline model by using the Taylor weights emerging from the regression in Section 5.

Additionally, Figure 15 also shows that the Taylor weights emerging from the regression described in Section 5 are not optimal. As the marker shows, this choice of parameter values yields a sub-optimal combination of output and inflation volatility.

7.2 What happens if the Central Bank has the "wrong" model?

For this exercise, I test what is the effect of the Central Bank believing natural markups are exogenous (i.e. $\phi = 0$), when in reality they are endogenous and react to house prices (i.e. $\phi > 0$, as in this paper). I therefore compute two additional sets of efficient frontiers: one in which the Central Bank does not react to house prices (i.e. $r_q = 0$); and one in which it does react to house prices (i.e. $r_q > 0$). In both cases, I assume that the Central Bank chooses the optimal value of the Taylor weights for inflation and output as if *phi* were equal to zero. Essentially, I investigate what are the effects of the Central Bank having the "wrong" model of reality and reacting to inflation and

Figure 16: Efficient Frontiers and Central Bank Misperception



The left panel shows a comparison between the optimal frontier when markups are endogenous ($\phi > 0$), against the frontier achieved by using the Taylor weights corresponding to a model in which markups are exogenous ($\phi = 0$), while not allowing the Central Bank to react to house prices ($r_q = 0$). The right panel repeats this exercise, but sets $r_q > 0$. In other words, the right panel shows the differences when the Central Bank is allowed to react to house prices ($r_q > 0$).

output without taking into consideration the effect that house prices have on inflation and output.

The results of this exercise are shown in Figure 16. The left panel shows the difference between the efficient frontier for the *true* model, and the frontier achieved when using the optimal values for the Taylor weights, when the Central Bank uses the model with exogenous markups. The Taylor weight on house prices is fixed at zero ($r_q = 0$), effectively preventing the Central Bank from reacting to house prices. The right panel shows again the difference between the efficient frontier with endogenous markups and the frontier achieved when using the values for the Taylor weights that emerge from a model with exogenous markups, but in this case I allow the Central Bank to also react to house prices.

Naturally, using the values for the Taylor weights that correspond to a model with exogenous markups ($\phi = 0$) leads to a sub-optimal response from the Central Bank. But as Figure 16 shows, the difference between the optimal frontier and the "erroneous" frontier is negligible. This suggests that the Central Bank does not have much to gain by effectively reacting to endogenous markups. It can nearly achieve the optimal combination of inflation and output volatility, even if it has the "*wrong*" model of the world by simply reacting to the inflation and output gaps.

8 Final Remarks

Stroebel and Vavra (2019) find that there is a positive relationship from local house prices into local retail prices. After exploring different possibilities, they conclude that this is due to an increase in the markups that they charge to the final customer. This behavior is consistent with house prices causing a decrease in the demand elasticity of households through a *wealth effect*, or a *relaxation of collateral constraints*, which should increase natural markups; where natural markups refer to the ratio of demand elasticity to demand elasticity minus one.

Given the possible aggregate implications of this relationship, I first investigate whether or not this relationship between house prices and natural markups holds at the aggregate level. To this purpose, I use the results of Lara Hinojos (2020), where I estimate a vector autoregression (VAR) system that includes the nominal interest rate, the inflation rate, real house prices, aggregate markups, and real output. The Impulse Response Functions (IRFs) of this system suggest that the relationship found in Stroebel and Vavra (2019) holds at the aggregate level as well. That is, after a positive housing price shock, both aggregate markups and inflation increase. From this exercise, I also extract other stylized facts. In particular, I find that after an aggregate markup shock, output decreases while house prices increase; and that after an output shock, house prices and markups increase.

In order to rationalize these results and to test the aggregate implications of this relationship between house prices and natural markups I extend the New Keynesian model of Iacoviello (2005), which features a housing sector. In the model, housing can be used as a factor of production, provides utility for households, and can be used as collateral. I include the relationship between house prices and natural markups of Stroebel and Vavra (2019), which effectively endogeneizes natural markups, by including a term that depends on the evolution of house prices into the law of motion of aggregate markups. The sensibility of aggregate markups with respect to house prices is then governed by an elasticity parameter whose value is chosen so as to replicate the empirical results. That is, I discipline the elasticity parameter, and other parameters in the model, by choosing the values that minimize the distance between the empirical IRFs and the model-implied IRFs.

The extended model with endogenous markups is able to qualitatively replicate the data well. In particular, it is able to capture the increase in inflation and natural markups that occurs after a housing price shock that the empirical VAR suggests. Furthermore, in order to understand the aggregate implications of this relationship, I then compute the responses from a restricted model, by holding the elasticity of markups equal to zero. In other words, a model with exogenous markups. The restricted model is unable to replicate the stylized facts described Section 2. However, the presence of endogenous markups only affects the responses of the system after a housing price shock with any economic significance. The responses from the model after each one of the remaining structural shocks are not significantly different, in the economic sense, between the model with endogenous markups and the model with exogenous markups.

An analysis of the optimal monetary policy suggests that the Central Bank does not gain much from reacting to house prices, as is common in the monetary economics literature. It also indicates that a sub-optimal policy that arises from the Central Bank believing that markups are exogenous, when in reality they are endogenous and related to house prices, is not significantly different from the optimal policy which considers endogenous markups that react to house prices.

Together, all of these results suggest that the aggregate implications of aggregate markups reacting to house prices are limited. It also suggests that the Central Bank could approximate the optimal combination of output and inflation volatility by reacting only to the inflation and output gaps, even if it thinks markups are exogenous. However, more research using larger and models with a richer structure are needed to confirm these initial results.

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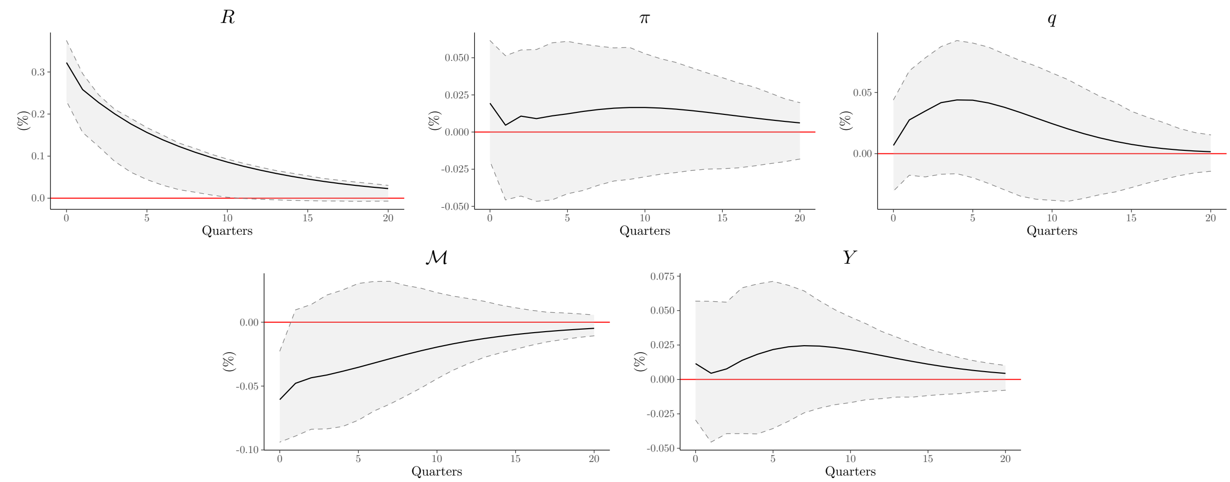
A Full IRFs

In this appendix I collect all of the IRFs emerging from the VAR described in Section 2.3. Here, the IRFs follow the ordering in the VAR. Namely, the interest rate, the inflation rate, aggregate house prices, aggregate markups, and output.

Each figure collects the responses of all the variables in the VAR after each one of the structural shocks with magnitude equal to one standard deviation.

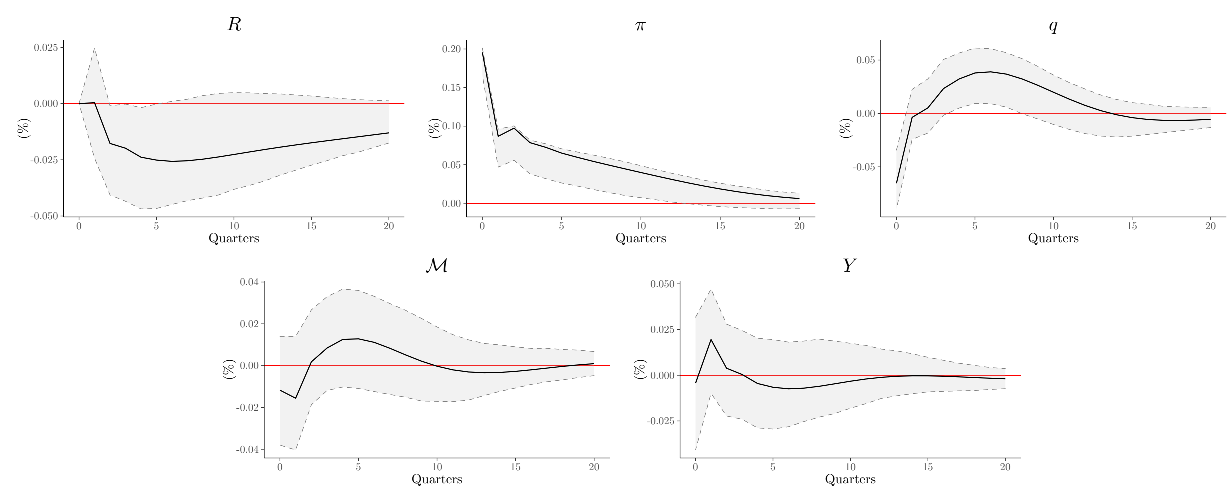
These IRFs are collected in figures Figures 17 to 21. In particular, the stylized facts described in the paper come from the IRFs depicted in Figures 19, 20, and 21. It can be seen that the stylized facts emerge from the responses that are estimated significantly.

Figure 17: Shock to the interest rate (R)



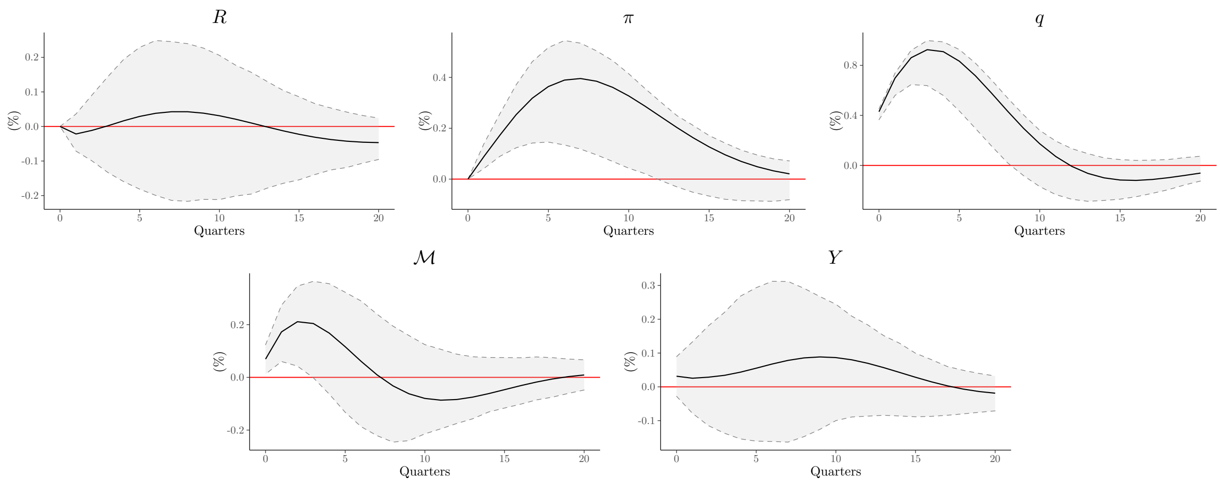
The figure shows the responses of the five variables in the VAR after a one-standard-deviation orthogonal shock to the interest rate (R). The variables in the VAR are the interest rate, R; inflation, π; house prices, q; aggregate markups, $\mathcal{M}$; and output, Y. The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.

Figure 18: Shock to the inflation rate (π)



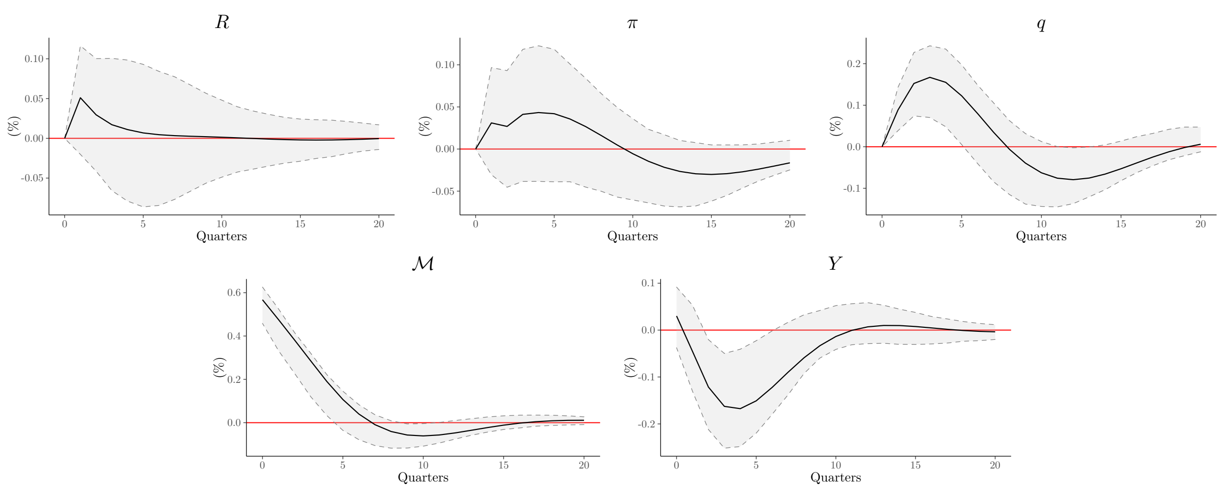
The figure shows the responses of the five variables in the VAR after a one-standard-deviation orthogonal shock to inflation (π). The variables in the VAR are the interest rate, R; inflation, π; house prices, q; aggregate markups, $\mathcal{M}$; and output, Y. The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.

Figure 19: Shock to house prices (q)



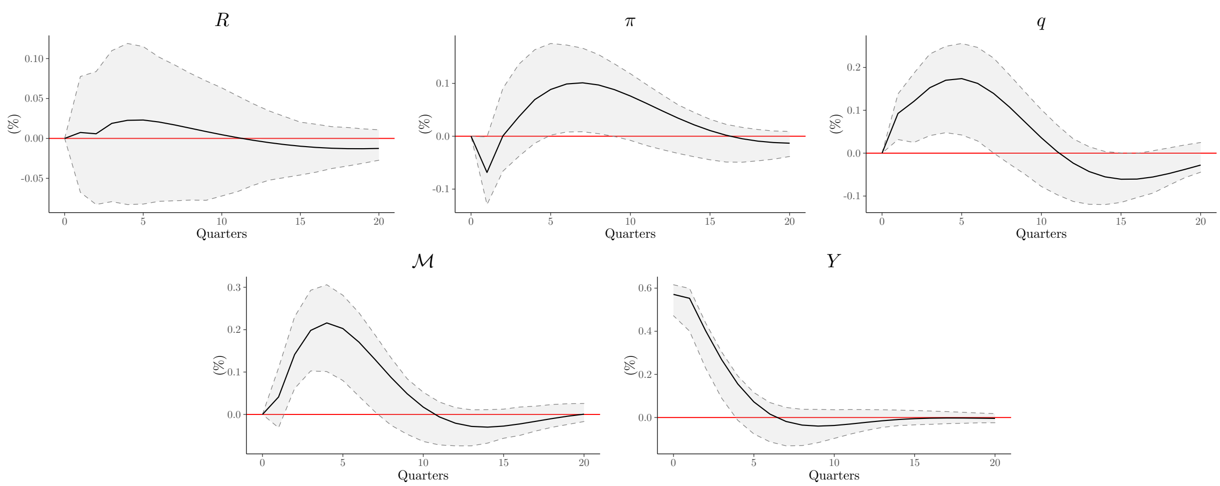
The figure shows the responses of the five variables in the VAR after a one-standard-deviation orthogonal shock to house prices (q). The variables in the VAR are the interest rate, R; inflation, π; house prices, q; aggregate markups, $\mathcal{M}$; and output, Y. The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.

Figure 20: Shock to aggregate markups ($\mathcal{M}$)



The figure shows the responses of the five variables in the VAR after a one-standard-deviation orthogonal shock to aggregate markups ($\mathcal{M}$). The variables in the VAR are the interest rate, R; inflation, π; house prices, q; aggregate markups, $\mathcal{M}$; and output, Y. The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.

Figure 21: Shock to real output (Y)



The figure shows the responses of the five variables in the VAR after a one-standard-deviation orthogonal shock to real output (Y). The variables in the VAR are the interest rate, R; inflation, π; house prices, q; aggregate markups, $\mathcal{M}$; and output, Y. The red reference line indicates a level of zero. The graphs show the estimated responses, in the solid dark line; and the 90% confidence regions, shaded in gray. A nonzero response is considered statistically significant when the shaded region lies clearly above or below the reference region. The confidence intervals are obtained by running a bootstrapping exercise with 1,000 draws.