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**Monetary Policy, Residential Investment,
and Search Frictions: An Empirical and
Theoretical Synthesis**

Kurt G. Lunsford



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Using a factor-augmented vector autoregression (FAVAR), this paper shows that residential investment contributes substantially to GDP following monetary policy shocks. Further, it shows that the number of new housing units built, not changes in the sizes of existing or new housing units, drives residential investment fluctuations. Motivated by these results, this paper develops a dynamic stochastic general equilibrium (DSGE) model where houses are built in discrete units and traded through searching and matching. The search frictions transmit shocks to housing construction, making them central to producing fluctuations in residential investment. The interest rate spread between mortgages and risk-free bonds also transmits monetary policy to the housing market. Following monetary shocks, the DSGE model matches the FAVAR's positive co-movement between nondurable consumption and residential construction spending. In addition, the FAVAR shows that the mortgage spread falls following an expansionary monetary shock, providing empirical support for the DSGE model's monetary transmission mechanism.

Keywords: Factor-augmented vector autoregression, interest rate spread, monetary policy, residential investment, search theory.

JEL Codes: C32, E30, E40, E50, R31.

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1 Introduction

Residential investment is important for the transmission of monetary policy to economic activity. Empirical research has shown that it is very responsive to monetary policy shocks.¹ Further, policy-makers regularly acknowledge the importance of housing markets for transmitting monetary policy. Frederic Mishkin (2007), then a member of the Board of Governors of the Federal Reserve, noted that “the housing market is of central concern to monetary policy makers” and that “monetary policy makers must understand the role that housing plays in the monetary transmission mechanism if they are to appropriately set policy instruments.” More recently, Janet Yellen (2014) said that a goal of the Federal Reserve’s low interest rates is to “revive the housing market.”

In this paper, I make both empirical and theoretical contributions to our understanding of monetary policy and housing markets. First, to demonstrate the importance of residential investment for transmitting monetary policy, I show that the earliest and largest changes in output from monetary shocks occur in residential investment. To do this, I follow Bernanke, Boivin, and Elias (2005) and Boivin, Giannoni, and Mihov (2009) and estimate a factor-augmented vector autoregression (FAVAR) by including factors extracted from a large data set along with the federal funds rate in a vector autoregression. To identify the monetary policy shocks, I follow Stock and Watson (2012), Montiel Olea, Stock, and Watson (2012) and Mertens and Ravn (2013) by using a variable that is external from the FAVAR to proxy for the monetary policy shock, where this proxy is constructed in the spirit of Romer and Romer (2004). The impulse response functions (IRFs) from the FAVAR show that residential investment makes a larger cumulative contribution to GDP growth than durable goods, non-durable goods and services, and non-residential investment in the first 15 months following a monetary policy shock. This finding is consistent with earlier work (Bernanke and Gertler, 1995), and my use of a different data set, sample period, and identification method shows the robustness of this result. Given its robustness, this result highlights the importance of including residential investment in theoretical models of monetary policy.

Second, I provide an empirical result that has been overlooked in the macroeconomics literature, which is that essentially all of the fluctuations in residential investment are driven by the number of new housing units built, not by changes in the sizes of existing or new housing units. To do this, I first look at the contribution to residential investment growth from new structures and improvements to existing structures. I show that new structures contribute 64% of the variance in residential investment growth while improvements only contribute 1%. Next, I decompose the total square footage of new housing into the number of new housing units completed and the average square footage per new unit. I show that the number of units completed contributes 97% of the variance in the growth of new total square footage while average square feet per unit only contributes 3%. Thus, models of residential

¹Bernanke and Gertler (1995), Edge (2000), Barsky, House, and Kimball (2003), Bańbura, Giannone, and Reichlin (2010) and Luciani (2015) all show the responsiveness of housing construction variables to monetary policy shocks.

investment should focus on the number of housing units being built, the extensive margin, and not on the size of the units, the intensive margin.

Motivated by these empirical results, the theoretical contribution of this paper is to develop a new Keynesian dynamic stochastic general equilibrium (DSGE) model where residential investment occurs along the extensive margin. In the model, houses are built in discrete units of one size, and households get utility from occupying one housing unit at a time. The decision for households is not how much housing stock to accumulate; it is whether to rent or own the housing unit they occupy. When a household decides to buy a house, it does so through a time-consuming search process. After matching with a house, the household buys it with a long-term mortgage that is subject to administrative costs borne by a financial intermediary.

This DSGE model deviates from the common approach to modeling residential investment, which is to treat it similarly to neoclassical capital accumulation and have households scale up or down their individual housing stocks in response to economic shocks.² As a result of this deviation, the model shows that search frictions are central to generating fluctuations in residential investment. Without search frictions, monetary, preference and productivity shocks will not cause the number of housing units under construction to deviate from its steady-state. This result is consistent with the previous literature,³ and the intuition for it is as follows. As matching efficiency decreases (as average search times increase), houses act less like substitutes with each other because they are less likely to match with each other's potential buyers. This causes the marginal value of new housing to be less responsive to the number of new houses built, and larger fluctuations in new housing units are needed to equate the marginal value of new houses to the marginal cost of building a new house.

A second result of the DSGE model is that monetary policy is transmitted to the housing sector by mortgages. In the model, the administrative costs of mortgages generate an interest rate spread between mortgage rates and long-term risk-free rates. Following an expansionary monetary shock, this interest spread falls, making it relatively cheap to finance a house and increasing the total surplus of a housing match. This incentivizes more households to begin searching to buy a house and spurs the construction of new houses. It is important to note that mortgage rates do not impact existing homeowners. Rather, they impact the households that are on the margin between wanting to rent and wanting to own, and it is this set of households that influence the demand side of the housing market.

A third result of the DSGE model is that residential investment and the production of non-durable goods co-move positively following a monetary policy shock. Hence, it does not suffer from the counterfactual features of new Keynesian models described in Barsky, House,

²Davis and Heathcote (2005) provide the standard real business cycle model with residential investment and Carlstrom and Fuerst (2010) and Iacoviello and Neri (2010) provide new Keynesian models. The Federal Reserve Board's DSGE model also includes residential investment that is treated in a manner parallel to capital investment, and Edge, Kiley, and Laforte (2007) provide details.

³Both Head, Lloyd-Ellis, and Sun (2014) and Hedlund (2015) have found that search frictions in the housing sector amplify the response of housing construction to economics shocks.

and Kimball (2007). They show that when flexibly-priced durable goods, such as houses, are added to an otherwise standard new Keynesian model, the model predicts that durable goods production should fall in response to an expansionary monetary policy shock while non-durable production rises. The intuition for this response is that the relative price of durable to non-durable goods rises following an expansionary shock, and because households do not need to purchase new durable goods every period, they can substitute their purchases of durable goods to the future when they will be relatively cheaper. My model's ability to overcome this counterfactual feature of new Keynesian models is a result of not treating housing similarly to neoclassical capital accumulation. Individual households do not adjust their stock of housing based on the relative price of new housing and non-durable goods. Rather, because households choose between staying in rental housing and searching for a house to buy, a cut in interest rates incentivizes more households to search for a house to buy by increasing the value of a housing match. In earlier work, Carlstrom and Fuerst (2010) and Iacoviello and Neri (2010) show that sticky wages can also overcome the Barsky, House, and Kimball (2007) result. Thus, my model provides an additional mechanism to help new Keynesian models match the empirical features of housing markets.

I developed the DSGE model so that it can be solved with linearization methods that are common in the new Keynesian literature. In order to maintain this tractability, the DSGE model has several stylized features. For example, it has linear dis-utility of labor and no defaults on mortgages. However, it still yields quantitative and qualitative predictions about the behavior of housing market variables. To check the DSGE model's predictions following monetary policy shocks, I calibrate it and then compare its theoretical IRFs to empirical IRFs from the FAVAR. First, the DSGE model is able to replicate the FAVAR's large and hump-shaped responses in residential construction spending and in the number of new houses under construction. Second, IRFs from the FAVAR show that the interest rate spread between 30-year mortgages and 10-year treasury bonds falls following an expansionary monetary policy shock, which is consistent with the transmission mechanism in the DSGE model. Third, the FAVAR shows that an expansionary monetary policy shock generates an increase in the perception that it is a good time to buy a house, an increase in how quickly houses are sold, and an increase in the homeownership rate. The IRFs from the DSGE model are consistent with all of these responses. Further, the last two responses cannot be explained by models of neoclassical housing accumulation as there is no concept of time on the market or a homeownership rate in those models.

This paper follows a long and active literature that uses search and matching models to study housing markets. This literature includes, but is not limited to, Stull (1978), Yinger (1981), Wheaton (1990), Williams (1995), Krainer (2001), Albrecht et al. (2007), Novy-Marx (2009), Caplin and Leahy (2011), Díaz and Jerez (2013), Ngai and Tenreyro (2014), Albrecht, Gautier, and Vroman (2015) and Ungerer (2015). To my knowledge, Ungerer (2015) is the only one of these papers to include search and matching in the housing market of a new Keynesian model. However, all of these papers, including Ungerer (2015), have a constant or exogenous housing stock with no role for residential investment. Head and Lloyd-Ellis

(2012), Karahan and Rhee (2013), Head, Lloyd-Ellis, and Sun (2014) and Hedlund (2015) provide a small, recent literature that includes both housing search and endogenous housing construction. However, all of these papers are real business cycle models, and none of them study monetary policy. The model presented in this paper is the first to include housing search, endogenous residential investment and monetary policy.

The rest of the paper proceeds as follows. Section 2 describes the FAVAR in detail and discusses the empirical contributions of the paper. Section 3 describes the DSGE model, and Section 4 discusses its equilibria and the importance of search frictions. Section 5 presents numerical results from the DSGE model, and Section 6 concludes.

2 Empirical Analysis

In this section, I discuss this paper’s empirical contributions. In Subsection 2.1, I lay out the FAVAR in detail. Then in Subsection 2.2, I use the FAVAR to show that the earliest and sharpest changes in output from a monetary policy shock occur in residential investment. Finally, I show that that essentially all of the fluctuations in residential investment are driven by the number of new housing units built in Subsection 2.3

2.1 The Factor-Augmented Vector Autoregression

The FAVAR follows Bernanke, Boivin, and Eliasziw (2005) and Boivin, Giannoni, and Mihov (2009). First, I assume that a large number, n , of time series characterize the economy. After removing the mean of these time series and normalizing their standard deviation to one, I denote them with the $n \times 1$ vector x_t . x_t follows

$$x_t = \Lambda \begin{bmatrix} r_t \\ f_t \end{bmatrix} + e_t, \quad (1)$$

where r_t is a univariate policy interest rate, f_t is a $k - 1 \times 1$ vector of unobserved macroeconomic factors, Λ is a $n \times k$ matrix of factor loadings, and k is much smaller than n . Next, the evolution of $[r_t, f_t']'$ follows the vector autoregression (VAR)

$$\begin{bmatrix} r_t \\ f_t \end{bmatrix} = \Gamma_0 + \Gamma_1 \begin{bmatrix} r_{t-1} \\ f_{t-1} \end{bmatrix} + \dots + \Gamma_p \begin{bmatrix} r_{t-p} \\ f_{t-p} \end{bmatrix} + u_t, \quad (2)$$

where $\Gamma_0, \Gamma_1, \dots, \Gamma_p$ are the VAR coefficients and u_t is the VAR innovation. To study the monetary policy shocks in the economy, I assume that

$$u_t = \Theta v_t, \quad (3)$$

where v_t is a $k \times 1$ vector of structural shocks and Θ is an invertible $k \times k$ matrix. Without loss of generality, I partition v_t into $[v_{1,t}, v'_{2,t}]'$, where $v_{1,t}$ is the scalar monetary policy shock

and $v_{2,t}$ is the $k - 1 \times 1$ vector of other structural shocks. The corresponding partition of Θ is $[\Theta_1, \Theta_2]$, where the estimate of Θ_1 identifies the effects of monetary policy shocks.

To estimate Equation (1), I first partition Λ into $[\Lambda_r, \Lambda_f]$, where Λ_r is the $n \times 1$ vector of loadings on r_t and Λ_f is the $n \times k - 1$ matrix of loadings on f_t . Next, using T to denote the sample size, I define the matrices $X = [x_1, \dots, x_T]'$, $R = [r_1, \dots, r_T]'$ and $F = [f_1, \dots, f_T]'$, which are $T \times n$, $T \times 1$ and $T \times k - 1$, respectively. Then, I follow Boivin, Giannoni, and Mihov (2009) and treat r_t as a macroeconomic factor that is orthogonal to f_t . Because of this orthogonality, Λ_r can be estimated with $\hat{\Lambda}_r = X'R(R'R)^{-1}$. Then, $\hat{\Lambda}_f$ is \sqrt{n} times the eigenvectors that correspond to the $k - 1$ largest eigenvalues of the matrix $(X - R\hat{\Lambda}_r)'(X - R\hat{\Lambda}_r)$. Finally, $\hat{F} = (X - R\hat{\Lambda}_r)\hat{\Lambda}_f/n$. By starting with the assumption that r_t and f_t are orthogonal, these estimators produce the same results as the procedure in Boivin, Giannoni, and Mihov (2009) without needing to use their iterative algorithm.

To estimate Equation (2), I plug \hat{F} in for F and estimate the VAR coefficients by least squares. To identify the monetary policy shock, I follow Stock and Watson (2012), Montiel Olea, Stock, and Watson (2012) and Mertens and Ravn (2013) by using a proxy variable that is external from any of the variables in Equations (1) and (2). I denote this proxy variable by z_t and assume that it is correlated with the monetary policy shock, $\mathbb{E}(v_{1,t}z_t) \neq 0$, and uncorrelated with the other structural shocks, $\mathbb{E}(v_{2,t}z_t) = 0$. These assumptions provide enough moments in the data to identify the monetary policy shocks, and I use the estimator in Lunsford (2015) to estimate Θ_1 .

This FAVAR has two appealing features that are not available in a standard low-dimension VAR. First, as discussed in Stock and Watson (2002), quarterly data can be merged with monthly data through an expectation-maximization (EM) algorithm to produce monthly factors. This allows me to include the contributions of durable goods, non-durable goods and services, non-residential investment, and residential investment to GDP growth, which are only available at a quarterly frequency, into a monthly FAVAR. Thus, I can estimate how much each of these sectors contributes to GDP growth following a monetary policy shock while using my monthly identification strategy discussed below. This also provides an alternative to Bernanke and Gertler (1995), who use interpolation to convert quarterly data to monthly data. Second, by including a large number of variables into one statistical model, I can produce a large number of IRFs. This allows me to use some of these IRFs to calibrate parameters in the DSGE model below while saving other IRFs to evaluate the predictions of the DSGE model.

The data set used to estimate Equation (1) contains a balanced panel of 231 monthly time series variables from 1984:01 to 2008:06, giving 294 observations of each series. Because the FAVAR is a linear model and the DSGE model below will be log-linearized, this sample period excludes the non-linearities created by the period where the zero lower bound constrained the federal funds rate. The variables in the sample cover capacity utilization and industrial production, personal consumption expenditures, consumer price indices, producer price indices, price indices for personal consumption expenditures, personal income and its disposition, labor market quantities, labor market prices, interest rates and interest

rate spreads, stock and bond market indices, exchange rates, monetary aggregates, consumer credit and commercial bank balance sheet aggregates, survey data, new residential construction, new residential sales, house and construction prices, and construction spending. A list of these series along with their transformations to stationarity are provided in the technical appendix.⁴ In addition to the monthly series, I include five quarterly series. The first is the homeownership rate, which I use for comparison against the DSGE model below. The other four are the contributions of durable goods, non-durable goods and services, non-residential investment, and residential investment to quarterly GDP growth. I use these series in the next subsection to study the sectoral contributions to GDP growth after a monetary policy shock. To merge these quarterly series with the monthly data, I use Stock and Watson's (2002) EM algorithm. To estimate Equations (1) and (2), I use the effective federal funds rate (FFR) as R_t , which I de-mean and normalize to a variance of one.⁵ I set $k = 7$ following Bai and Ng's (2002) second information criterion, and the VAR has 6 lags.

The proxy variable that I use follows in the spirit of Romer and Romer (2004). The idea is to use the Federal Reserve's Greenbook forecasts, which are prepared by the staff of the Board of Governors for each Federal Open Market Committee (FOMC) meeting, to purge the changes in the target FFR of the state of the economy at the time that monetary policy decisions are being made. This will leave only the portion of the change in the target FFR that is attributable to monetary policy shocks and remove the portion that is attributable to other shocks in the economy, yielding a valid proxy of monetary policy shocks. I estimate

$$\Delta \bar{r}_m = \Phi_0 + \Phi_1 \bar{r}_{b,m} + \Phi_3 w_{m,-1} + \Phi_4 w_{m,0} + \Phi_5 w_{m,1} + \Phi_6 w_{m,2} + z_m \quad (4)$$

where $\Delta \bar{r}_m$ denotes the change in the target FFR at the FOMC meeting m , $\bar{r}_{b,m}$ is the target FFR prior to meeting m , and $w_{m,i}$ is a vector of forecasts at meeting m with a forecast horizon of i quarters.⁶ That is, $w_{m,0}$ contains the forecasts for the quarter in which the FOMC meeting is held, $w_{m,1}$ contains the forecasts for the quarter following the FOMC meeting, and so on. In to order purge the changes in the target FFR of the Federal Reserve's endogenous responses to its dual mandate, I include forecasts of inflation measured by the GDP deflator and the unemployment rate in $w_{m,i}$. Given the six lags in the VAR, the VAR errors exist for 1984:07 to 2008:06. To get the proxy variable over this same sample, I estimate Equation (4) beginning with the July 1984 FOMC meeting and ending with the June 2008 meeting.

Because Greenbook forecasts are only available for FOMC meetings, which occur eight times per year and are irregularly spaced, Romer and Romer (2004) convert z_m to a monthly

⁴This appendix is available online at <https://sites.google.com/site/kurtglunford/research>.

⁵I re-scale both the federal funds rate and the variables in x_t by their standard deviations when producing the IRFs so that the IRFs are displayed in their original units.

⁶I use the target federal funds rate from the Federal Reserve Bank of St. Louis's FRED database, which is identified as DFEDTAR. Prior to 1994 when the FOMC began releasing statements with every meeting, this target rate did not necessarily change on the last day of the FOMC meeting. I attribute any changes within three days of a FOMC meeting to that particular meeting.

time series by assigning z_m to the month in which the FOMC meeting occurred and assigning a value of zero to months with no FOMC meeting. I follow this procedure and make one additional adjustment. After assigning z_m to the month of its meeting, I weight it by when the change in the target FFR occurred in the month. I do this because these changes occur at various times in each month. For example, the Fed made a 50 basis point cut on January 31, 2001 and on October 2, 2001. Because the January cut occurred at the very end of the month, it would not be able to affect economic activity during January. In contrast, it is reasonable to assume that the October cut could impact economic activity in October. I weight z_m by the days remaining in the month divided by the total days in that month. For example, I scale the October 2, 2001 meeting by $29/31 = 0.935$. For target FFR cuts that occur on the last day of the month, such as on January 31, 2001, I assign the full value of z_m to the following month.

To test for weakness of this proxy variable, I project z_t on \hat{u}_t and compute the F statistic for the null hypothesis that \hat{u}_t has zero effect on z_t . This statistic is 8.3. While this may be considered weak by the thresholds of the weak instrumental variables literature, Lunsford (2015) argues that those thresholds are not applicable when identifying a structural VAR with a proxy variable. Rather, for a VAR with 7 variables Lunsford (2015) provides a critical value of 7.7, indicating that this proxy is strong.⁷

Finally, I describe the bootstrap algorithm for estimating confidence intervals for the IRFs from the FAVAR. The algorithm begins by following the wild bootstrap procedure for factor-augmented regressions in Gonçalves and Perron (2014). First, take the estimated \hat{e}_t from Equation (1) and multiply it by an i.i.d. random variable that takes a value of -1 with probability 0.5 and a value of 1 with probability 0.5 to produce e_t^* . Second, plug e_t^* , $\hat{\Lambda}$, r_t and \hat{f}_t into Equation (1) to produce x_t^* . Third, using x_t^* and r_t , re-estimate the factors and the loadings to get Λ^* and f_t^* .⁸ Fourth, multiply the estimated \hat{u}_t from Equation (2) by an i.i.d. random variable that takes a value of -1 with probability 0.5 and a value of 1 with probability 0.5 to produce u_t^* .⁹ Fifth, plug u_t^* , r_t , \hat{f}_t , and $\hat{\Gamma}_0, \hat{\Gamma}_1, \dots, \hat{\Gamma}_p$ into Equation (5) to produce the left-hand side variables $[\tilde{r}_t, \tilde{f}_t]'$. Sixth, regress $[\tilde{r}_t, \tilde{f}_t]'$ on the collection $[r_{t-1}, f_{t-1}^*]', \dots, [r_{t-p}, f_{t-p}^*]'$ to estimate the bootstrapped values $\Gamma_0^*, \Gamma_1^*, \dots, \Gamma_p^*$ and \hat{u}_t^* . Seventh, using the same wild bootstrap shock that was used to produce u_t^* , produce z_m^* .¹⁰ Eighth, use z_m^* and Equation (4) to produce $\Delta \bar{r}_m^*$. Ninth, using $\Delta \bar{r}_m^*$ and Equation (4), estimate \hat{z}_m^* and use it to produce z_t^* . Tenth, randomly sample from $[\hat{u}_t^*, z_t^*]$ with replacement to produce \tilde{u}_t and \tilde{z}_t . Tenth, use \tilde{u}_t and \tilde{z}_t to estimate Θ_1^* . Finally, use Λ^* , $\Gamma_0^*, \Gamma_1^*, \dots, \Gamma_p^*$ and Θ_1^* to produce a bootstrapped IRF. I use 2,000 replications of this process to compute

⁷This critical value is based on a test with a level of significance of 0.05 for a proxy that gives less than a 10% bias. This significance level and amount of bias are also the convention for the weak instrumental variables literature (Stock, Wright, and Yogo, 2002).

⁸I also check that the correlations between Λ_F^* and $\hat{\Lambda}_F$ are positive to ensure that the sign of the eigenvectors have not flipped as part of the bootstrap process.

⁹The wild bootstrap shock used to produce u_t^* is independent from the one used to produce e_t^* .

¹⁰Because z_m applies to FOMC meetings, there may not be a z_m for every month that there is a wild bootstrap shock. Because of this, I apply the bootstrap shocks for the months that contain z_m .

Hall’s (1992) percentile confidence intervals. This algorithm accounts for the uncertainty in estimating the factors and loadings in Equation (1), the VAR coefficients in Equation (2), the identification of monetary policy shocks in Equation (3), and the proxy variable in Equation (4). In particular, the re-sampling of $[\hat{u}_t^*, z_t^*]$ in the tenth step accounts for the uncertainty in identifying the monetary policy shock. While the wild bootstrap can account for the uncertainty in estimating the VAR coefficients (Gonçalves and Kilian, 2004), it does not capture the uncertainty in estimating the covariance of u_t with itself (Brüggemann, Jentsch, and Trenkler, 2016) or with z_t . Thus, the wild bootstrap alone is insufficient for capturing the variance of $\hat{\Theta}_1$.

2.2 Sectoral Contributions to GDP after a Monetary Policy Shock

Figure 1 shows that the earliest and sharpest changes in output from monetary policy shocks occur in residential investment. It does so by displaying the cumulative contribution of residential investment, durable goods, non-durable goods and services, and non-residential investment to GDP growth following a monetary policy shock normalized to a 0.25% cut to the effective FFR. Because this shock generates a surprise drop in the FFR, it is expansionary and causes all four series to increase. In the first 15 months after the shock, residential investment makes the largest cumulative contribution to GDP, followed by non-durable goods and services, non-residential investment, and durable goods. Past 15 months, the cumulative contribution of residential investment plateaus while those of non-durable goods and services, durable goods, and especially non-residential investment continue to increase. While there is estimation uncertainty surrounding these point estimates (confidence intervals are not shown in Figure 1 to simplify the presentation), Figure 1 indicates that residential investment is at least as important for transmitting monetary policy shocks to GDP as the other sectors in the economy. Bernanke and Gertler (1995) also find that residential investment has the largest short-run impact on GDP following a monetary policy shock, and the different sample period, data set and identification method used here highlight the robustness of this result.

While residential investment is a volatile sector of the U.S. economy (Davis and Heathcote, 2005), the fact that it makes the largest contribution to GDP growth immediately following a monetary policy shock is somewhat surprising. This is because residential investment is a small component of GDP on average. From the beginning of 1984 to mid 2008, which corresponds to the sample used in the FAVAR, expenditures on residential investment averaged 4.8% of GDP. Over this same sample, expenditures on durable goods, non-durable goods and services, and non-residential investment averaged 8.5%, 56.6% and 12.8% of GDP, respectively. Thus, it must be the case that residential investment is much more responsive to monetary policy than the other components of GDP. The FAVAR shows that this is the case. For the 12 months after the monetary policy shock, cumulative real spending on new single family homes increases by 1.65%. The corresponding growth percents for durable goods, non-durable goods, and services are 0.61%, 0.15% and 0%, respectively.

Given the average sizes of the sectors listed in the previous paragraph, it may seem

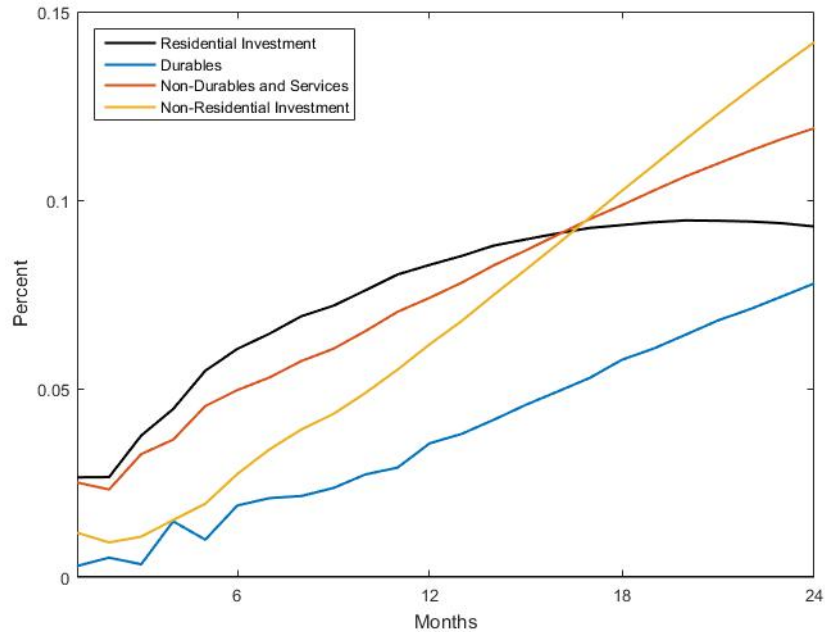


Figure 1: Cumulative contribution to GDP growth following a monetary policy shock normalized to a 0.25% cut in the effective federal funds rate.

natural to only include non-durable goods and services and non-residential investment in theoretical models of monetary policy. However, Figure 1 shows that residential investment is central for the transmission of monetary policy to GDP. Thus, it should be a focus of theoretical models of monetary policy.

2.3 Decomposition of Residential Investment Fluctuations

In this subsection, I show that that nearly all of the fluctuations in residential investment are driven by the number of new housing units built, not by changes in the sizes of existing or new housing units. I do this in two steps. First, I decompose annual residential investment growth into its contribution from new structures and improvements to existing structures. Second, I decompose the annual growth in the total square footage of new single-family housing units completed into its contributions from the number of housing units completed and the average square footage per unit.

Figure 2 displays annual residential investment growth along with the contributions of new structures and improvements to existing structures. These data are from the National Income and Product Accounts Tables 5.4.1 and 5.4.2. Figure 2 shows that new structures make a large contribution to residential investment growth while improvements do not. From 1959 to 2014, new structures contributed 64% of the variance in residential investment growth

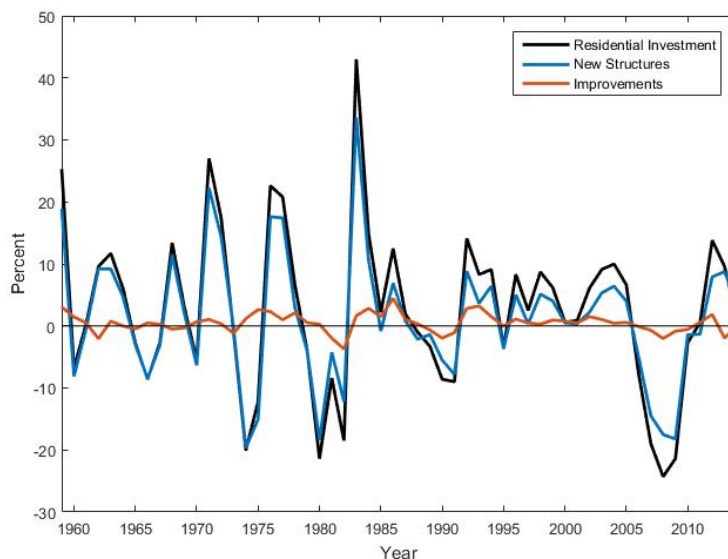


Figure 2: Percent growth in residential investment and the contribution of new structures and improvements to existing structures to residential investment growth.

while improvements only contributed 1%. This is despite the fact that improvements is a broad category defined as any additions, alterations, and major replacements to structures subsequent to their completion. This includes the construction of additional housing units in existing residential structures, finishing of basements and attics, remodeling of kitchens and bathrooms, the addition of swimming pools and garages, and major replacements such as new roofs, water heaters, furnaces, and central air conditioners that prolong the expected life of a structure or add to its value.¹¹ Thus, Figure 2 shows that fluctuations in the sizes of existing housing units contribute very little to total residential investment fluctuations. Rather, the construction of new housing drives residential investment fluctuations.

Turning to the composition of new housing units, Figure 3 displays the annual growth of total completed square footage of new single-family housing along with growth in the number of units completed and growth in average square footage per unit. This figure is based on the decomposition of total square feet completed into the number of units completed times the average square feet per unit.¹² Figure 3 shows that the number of housing units completed is responsible for essentially all of the fluctuations in total new square footage. From 1974 to 2014, growth in the number of units completed contributed 97% of the variance in the growth of new square footage. In contrast, growth in average square feet per unit contributed only

¹¹See chapter 6 of *NIPA Handbook: Concepts and Methods of the U.S. National Income and Product Accounts* at <http://www.bea.gov/methodologies/index.htm>.

¹²Data are from the Census Bureau's annual characteristics of new housing, which can be found at <http://www.census.gov/construction/chars/>.

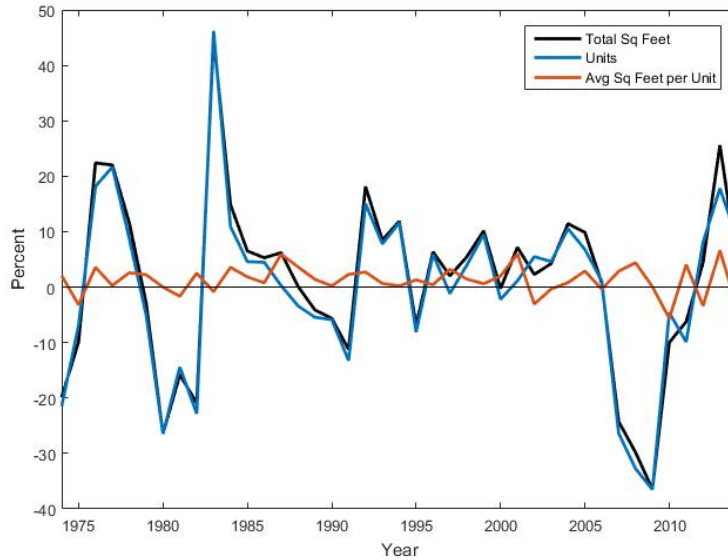


Figure 3: Percent growth in total square footage of new single-family houses completed and the contributions from the number of units and the average square footage per unit.

3% of the variance. Thus, fluctuations in the amount of new housing produced is driven by the number of new housing units and not by the size of new housing units.

Taken together, Figures 2 and 3 show that fluctuations in residential investment do not depend on fluctuations in the size housing units, the intensive margin. Rather, the number of housing units built, the extensive margin, drives fluctuations in residential investment.

3 The DSGE Model

This section develops a DSGE model that is motivated by the large contribution of residential investment following a monetary shock and by the importance of the extensive margin for residential investment fluctuations. The model uses common new Keynesian specifications for the production and consumption of non-durable goods and for monetary policy. However, it builds on Head, Lloyd-Ellis, and Sun (2014) from the housing search literature to model the production and consumption of housing. Five types of agents populate the economy:

- **Households:** There is a measure one of households, indexed by $h \in [0, 1]$. They get utility from non-durable consumption goods and dis-utility from providing labor to firms, which is the only factor of production in the economy. Further, households get utility from occupying one housing unit, which can either be owned by that household or rented.¹³ They buy housing through random bilateral matching and bargaining,

¹³Households may own many housing units but only receive utility from occupying one unit at a time.

and they pay a fraction of the purchase price by borrowing a mortgage. Households own all of the firms in the economy as well as the financial intermediary.

- **Investment firms:** There is an arbitrarily large measure of housing investment firms that use labor to build new housing. Investment in housing takes one period so that investment in period t becomes available for sale in period $t + 1$. Housing is built in discrete units, and investment firms can only hold one house at a time in inventory.
- **Financial intermediary:** The financial intermediary makes mortgage loans, which requires real administrative costs, and collects mortgage payments. The financial intermediary's optimal choice for mortgage loans determines the interest rate on mortgages.
- **Non-durable consumption firms:** There are two types of non-durable consumption firms. First, there is a continuum of intermediate-goods firms that produce unique goods, and both the firms and their goods are indexed by $i \in [0, 1]$. These intermediate-goods firms are monopolistic and face Calvo (1983) pricing rigidities. Second, there are final-goods firms that aggregate the intermediate goods according to Dixit and Stiglitz (1977) and sell the aggregated bundle in a competitive market.
- **Monetary authority:** The monetary authority sets the nominal interest rate on risk-free bonds that are traded by consumers according to a Taylor (1993) style rule.

3.1 Households

There is a continuum of households, indexed by $h \in [0, 1]$. The utility of household h is

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t(h) - \nu C_{t-1}) + \gamma_{H,t}(h) - \gamma_N N_t(h)],$$

where $\beta \in (0, 1)$ is the subjective discount factor, $C_t(h)$ is non-durable consumption and $N_t(h)$ is labor provided by household h . Following Smets and Wouters (2003), non-durable consumption has an external habit, where C_t denotes aggregate consumption and ν gives the degree of habit persistence. $\gamma_{H,t}(h)$ gives the instantaneous utility from housing for household h , depending on whether it owns or rents the house it occupies. It follows

$$\gamma_{H,t}(h) = \begin{cases} \gamma_{H,r} & \text{if household } h \text{ is a renter} \\ \gamma_{H,o,t} + \gamma_{H,r} & \text{if household } h \text{ is an owner-occupier} \end{cases} \quad (5)$$

where $\gamma_{H,r}$ is the instantaneous utility from renting, and $\gamma_{H,o,t}$ is the premium that households get from being owner-occupiers. Both $\gamma_{H,o,t}$ and $\gamma_{H,r}$ are the same across households, and $\gamma_{H,o,t}$ is an aggregate stochastic process while $\gamma_{H,r}$ is constant over time. I assume $\gamma_{H,o,t} > 0$, motivating the desire of households to be owner-occupiers of housing. Further, I assume that $\gamma_{H,o,t}$ is stationary with an unconditional mean of $\gamma_{H,o}$.

The labor market is competitive, and households take the nominal wage of W_t as given. Every household can split their labor to produce non-durable goods and housing investment

$$N_t(h) = \int_0^1 N_{X,t}(i, h) di + N_{I,t}(h), \quad (6)$$

where household h provides $N_{X,t}(i, h)$ of labor to non-durable goods firm i and $N_{I,t}(h)$ of labor to housing investment. Households also trade risk-free bonds amongst one another in a competitive market with a gross interest rate of $R_{f,t}$. The budget for household h is

$$P_t C_t(h) + R_{f,t}^{-1} B_t(h) + \text{spending on housing}_t = W_t N_t(h) + B_{t-1}(h) + \text{dividends}_t.$$

I discuss how households spend on housing in depth below.

Household h 's first-order conditions yield an optimal consumption-labor condition of $\gamma_N(C_t(h) - \nu C_{t-1}) = W_t/P_t$. Because $C_t(h)$ is the only variable in this condition that depends on h , all households choose the same quantity of consumption. This follows from the linear dis-utility of labor, which generates the result that all households fully offset any wealth effects through their labor market choices. This allows me to treat households homogenously for the purposes of consumption, and it allows me to solve for the equilibrium of aggregate variables without having to track the distribution of wealth across households. Thus, the Euler equation and optimal consumption-labor condition for households are

$$\frac{1}{P_t(C_t - \nu C_{t-1})} = \beta R_{f,t} \mathbb{E}_t \left[\frac{1}{P_{t+1}(C_{t+1} - \nu C_t)} \right] \quad (7)$$

and

$$\gamma_N(C_t - \nu C_{t-1}) = W_t/P_t. \quad (8)$$

3.2 Evolution of Home Ownership

Households can take one of three states with respect to housing. They can be owner-occupiers, in which case they own the house they occupy, they can be non-searching renters, in which case they rent the house they occupy and are not trying to become owner-occupiers, or they can be searching renters, in which case they rent the house they occupy but are trying to become owner-occupiers. I denote the measure of owner-occupiers, the measure of non-searching renters, and the measure of searching renters by $H_{o,t}$, $H_{r,t}$ and $H_{s,t}$, respectively. Because there is a measure one of total consumers in the economy, it must be the case that

$$1 = H_{o,t} + H_{s,t} + H_{r,t}. \quad (9)$$

In between periods $t - 1$ and t a fraction $\delta \in (0, 1)$ of houses depreciate completely, and a fraction $\chi_r \in (0, 1)$ of owner-occupiers separate from their house and become renters. The depreciation of houses provides a role for new residential construction. The separation from

houses is meant to stand in for factors that cause households to become mismatched with a house, such as changes in employment location. It is included because existing home sales make up the bulk of total home sales in the U.S, and it is standard in the housing search literature. Depreciation and separation imply that there is a measure of $(1 - \delta)(1 - \chi_r)H_{o,t-1}$ owner-occupiers at the beginning of period t .

All households that are not owner-occupiers rent housing in a competitive rental market, and there is no homelessness. Non-searching renters choose to rent this period and enter the following period as non-searching renters. Searching renters that do not match with a house stay searching renters in the following period.¹⁴ Searching renters that match with a house become owner-occupiers. In addition, a fraction $\chi_{s,t}$ of non-searching renters decide to become searching renters in period t . Thus, the measure of households searching to buy a house at the beginning of period t is $H_{s,t-1} + \chi_{s,t}H_{r,t-1} + \chi_{s,t}[1 - (1 - \delta)(1 - \chi_r)]H_{o,t-1}$.

On the supply side of the housing market, there is a stock of housing that is not owner-occupied, denoted by U_t . In between periods $t-1$ and t a fraction δ of these houses depreciate, a measure $(1 - \delta)\chi_r H_{o,t-1}$ of houses become mismatched, and new houses invested in in period $t-1$, denoted I_{t-1} , becomes available for sale. This implies that the stock of housing that is not owner-occupied at the beginning of period t is $(1 - \delta)(U_{t-1} + \chi_r H_{o,t-1}) + I_{t-1}$. I assume that rental housing cannot also be available for sale, and a measure $H_{s,t} + H_{r,t}$ of housing units must be taken off the sales market and rented. This implies that the measure of houses available for sale is $(1 - \delta)(U_{t-1} + \chi_r H_{o,t-1}) + I_{t-1} - H_{s,t} - H_{r,t}$.

Market tightness is the ratio of households searching for a house to the number of houses available for sale, and it is given by

$$\tau_t = \frac{H_{s,t-1} + \chi_{s,t}H_{r,t-1} + \chi_{s,t}[1 - (1 - \delta)(1 - \chi_r)]H_{o,t-1}}{(1 - \delta)(U_{t-1} + \chi_r H_{o,t-1}) + I_{t-1} - H_{s,t} - H_{r,t}}. \quad (10)$$

Following Díaz and Jerez (2013), I use an urn-ball matching function that is scaled by an efficiency parameter ζ .¹⁵ Thus, the fraction of houses for sale that are sold is given by

$$G_t = \zeta (1 - e^{-\tau_t}). \quad (11)$$

The fraction of searching households that find a house is given by

$$F_t = G_t/\tau_t. \quad (12)$$

¹⁴I assume that searching renters do not revert back being non-searching renters in the following period. The idea is that households may require several consecutive periods of search in order to find a house.

¹⁵Let \mathcal{B} be the number of buyers in the market (the numerator in Equation (10)), and let \mathcal{S} be the number of sellers (the denominator in Equation (10)). Then, the urn-ball matching function takes the form $\mathcal{M}(\mathcal{B}, \mathcal{S}) = \mathcal{S}(1 - e^{-\mathcal{B}/\mathcal{S}})$, where $\mathcal{M}(\mathcal{B}, \mathcal{S})$ denotes the measure of houses sold, given measures of buyers and sellers. For $\mathcal{B} \geq 0$ and $\mathcal{S} \geq 0$, this function has the standard properties that it is increasing both arguments, it is homogeneous of degree one, and $\mathcal{M}(0, \mathcal{S}) = \mathcal{M}(\mathcal{B}, 0) = 0$. Given homogeneity of degree one, the fraction of houses for sale that actually get sold, which is $\mathcal{M}(\mathcal{B}, \mathcal{S})/\mathcal{S}$, can be re-written in terms of market tightness: $\mathcal{M}(\tau, 1) = 1 - e^{-\tau}$. Similarly, the fraction of buyers that find a house is $\tau\mathcal{M}(\tau, 1) = 1 - e^{-\tau}$.

The virtue of this matching function is that $G_t \rightarrow 0$ and $F_t \rightarrow \zeta$ as $\tau_t \rightarrow 0$, and $G_t \rightarrow \zeta$ and $F_t \rightarrow 0$ as $\tau_t \rightarrow \infty$. Thus, for any non-negative measures of buyers and sellers and for $\zeta \in [0, 1]$, F_t and G_t are between zero and one, and I interpret F_t and G_t as the probabilities that a searching renter buys a house and that a seller sells a house, respectively. The number of houses that are sold every period is given by

$$S_t = F_t \{H_{s,t-1} + \chi_{s,t} H_{r,t-1} + \chi_{s,t} [1 - (1 - \delta)(1 - \chi_r)] H_{o,t-1}\}, \quad (13)$$

which is the probability of buying a house times the number of searching households.

The evolution of non-searching renters is

$$H_{r,t} = (1 - \chi_{s,t}) [1 - (1 - \delta)(1 - \chi_r)] H_{o,t-1} + (1 - \chi_{s,t}) H_{r,t-1}, \quad (14)$$

and the evolution of searching renters is

$$H_{s,t} = (1 - F_t) \{H_{s,t-1} + \chi_{s,t} H_{r,t-1} + \chi_{s,t} [1 - (1 - \delta)(1 - \chi_r)] H_{o,t-1}\}. \quad (15)$$

Given the evolutions of $H_{s,t}$ and $H_{r,t}$, $H_{o,t}$ evolves according to Equation (9). Finally, the stock of housing that is not owner-occupied evolves according to

$$U_t = H_{s,t} + H_{r,t} + (1 - G_t) [(1 - \delta)(U_{t-1} + \chi_r H_{o,t-1}) + I_{t-1} - H_{s,t} - H_{r,t}]. \quad (16)$$

3.3 Mortgages and Financial Intermediaries

Following Garriga, Kydland, and Sustek (2013), I assume that all households use a mortgage to finance part of the purchase price. Given a house price of Q_t , a household makes a down payment of $(1 - \theta)Q_t$ and borrows θQ_t , where $\theta \in [0, 1]$. Because all households have the same level of consumption, the bargaining protocol below will yield the same Q_t for all households. Thus, all households that buy a house in period t borrow the same θQ_t .

Households with loans repay a fraction η of the principal every period. They also pay a fixed, nominal, net interest rate on the principal every period, denoted by $R_{m,t} - 1$ for households that buy in period t . This set-up yields a stream of geometrically decaying nominal mortgage payments of $(1 - \eta)^{j-1} (R_{m,t} - 1 + \eta) \theta Q_t$ for period $t + j$, where $j = 1, 2, \dots$

Households get mortgages from the financial intermediary. I deviate from Garriga, Kydland, and Sustek (2013) by assuming that each mortgage has a real administrative cost to the financial intermediary of $\kappa_1 S_t^\phi$ with $\phi > 0$.¹⁶ This cost increases with the number of houses sold, and hence, the number of mortgages made. Thus, the financial intermediary has increasing marginal costs in administering mortgages, where ϕ is the elasticity of this marginal administrative cost with respect to mortgages made. In the searching equilibrium below, this assumption ensures that the system of equations yields a unique steady-state

¹⁶I assume that the administrative costs use up non-durable consumption goods.

and satisfies the Blanchard and Kahn (1980) conditions when it is log-linearized.¹⁷

In order to make one additional mortgage, the financial intermediary must reduce its dividend payments to households by $\theta Q_t + P_t \kappa_1 S_t^\phi$ in period t . Once the mortgage is made, it then receives the stream of mortgage repayments that can be used to increase future dividends to households. Because the financial intermediary is owned by households, it converts all dividend payments into utility using the Lagrange multiplier of the households' budget constraint. Thus, in the eyes of the financial intermediary, extending mortgages costs the households utility today in exchange for additional future utility, and it extends mortgages in period t up to the point where the utility cost of one mortgage today equals that mortgage's future utility increase. Mathematically, this condition is

$$\frac{\theta Q_t + P_t \kappa_1 S_t^\phi}{P_t(C_t - \nu C_{t-1})} = \sum_{j=0}^{\infty} \beta^{j+1} \mathbb{E}_t \left[\frac{1}{P_{t+j+1}(C_{t+j+1} - \nu C_{t+j})} \right] (1 - \eta)^j (R_{m,t} - 1 + \eta) \theta Q_t$$

This is the same as

$$\theta \frac{Q_t}{P_t} + \kappa_1 S_t^\phi = (R_{m,t} - 1 + \eta) \theta \frac{Q_t}{P_t} V_{\eta,t} \quad (17)$$

where

$$V_{\eta,t} = \sum_{j=0}^{\infty} \beta^{j+1} (1 - \eta)^j \mathbb{E}_t \left[\frac{P_t(C_t - \nu C_{t-1})}{P_{t+j+1}(C_{t+j+1} - \nu C_{t+j})} \right].$$

These equations determine the gross interest rate on mortgages, $R_{m,t}$.

The variable $V_{\eta,t}$ converts the nominal mortgage payments with geometric decay of η into real, present-value terms by scaling them with the nominal price changes P_t/P_{t+j+1} and with the stochastic discount factors of the households. $V_{\eta,t}$ can be written in the recursive form

$$V_{\eta,t} = \beta \mathbb{E}_t \left[\frac{C_t - \nu C_{t-1}}{\Pi_{t+1}(C_{t+1} - \nu C_t)} \right] + \beta(1 - \eta) \mathbb{E}_t \left[\frac{C_t - \nu C_{t-1}}{\Pi_{t+1}(C_{t+1} - \nu C_t)} V_{\eta,t+1} \right], \quad (18)$$

where $\Pi_{t+1} = P_{t+1}/P_t$ is inflation of non-durable goods prices. To better understand how $V_{\eta,t}$ impacts the pricing of $R_{m,t}$, I log-linearize Equation (18) around the non-stochastic steady-state. This, along with the log-linearized Euler equation in (7), yields

$$\hat{V}_{\eta,t} = -\hat{R}_{f,t} + \beta(1 - \eta) \Pi^{-1} \mathbb{E}_t \hat{V}_{\eta,t+1},$$

where “ $\hat{\cdot}$ ” denotes log-deviations from the steady-state and Π is steady-state inflation.

¹⁷The intuition for why increasing marginal administrative costs stabilizes the equilibrium is as follows. Consider a hot housing market where there are many searching households and houses available for sale. This increases the number of house sales, causing marginal administrative costs to increase. This increase in costs increases mortgage rates and incentivizes fewer households to search, cooling the market. The converse of this reasoning also holds in cold housing markets with few searching households and houses for sale.

Solving this forward yields

$$\hat{V}_{\eta,t} = - \sum_{j=0}^{\infty} [\beta(1-\eta)\Pi^{-1}]^j \mathbb{E}_t \hat{R}_{f,t+j}. \quad (19)$$

Equation (19) shows that to a first-order approximation, $V_{\eta,t}$ discounts the mortgage payments by the future expected stream of discounted risk-free interest rates. Thus, the pricing of $R_{m,t}$ in Equation (17) is partially determined by the expected future stream of risk-free rates, giving monetary policy influence over mortgage rates.

In addition to converting the mortgage payments into a real present discounted value, $V_{\eta,t}$ can convert any nominal stream of payments with principal repayment η into its real present discounted value. Consider a risk-free bond that costs 1 unit of account today and repays η of the principal every period in the future along with net interest of $R_{\eta,t} - 1$ on the outstanding principal. Households will invest in this bond until the marginal cost of doing so equals the marginal benefit. Mathematically, this optimality condition is

$$\frac{1}{P_t(C_t - \nu C_{t-1})} = \sum_{j=0}^{\infty} \beta^{j+1} \mathbb{E}_t \left[\frac{1}{P_{t+j+1}(C_{t+j+1} - \nu C_{t+j})} \right] (1-\eta)^j (R_{\eta,t} - 1 + \eta),$$

which is equivalent to

$$1 = (R_{\eta,t} - 1 + \eta)V_{\eta,t}. \quad (20)$$

Log-linearizing this equation around the non-stochastic steady-state and applying Equation (19) yields

$$\hat{R}_{\eta,t} = [1 - \beta(1-\eta)\Pi^{-1}] \sum_{j=0}^{\infty} [\beta(1-\eta)\Pi^{-1}]^j \mathbb{E}_t \hat{R}_{f,t+j}. \quad (21)$$

Thus, $V_{\eta,t}$ sets long-term risk-free interest rates to be weighted sums of future expected short-term interest rates consistent with the expectations hypothesis of the term structure. Hence, monetary policy influences long-term rates by adjusting the path of short-term rates.

Finally, Equations (17) and (20) yield

$$\theta \frac{Q_t}{P_t} + \kappa_1 S_t^\phi = \theta \frac{Q_t}{P_t} \left(\frac{R_{m,t} - 1 + \eta}{R_{\eta,t} - 1 + \eta} \right). \quad (22)$$

This implies that the administrative costs create a wedge between the nominal payments on mortgages, $R_{m,t} - 1 + \eta$, and the nominal payments on risk-free debt with the same term structure, $R_{\eta,t} - 1 + \eta$. Because the interest rates on mortgages and long-term risk-free bonds are influenced by monetary policy, this wedge will also be influenced by monetary policy.

3.4 Investment Firms

The production technology for a house is given by

$$\bar{H} = A_{I,t}N_{I,t}, \quad (23)$$

where \bar{H} is the size of a house, $N_{I,t}$ is the amount of labor needed to build one house, and $A_{I,t}$ is the productivity of labor in the housing market, which is a stationary random variable with an unconditional mean of A_I . I assume that a housing investment firm can only invest in one house at a time. Because all investment firms share this technology, they all use $N_{I,t} = \bar{H}/A_{I,t}$ of labor. Thus, total labor used to build houses in period t is $N_{I,t}I_t = \int_0^1 N_{I,t}(h)dh$, where I_t is the number of new houses started. In addition to the labor costs of investment, there is a real adjustment cost of $\iota(I_t - I_{t-1})/I_{t-1}$ imposed on all investment firms that build a house in period t .¹⁸

To finance the construction of a house, investment firms get equity injections from (that is, they pay negative dividends to) households, and then repay the households when the houses sell. Thus, to provide financing to one additional investment firm, a household must give up $W_t\bar{H}/A_{I,t} + P_t\iota(I_t - I_{t-1})/I_{t-1}$ units of account. In return, it gets the utility value of owning an investment firm when that firm has a house available for sale, which I denote by $\beta\mathbb{E}_t J_{t+1}$.¹⁹ I assume that there is free entry of new housing firms, and that households finance new housing investment until the utility cost of one extra house equals the utility benefit. Formally, the free entry condition is

$$\frac{1}{P_t(C_t - \nu C_{t-1})} \left[\frac{W_t\bar{H}}{A_{I,t}} + P_t\iota \frac{I_t - I_{t-1}}{I_{t-1}} \right] = \beta\mathbb{E}_t J_{t+1}. \quad (24)$$

Firms with a house can rent them or try to sell them. If the firm tries to sell, there is a probability G_t that it does and gets a nominal house price of Q_t . If the firm rents, it does so in a competitive market with a nominal rental price of $P_{r,t}$. Houses listed for rent are not available for sale. Thus, J_t is given by

$$J_t = \max \left\{ \frac{P_{r,t}}{P_t(C_t - \nu C_{t-1})} + \beta(1 - \delta)\mathbb{E}_t J_{t+1}, \right. \\ \left. G_t \frac{Q_t}{P_t(C_t - \nu C_{t-1})} + (1 - G_t)\beta(1 - \delta)\mathbb{E}_t J_{t+1} \right\}. \quad (25)$$

The first expression in the maximum function is the value if the firm rents, and the second expression in the maximum function is the value if the firm tries to sell.

¹⁸I assume that the adjustment cost uses up non-durable consumption goods.

¹⁹Because housing investment takes one period to become available for sale, the household gets an expected discounted benefit from investing today.

3.5 Valuing Housing

The utility benefits of being an owner-occupier at the beginning of period t are

$$V_{o,t} = \gamma_{H,o,t} + \gamma_{H,r} + \beta(1 - \delta)(1 - \chi_r)\mathbb{E}_t V_{o,t+1} + \beta[1 - (1 - \delta)(1 - \chi_r)]\mathbb{E}_t V_{r,t+1} + \beta(1 - \delta)\chi_r\mathbb{E}_t J_{t+1}, \quad (26)$$

which is the instantaneous utility of being an owner-occupier, the expected value of staying an owner-occupier from period t to $t+1$, the expected value of becoming a renter from period t to $t+1$ (either through depreciation or separation), and the expected value of the empty house if separation occurs without depreciation. I treat a separated house as reverting back to an investment firm with a continuation value of $\beta\mathbb{E}_t J_{t+1}$. The idea is that when a household has a house that it does not want to live in, it can either rent it to other households or sell it in exactly the same way that an investment firm would. Hence, separation effectively grants the household ownership of an investment firm that has already built a house.

Searching renters pay a utility cost of κ_2 for every period that they search for a house. The value of entering period t as a searching renter is

$$V_{s,t} = -\kappa_2 + (1 - F_t) \left[\gamma_{H,r} - \frac{P_{r,t}}{P_t(C_t - \nu C_{t-1})} + \beta\mathbb{E}_t V_{s,t+1} \right] + F_t \left[V_{o,t} - \frac{(1 - \theta)Q_t}{P_t(C_t - \nu C_{t-1})} - \frac{\theta Q_t}{P_t(C_t - \nu C_{t-1})} (R_{m,t} - 1 + \eta)V_{\eta,t} \right]. \quad (27)$$

The second term on the right-hand side of Equation (27) is the expected value of not buying a house, which is the probability of not matching times the utility of not matching. The third term on the right-hand side is the expected value buying a house, where $V_{o,t}$ is the owner-occupier value, $(1 - \theta)Q_t/(P_t(C_t - \nu C_{t-1}))$ is the utility cost of a down payment, and $(\theta Q_t/(P_t(C_t - \nu C_{t-1}))) (R_{m,t} - 1 + \eta)V_{\eta,t}$ is the utility cost of mortgage payments.

The value of entering period t as a non-searching renter is

$$V_{r,t} = \max \left\{ \gamma_{H,r} - \frac{P_{r,t}}{P_t(C_t - \nu C_{t-1})} + \beta\mathbb{E}_t V_{r,t+1}, V_{s,t} \right\}. \quad (28)$$

Equation (28) reflects the choice faced by non-searching renters. The first term in the maximization is the value of staying a non-searching renter, and the second term is the value of becoming a searching renter.

3.6 Consumption Goods, Inflation and Monetary Policy

In this subsection, I briefly summarize the remainder of the model, which covers the production of non-durable consumption goods, inflation of non-durable goods prices and monetary

policy. These features follow the standard New Keynesian set up, and I provide a full description in the technical appendix.

Consumption goods are produced in two steps. First, monopolistic intermediate-goods firms use labor to produce unique intermediate goods, indexed by $i \in [0, 1]$. Second, competitive final-goods firms bundle the intermediate goods according to a Dixit and Stiglitz (1977) aggregator and sell a homogeneous final good. Final-goods firms produce final goods according to a constant elasticity of substitution aggregator $X_t = [\int_0^1 X_t(i)^{(\epsilon-1)/\epsilon} di]^{\epsilon/(\epsilon-1)}$, where X_t is the final good, $X_t(i)$ is the good produced by intermediate firm i , and $\epsilon > 1$ is the elasticity of substitution. This yields the standard demand function for good i , which is $X_t(i) = [P_t(i)/P_t]^{-\epsilon} X_t$, where $P_t(i)$ is the price of intermediate good i and P_t is a price index given by $P_t = [\int_0^1 P_t(i)^{1-\epsilon} di]^{1/(1-\epsilon)}$.

Intermediate-goods firms face Calvo (1983) pricing rigidities, where a measure $\alpha \in [0, 1]$ of consumption firms keep their price from the previous period and a measure $1 - \alpha$ re-optimize their price. The production function for intermediate good firm i is

$$X_t(i) = A_{X,t} N_{X,t}(i), \quad (29)$$

where $N_{X,t}(i) = \int_0^1 N_{X,t}(i, h) dh$ is the labor used by firm i , and $A_{X,t}$ is aggregate productivity of labor in producing non-durable goods, which is a stationary random variable with an unconditional mean of A_X .

The monetary authority follows a Taylor (1993) style rule. To implement this rule, I define gross domestic product (GDP) to be

$$Y_t = C_t + \frac{P_{r,t}}{P_t} (H_{o,t} + H_{s,t} + H_{r,t}) + RI_t + \kappa_1 S_t^{1+\phi}.$$

The first term is non-durable consumption. The second term is the real rental services from housing, which includes both the imputed rent for owner-occupied dwellings, $P_{r,t} H_{o,t} / P_t$, and the rental services paid for by renting households, $P_{r,t} (H_{s,t} + H_{r,t}) / P_t$. I include both terms in order to follow the Bureau of Economic Analysis's treatment of housing services.²⁰ The third term is real residential investment, and the fourth term is the administrative costs of mortgages. Because the number of households equals one, GDP can be written as

$$Y_t = C_t + P_{r,t} / P_t + RI_t + \kappa_1 S_t^{1+\phi}. \quad (30)$$

I define real residential investment to be the real wages plus adjustment costs spent on the

²⁰The Bureau of Economic Analysis writes "PCE for housing services includes both the monetary rents paid by tenants and an imputed rental value for owner-occupied dwellings (measured as the income the homeowner could have received if the house had been rented to a tenant). This treatment is designed to make PCE (and GDP) invariant to whether the house is rented by a landlord to a tenant or is lived in by the homeowner." See <http://www.bea.gov/national/pdf/chapter5.pdf> for more details.

building of housing units times the number of housing units built

$$RI_t = \left(\frac{W_t \bar{H}}{P_t A_{I,t}} + \iota \frac{I_t - I_{t-1}}{I_{t-1}} \right) I_t. \quad (31)$$

Then, the policy rule is

$$\frac{R_{f,t}}{R_f} = \left(\frac{R_{f,t-1}}{R_f} \right)^{\rho_r} \left[\left(\frac{\Pi_t}{\Pi} \right)^{\psi_\pi} \left(\frac{Y_t}{Y} \right)^{\psi_Y} \right]^{1-\rho_r} e^{\xi_{R,t}} \quad (32)$$

where $\xi_{R,t}$ is white noise and variables without time subscripts denote steady-states. The parameter ρ_r governs the persistence of the of the interest rate, and the parameters ψ_π and ψ_Y govern the monetary authority's response to inflation and GDP gaps.

4 Equilibrium

Equilibrium in the non-durable goods market, the labor market and the risk-free bonds market requires market clearing:

$$X_t = C_t + \iota \frac{I_t - I_{t-1}}{I_{t-1}} I_t + \kappa_1 S_t^{1+\phi}, \quad (33)$$

$$N_t = N_{X,t} + N_{I,t} I_t, \quad (34)$$

where $N_{X,t} = \int_0^1 N_{X,t}(i) di$, and

$$B_t = 0. \quad (35)$$

4.1 Non-Searching and Searching Equilibria

In the housing market, there are two potential equilibria. First, there is an equilibrium where housing investment firms only supply their houses to the rental market and all households are non-searching renters. I call this equilibrium the *non-searching equilibrium*. The intuition for this equilibrium is as follows. If houses are only supplied to the rental market, then the probability that a searching renter matches with a house is $F_t = 0$. Thus, the household would face the utility cost of searching but be guaranteed to stay a renter. In this case, the household is better off by simply renting without searching for a house to buy. Thus, no households search. When no households search, then the probability that an investment firm can sell a house is $G_t = 0$. If an investment firm makes its house available for sale, it forgoes the rental income but is guaranteed not to sell the house. In this case, the firm is better off renting the house. Thus, all investment firms rent their houses.

While this equilibrium is theoretically possible, it does not realistically characterize the housing market. Thus, the remainder of the paper focuses on the second equilibrium, which I

call the *searching equilibrium*. In this equilibrium, the fraction of non-searching renters that become searching renters, $\chi_{s,t}$, adjusts so that renting households are indifferent between searching and not searching. From Equation (28), this implies

$$V_{r,t} = V_{s,t} \quad (36)$$

and

$$V_{r,t} = \gamma_{H,r} - \frac{P_{r,t}}{P_t(C_t - \nu C_{t-1})} + \beta \mathbb{E}_t V_{r,t+1}. \quad (37)$$

The indifference condition in Equation (36) occurs because if $V_{s,t} > V_{r,t}$, then more households would begin searching, market tightness would increase, the probability of buying a house would fall, and $V_{s,t}$ would fall. If $V_{s,t} < V_{r,t}$, then fewer household would begin searching, market tightness would decrease, the probability of buying a house would increase, and $V_{s,t}$ would rise.²¹ Similarly, in the searching equilibrium, investment firms are indifferent between renting their houses and trying to sell their houses. From Equation (25), this implies

$$J_t = \frac{P_{r,t}}{P_t(C_t - \nu C_{t-1})} + \beta(1 - \delta) \mathbb{E}_t J_{t+1} \quad (38)$$

and

$$J_t = G_t \frac{Q_t}{P_t(C_t - \nu C_{t-1})} + (1 - G_t) \beta(1 - \delta) \mathbb{E}_t J_{t+1}. \quad (39)$$

This indifference comes from the competitive rental market and free entry into both the rental and sales markets. Because there is a measure of $H_{s,t} + H_{r,t}$ of renting households, investment firms must supply exactly $H_{s,t} + H_{r,t}$ houses to the rental market for it to clear. To achieve this, the rental price adjusts so that investment firms are indifferent between supplying to the rental and sales markets. If they were not indifferent, then they could freely switch to the other market, violating market clearing in the rental market.

For buyers in a match, the consumer surplus is

$$CS_t = V_{o,t} - \frac{(1 - \theta)Q_t}{P_t(C_t - \nu C_{t-1})} - \frac{\theta Q_t}{P_t(C_t - \nu C_{t-1})} (R_{m,t} - 1 + \eta) V_{\eta,t} - V_{s,t}, \quad (40)$$

which is the utility benefit of owning a house less the less the utility cost of the down payment, the utility cost of the mortgage payments, and the opportunity cost of not staying

²¹There is the possibility of a corner solution where $V_{s,t} > V_{r,t}$ even when all renters search (that is, when $\chi_{s,t} = 1$). However, the solution in the calibrated steady-state below is interior (that is, $\chi_{s,t} \in (0, 1)$), and I solve the model with log-linearization so that only states of the world within a neighborhood of the steady-state are analyzed. For this reason, I only consider the interior equilibrium going forward and leave the study of corner solutions for future research.

a searching renter. For sellers in a match, the producer surplus is

$$PS_t = \frac{Q_t}{P_t(C_t - \nu C_{t-1})} - \beta(1 - \delta)\mathbb{E}_t J_{t+1}, \quad (41)$$

which is the utility value of the sales price less the opportunity cost of not keeping the house. In the steady-state of the calibration below, both consumer and producer surpluses are positive, implying that both buyers and sellers benefit from trading houses once they are in a match and that trades occur in equilibrium.

Adding the consumer and producer surpluses gives the total surplus. Using Equations (40) and (41) and applying Equation (20) yields a total surplus that can be written as

$$TS_t = V_{o,t} - V_{s,t} - \beta(1 - \delta)\mathbb{E}_t J_{t+1} + \frac{\theta Q_t}{P_t(C_t - \nu C_{t-1})} - \frac{\theta Q_t}{P_t(C_t - \nu C_{t-1})} \frac{R_{m,t} - 1 + \eta}{R_{\eta,t} - 1 + \eta}. \quad (42)$$

The first line on the right-hand side of Equation (42) gives the standard definition of total surplus, which is the value that the household gets from buying a house, $V_{o,t} - V_{s,t}$, less the opportunity cost to the investment firm of selling a house, $\beta(1 - \delta)\mathbb{E}_t J_{t+1}$. The second line of Equation (42) introduces the effects of mortgages into the total surplus. Equation (22) implies that this line is zero when the administrative costs of mortgages are zero. Thus, the administrative costs allow the spread between the mortgage payments and payments of risk-free debt with the same term structure to directly influence the total surplus of a match. Because $(R_{m,t} - 1 + \eta)/(R_{\eta,t} - 1 + \eta)$ enters with a negative sign, reducing this spread increases total surplus and increasing the spread reduces total surplus. Thus, because monetary policy can influence this spread, it can influence the total surplus from buying and selling houses.

To close the equilibrium, I assume that house prices are determined through a bargaining protocol where total surplus is split so that $CS_t = \omega TS_t$ and $PS_t = (1 - \omega)TS_t$, where $\omega \in (0, 1)$. This implies that house prices adjust so that

$$(1 - \omega)CS_t = \omega PS_t. \quad (43)$$

Because consumer and producer surpluses are simply a fraction of the total surplus, monetary policy impacts them in the same way that it impacts total surplus in Equation (42). Thus, by changing the total surplus of a housing match, monetary policy can change consumer surplus and influence how many households begin searching for a house to buy.

The equations that characterize the searching equilibrium are provided in the technical appendix, which also shows that the non-stochastic steady-state of the searching equilibrium is unique. To solve the model, I log-linearize around the steady-state and follow Klein (2000). Given the calibration below, the Blanchard and Kahn (1980) conditions are satisfied. However, before discussing the calibration and numerical results, I first address a more general result on the importance of search frictions.

4.2 The Importance of Search Frictions

The time-consuming search frictions in the model are central to understanding why residential construction is so responsive to economic shocks. To highlight this, I compare the searching equilibrium to an extreme case of the model with no searching frictions. That is, I dispense with the matching function and assume that $F_t = 1$ and $G_t = 1$ for all t . In this case, Equations (9), (10), (12), (14), (15) and (16) yield

$$I_{t-1} = \delta.$$

Thus, without search frictions, residential construction is fixed at the rate of depreciation and neither monetary, preference, nor productivity shocks affect it. This is because when all households can perfectly match with a house and all houses can perfectly match with households, then the number of houses will always equal the population of households. Given the constant quantity of households in the model, this implies that residential construction only exists to replace depreciated houses.²² Thus, search frictions are essential for economic shocks to impact the quantity of houses under construction.

To understand why search frictions influence the number of houses under construction, it is helpful to further consider the problem facing residential investment firms. The first component of the problem is that the number of new houses built, I_t , reduces the expected value of a house in the next period, $\mathbb{E}_t J_{t+1}$. This is because an increase in I_t leads to an increase in the number of houses available for sale in period $t + 1$, driving down the market tightness, the house selling rate, and the expected value of an additional house. I denote this relationship by $\mathbb{E}_t J_{t+1}(I_t)$. The second component of the problem for residential investment firms is the free entry condition. Because of free entry, investment firms add new housing until the marginal cost of a new house equals the expected marginal benefit. Equations (8) and (24) imply that this free entry condition is

$$\beta \mathbb{E}_t J_{t+1} = \frac{\gamma_N \bar{H}}{A_{I,t}} + \frac{\iota(I_t - I_{t-1})}{I_{t-1}(C_t - \nu C_{t-1})} \quad (44)$$

so that $\mathbb{E}_t J_{t+1}$ is increasing with I_t as a result of the adjustment costs.

Panel (a) of Figure 4 displays the two components of the problem of investment firms. It shows that firms invest in new housing up to the point where $\mathbb{E}_t J_{t+1}(I_t)$ intersects with the free entry condition. That is, investment firms choose I_t to satisfy

$$\beta \mathbb{E}_t J_{t+1}(I_t) = \frac{\gamma_N \bar{H}}{A_{I,t}} + \frac{\iota(I_t - I_{t-1})}{I_{t-1}(C_t - \nu C_{t-1})}. \quad (45)$$

²²Allowing for trend population growth, as in Head, Lloyd-Ellis, and Sun (2014), will not substantially change this results. Housing construction will still be constant, but it will be larger in order to cover both depreciation and provide housing units for new households.

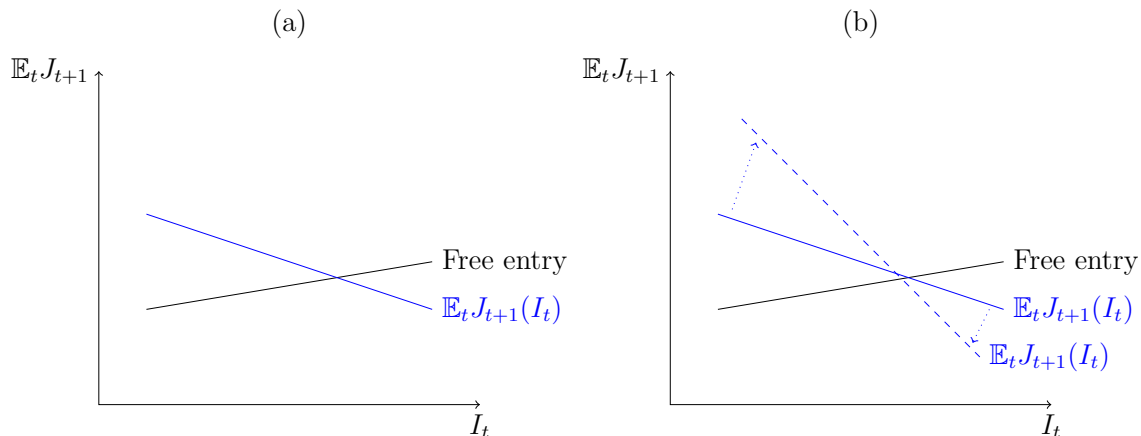


Figure 4: Panel (a) displays the two curves summarizing the problem for housing investment firms. Panel (b) displays the change in the problem when matching efficiency increases.

An increase in matching efficiency (a decrease in search frictions) causes the $\mathbb{E}_t J_{t+1}(I_t)$ curve to steepen as in panel (b) of Figure 4. The reason for this is that as matching efficiency increases, houses act like closer substitutes and are more likely to match with and take away potential buyers from each other. This means that the first house built will have a greater impact on the value of the second house built, causing the marginal value of housing to fall more quickly. In the extreme case where $F_t = 1$ and $G_t = 1$ for all t , the $\mathbb{E}_t J_{t+1}(I_t)$ curve turns vertical at $I_t = \delta$, yielding the above result that the number of houses under construction will be constant at the rate of depreciation.

With a steeper $\mathbb{E}_t J_{t+1}(I_t)$ curve, shifts in either curve generate smaller movements in I_t , as demonstrated in Figures 5 and 6. This is because when $\mathbb{E}_t J_{t+1}(I_t)$ is steep, it takes smaller movements in I_t for the free entry condition in Equation (45) to equate the benefit of one additional house to its marginal cost. Figure 5 shows a shift in the $\mathbb{E}_t J_{t+1}(I_t)$ curve under low and high matching efficiency. This shift can come from a shock to households' preference for being owner-occupiers, $\gamma_{H,o,t}$. With higher matching efficiency, the change is smaller for both I_t and $\mathbb{E}_t J_{t+1}$. Figure 6 shows a shift in the free entry under low and high matching efficiency. From Equation (44), this shift can come from a shock to labor productivity for housing construction. With higher matching efficiency, the change in I_t is smaller but the change in $\mathbb{E}_t J_{t+1}$ is larger. In the extreme case of $F_t = 1$ and $G_t = 1$ where $\mathbb{E}_t J_{t+1}(I_t)$ is vertical, shifts in either curve no impact on the level of housing investment.

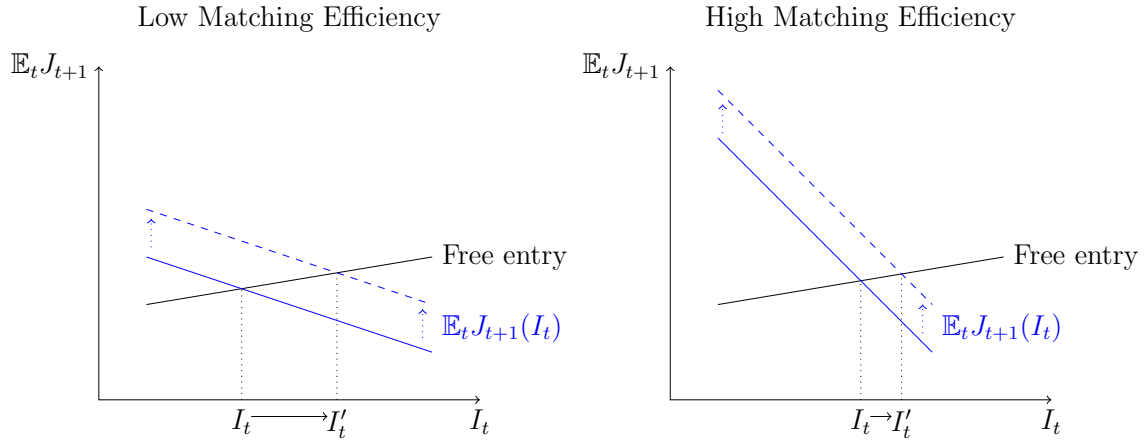


Figure 5: A shift in the $\mathbb{E}_t J_{t+1}(I_t)$ curve under low and high matching efficiency.

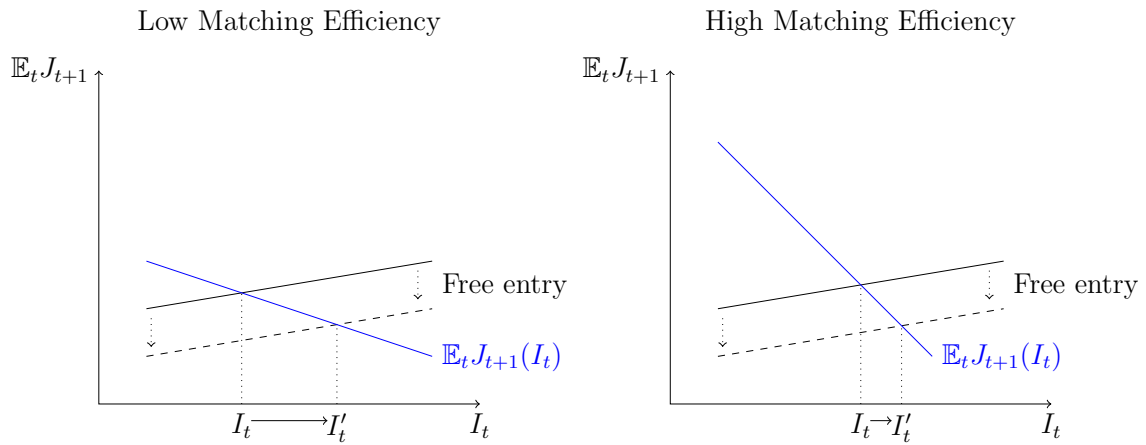


Figure 6: A shift in the free entry curve under low and high matching efficiency.

5 Numerical Results of the DSGE Model

5.1 Calibration of Parameter Values

The model has 24 parameters that I calibrate in three groups. I calibrate the first group on a parameter-by-parameter basis. I calibrate the second group jointly to match steady-state targets. For both of these groups, the parameters are calibrated to using 1984:1 to 2008:6 as a baseline time period for many of the parameters, corresponding to the sample period of the FAVAR. Finally, I calibrate the third group to minimize the distance between the DSGE model's and the FAVAR's IRFs. Table 1 summarizes the calibrated values.

In the first group of parameters, I calibrate steady-state inflation, Π , to be 2% in order to match the the Fed's target inflation rate. Given this, I calibrate the subjective discount factor, β , to give a steady-state risk-free interest rate of 5.3%, which was the average effective federal funds rate from 1984:1 to 2008:6. Next, I calibrate the probability of not changing non-durables prices, α , to give a mean price duration of 12 months, which is the effective duration suggested by Kehoe and Midrigan (2015). I calibrate ϵ so that $\epsilon/(\epsilon - 1) = 1.2$, yielding a steady-state price mark-up of 20%, which is common in the new Keynesian literature (Galí, 2008; Christiano, Trabandt, and Walentin, 2010). Following Galí (2008), I calibrate the policy responses to the GDP gap and the inflation gap, ψ_y and ψ_π , to be 0.5/12 and 1.5.²³ To calibrate depreciation, Equations (10), (12), (14), (15) and (16) yield $\delta = I/(H_o + U)$ in the steady-state. Because $H_o + U$ represents the entire housing stock (both owner-occupied and not owner-occupied), depreciation equals the steady-state ratio of housing units that get built to the entire housing stock. Thus, I set $\delta = 0.0011$, which reflects the monthly average of housing starts provided in the Census's new residential construction data divided by the average housing inventory provided in the Census's housing vacancies and homeownership data.²⁴ To calibrate the rate of separation, χ_r , I use migration data from the Current Population Survey, which indicates that about 8% of owner-occupiers moved per year from 1988 to 2008.²⁵ Thus, given the value of δ , I set χ_r to solve $1 - ((1 - \delta)(1 - \chi_r))^{12} = 0.08$. I calibrate the bargaining weight, ω , to be 0.5, giving buyers and sellers equal bargaining power. The fraction of the house price borrowed, θ , is 0.85. This suggests that households can borrow slightly more than the standard 20% down payment, and it is the parameter value used in Iacoviello and Neri (2010). I set $\eta = 0.02$ which implies that 99.9% of the mortgage principal is paid off after 30 years. Finally, I take the steady-state productivity of labor in both the non-durables and housing sectors to be the unconditional means of these productivities and normalize them to $A_X = A_I = 1$.

The second group of parameters, which I calibrate jointly, includes $\gamma_{H,o}$, the unconditional

²³These values are also similar to the estimates in Christiano, Trabandt, and Walentin (2010).

²⁴This yields an annualized depreciation rate of 1.3%, which falls in the the 1% to 3% range noted in Davis and Van Nieuwerburgh (2015).

²⁵Migration data can be found at <http://www.census.gov/hhes/migration/data/cps/historical.html>. Dieleman, Clark, and Deurloo (2000) use data from the American Housing Survey that yields similar values.

Table 1: Summary of Calibrated Parameter Values

| Parameter | Description | Value |
|---|---|--------|
| Parameters calibrated individually: | | |
| Π | Steady-state inflation | 1.0017 |
| β | Household discount factor | 0.9974 |
| α | Probability of no price change for non-durables | 0.9167 |
| ϵ | Elasticity of substitution for non-durables | 6 |
| ψ_π | Policy response to inflation gap | 1.5 |
| ψ_y | Policy response to output gap | 0.0417 |
| δ | Housing depreciation | 0.0011 |
| χ_r | Probability of owner-occupiers separating | 0.0058 |
| ω | Bargaining weight | 0.5 |
| θ | Fraction of house price borrowed | 0.85 |
| η | Monthly fraction of principal repaid | 0.02 |
| A_X | Steady-state non-durable productivity | 1 |
| A_I | Steady-state housing productivity | 1 |
| Parameters calibrated jointly to steady-state moments: | | |
| $\gamma_{H,o}$ | Steady-state owner-occupier premium | 0.2989 |
| $\gamma_{H,r}$ | Renter utility | 1.8884 |
| γ_N | Dis-utility of labor | 14.151 |
| \bar{H} | Size of a house | 35.470 |
| ζ | Matching efficiency | 0.6057 |
| κ_1 | Administrative costs | 1.4021 |
| κ_2 | Utility cost of search | 1.7460 |
| Parameters calibrated to empirical IRFs: | | |
| ν | Habit persistence | 0.9383 |
| ρ_r | Persistence of policy rule | 0.9853 |
| ι | Degree of housing investment costs | 21.316 |
| ϕ | Elasticity of marginal administrative cost | 0.0007 |

mean of the utility premium from being an owner-occupier that I also use to be the steady-state value, $\gamma_{H,r}$, the utility value of renting a house, γ_N , the dis-utility of labor, \bar{H} , the size of a housing unit, ζ , the efficiency parameter of the matching function, κ_1 , the administrative cost of mortgages, and κ_2 , the utility cost of searching for a house. I calibrate these 7 parameters to 7 steady-state values. First, I set $H_o = 0.658$, which corresponds to an average homeownership rate of 65.8%. Second, I normalize $V_r = 1$ to ensure that V_r , V_s and V_o are all non-negative and that log-linearizations can be taken. Third, I set $N = 1$. Fourth, I set the ratio $Q/(PY)$ to 27 because it takes 27 months of GDP per household to pay for the price of a house. Using annual data from from 1984 to 2008, the ratio of the average sales price of a new house to GDP per capita is about 6. Given an average number people per household of 2.62 over this sample, it takes a little under 2.3 years or about 27 months of GDP per household to pay for a house.²⁶ Fifth and sixth, I target $1/F = 2.7$ and $1/G = 2.5$ so that searching renters expect to search for 2.7 months before buying a house and that houses average 2.5 months on the market. This is from Genesove and Han (2012), who use survey data from the National Association of Realtors from 1987 to 2008 and show that the average search time for a house is a little under 12 weeks and the average selling time of a house is a little under 11 weeks.²⁷ Seventh, I target a mortgage spread of 1.7%, which is the average of the 30-year conventional mortgage rate less the 10-year treasury bond at a constant maturity rate.

Finally, I calibrate the third group of parameters to minimize the distance between four of the IRFs from the DSGE model and four corresponding IRFs from the FAVAR. These parameters are habit persistence in consumption, ν , persistence of the policy rule, ρ_r , housing investment adjustment costs, ι , and the elasticity of marginal administrative costs, ϕ . From the DSGE model, I use the IRFs for the risk-free interest rate, inflation of non-durable goods, consumption of non-durable goods, and residential investment. The corresponding IRFs from the FAVAR are the effective federal funds rate, inflation of the consumer price index excluding shelter, personal consumption expenditures of non-durable goods, and real residential spending on new single family houses.²⁸ I use the first 36 steps for both the DSGE and FAVAR IRFs. Collecting these IRFs into vectors gives a 144×1 vector of DSGE IRFs, denoted by Ψ_D , and a 144×1 vector of FAVAR IRFs, denoted by Ψ_F . Then, the third group of parameters minimize $(\Psi_F - \Psi_D)'(\Psi_F - \Psi_D)$.

Before examining the dynamic responses from the DSGE model, I first discuss three parameter values in the calibration. First, κ_1 has a value of 1.4. While this is difficult to

²⁶Historical data about the size of households is from the Census Bureau: <http://www.census.gov/hhes/families/data/households.html>.

²⁷Genesove and Han (2012) provide a median buyer search time of 8.1 or 8.2 weeks and a median seller time of 7.3 or 7.6 weeks, depending on the survey they present. Because the geometric distribution used in this paper to estimate average search times does not provide a unique mapping from median to mean search times, I convert from median to mean using the exponential distribution. This provides a mean buyer search time of 11.7 or 11.8 weeks and a mean selling time of 10.5 or 11 weeks.

²⁸I use residential spending on single family houses because housing units in the DSGE model function as single family homes.

interpret on its own, we can use it to compare the size of the administrative costs relative to the total value of loans made in the steady state. Total administrative costs are $\kappa_1 S_t^{1+\phi}$, and the total value of loans is $\theta Q_t S_t$. In the steady-state, the calibrated DSGE suggests that total administrative costs are 5.5% of the total value of loans made. To assess this value, I compare it to data from the annual report and the consolidated financial statements of the University of Wisconsin Credit Union (UWCU). This particular institution has two appealing features. First, because it is a credit union, its financial services are directed towards consumers and not towards firms, making it comparable to the DSGE model. Second, it discloses its loan processing expense. In 2014, UWCU made \$602 million in student, auto and mortgage loans and had a loan processing expense of \$10 million.²⁹ Thus, their loan processing costs were 1.7% of new loans made. However, this expense is a narrow category that excludes other expenses that are necessary for administering loans, such as salaries, office occupancy and operations expenses, and marketing and advertising. Thus, this 1.7% should be viewed as a lower bound on administrative costs. When all non-interest expenses are included (excluding a one-time valuation allowance), UWCU had \$66 million in expenses, which is 11.0% of new loans made. Because some of these expenses are surely for services other than making loans, this 11.0% should be viewed as an upper bound on administrative costs. Because the 5.5% from the steady-state of the DSGE model falls within 1.7% and 11.0% bounds, κ_1 provides an empirically reasonable degree of administrative expenses for use in the DSGE model.

As with κ_1 , the size of κ_2 is difficult to interpret on its own. So, I compare it to the value steady-state value of $V_{o,t} - V_{r,t}$, which is the value of switching from being a renter to being an owner occupier. In the steady state, κ_2 is 0.3% of this switching value, suggesting that the utility cost of searching for a house for one month is very small compared to the utility benefit of switching from being a renter to being an owner.

Finally, the calibrated value of ϕ is 0.0007. This is the effective lower bound for this parameter that allows the model to satisfy the Blanchard and Kahn (1980) condition. Hence, even though $\phi > 0$, implying that the financial intermediary has increasing marginal costs in administering mortgages, the elasticity of these marginal costs with respect to number of mortgages is very small.

5.2 The Dynamic Effects of a Monetary Policy Shock

Figure 7 displays the IRFs from the DSGE model and the FAVAR to a monetary shock that is normalized to a 0.25% reduction in the federal funds rate along with the bootstrapped 90% confidence intervals from the FAVAR. The four panels of Figure 7 show the four IRFs from the DSGE model that were fit to the IRFs from the FAVAR. There are two important takeaways from this figure. First, residential investment in the DSGE model fits the FAVAR's IRF for real residential spending on single family homes well. While the initial response from the DSGE model is a little too large, the DSGE model matches the hump-shaped response

²⁹Of the \$602 in new loans, 73% was mortgage lending.

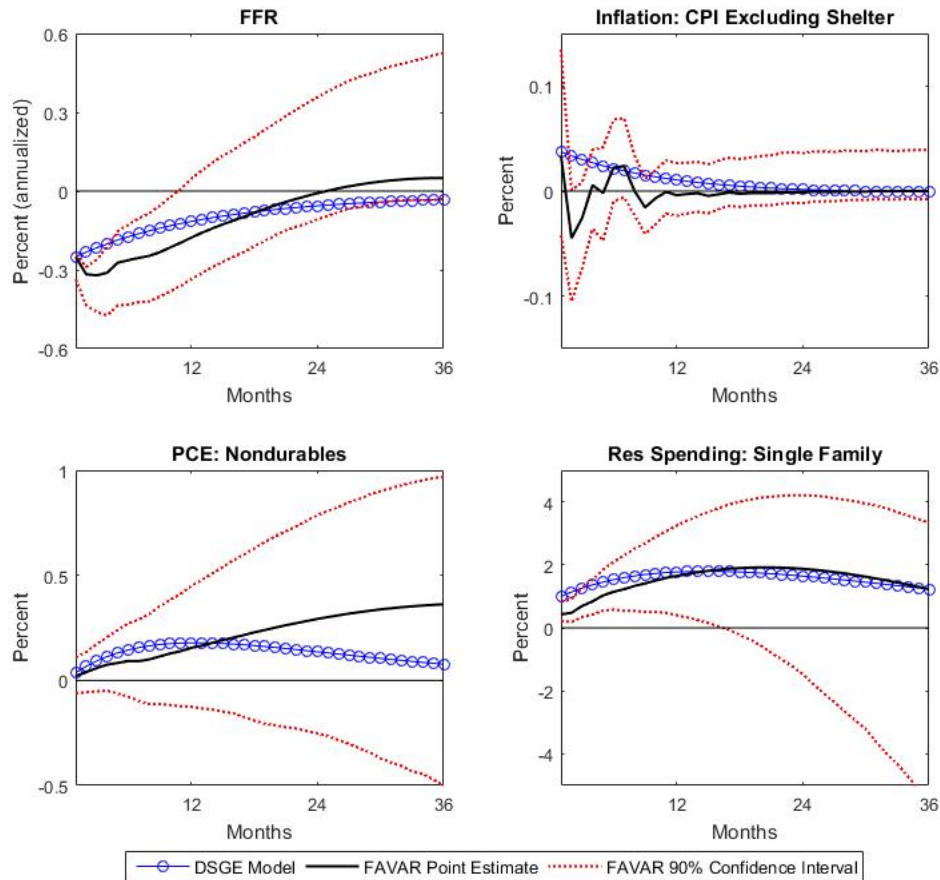


Figure 7: Impulse response functions from the DSGE model and the FAVAR to a monetary policy shock normalized to a 0.25% cut to the effective funds rate.

that is present in the data. In addition, the peak response from the DSGE model is 1.8%, and the peak response from the FAVAR is 1.9%. This shows that target matching rates, F_t and G_t , in the calibration provide enough search frictions to produce the large response of housing construction in the DSGE model that we see in the data.

The second important takeaway from Figure 7 is that both non-durable consumption and residential investment increase in the DSGE model following a surprise cut to the risk-free rate, which is consistent with the IRFs from the FAVAR. Thus, the DSGE model does not suffer from the new Keynesian puzzle in Barsky, House, and Kimball (2007) where production of flexibly-priced durable goods, such as houses, falls in response to an expansionary monetary policy shock while non-durable production rises. Barsky, House, and Kimball's (2007) intuition for this response is that the relative price of durable to non-durable goods rises following an expansionary shock, and because households do not need to purchase new durable goods every period, they can substitute their purchases of durable goods to the

future when they will be relatively cheaper. However, this reasoning does not apply here because individual households do not adjust their stock of housing in my DSGE model.

The intuition for the positive response in residential investment in my model is laid out by the DSGE's IRFs displayed in Figure 8. This figure shows that a surprise cut in the risk-free rate causes a jump in the number of households that begin searching for a house to buy. They are incentivized to do this by the drop in the mortgage spread that follows a cut in the risk-free rate. As shown in Equation (42), a drop in the mortgage spread increases the total surplus of a housing match, leading to a jump in consumer surplus that makes searching for a house more attractive. The increase in the number of searching households causes an increase in house sales and an increase in the house selling rate, incentivizing investment firms to produce more housing units. In addition, Figure 8 shows that an expansionary monetary shock increases the homeownership rate and house prices in the DSGE model.

To study the empirical validity of the results in Figure 8, I compare them to IRFs from the FAVAR, which are displayed in Figure 9 along with the FAVAR's 90% confidence intervals. Unlike Figure 7, which overlays the IRFs from both the DSGE model and the FAVAR, I display the IRFs in Figures 8 and 9 separately because the data in the FAVAR is not always directly comparable to the variables in the DSGE model. To begin with, there is no monthly or quarterly data that tracks how many renting households begin searching to buy a house. Hence, the first panel of Figure 9 is left blank. However, the remaining panels in Figure 9 all show that the IRFs from the DSGE model are qualitatively consistent with those from the FAVAR. Further, several of the DSGE's IRFs in Figure 8 are quantitatively similar to the FAVAR's IRFs in Figure 9. This is true despite the fact that only the IRFs in Figure 7 have been calibrated to fit the data. Thus, the IRFs in Figures 8 and 9 provide extra data moments to compare the DSGE model to the FAVAR.

In the DSGE model, a drop in the mortgage spread transmits an expansionary monetary policy shock to the housing market. Consistent with this mechanism, Figure 9 shows that the mortgage spread drops following an expansionary monetary policy shock in the FAVAR. While the FAVAR indicates that this drop is hump-shaped, unlike in the DSGE model, the peak responses are similar for the FAVAR and the DSGE model. The peak drop in the FAVAR is 0.023% while the peak drop in the DSGE model 0.016%. Thus, the DSGE accounts for about 70% of the observed drop in the mortgage spread.

Next, Figure 9 shows that an expansionary monetary policy shock causes a jump in consumer perceptions that now is a good time to buy a house. This series is from the University of Michigan's survey of consumers, which asks the question, "Generally speaking, do you think now is a good time or a bad time to buy a house?" These responses form an index that subtracts the number of consumers who respond "bad" from the number who respond "good" and adds 100. While this index does not measure utility units, I use it as an analog to consumer surplus in the DSGE model, and its response in Figure 9 is consistent with the response of consumer surplus in Figure 8.

House sales in both the DSGE model and the FAVAR increase following a monetary policy shock. However, the size of the increase in the DSGE model is between 2 and 8 times

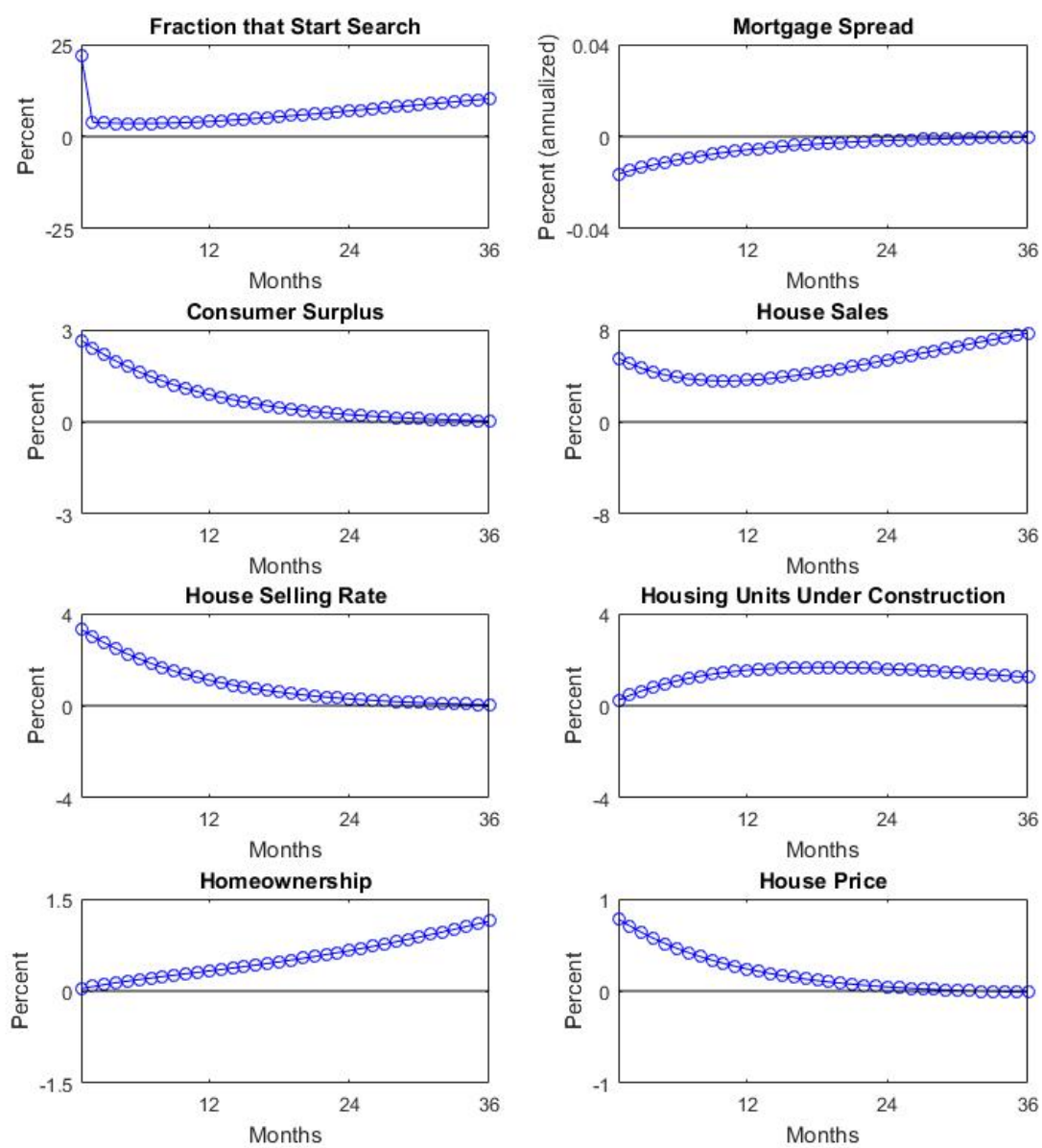


Figure 8: Impulse response functions from the DSGE model to a monetary policy shock normalized to a 0.25% cut to the effective funds rate.

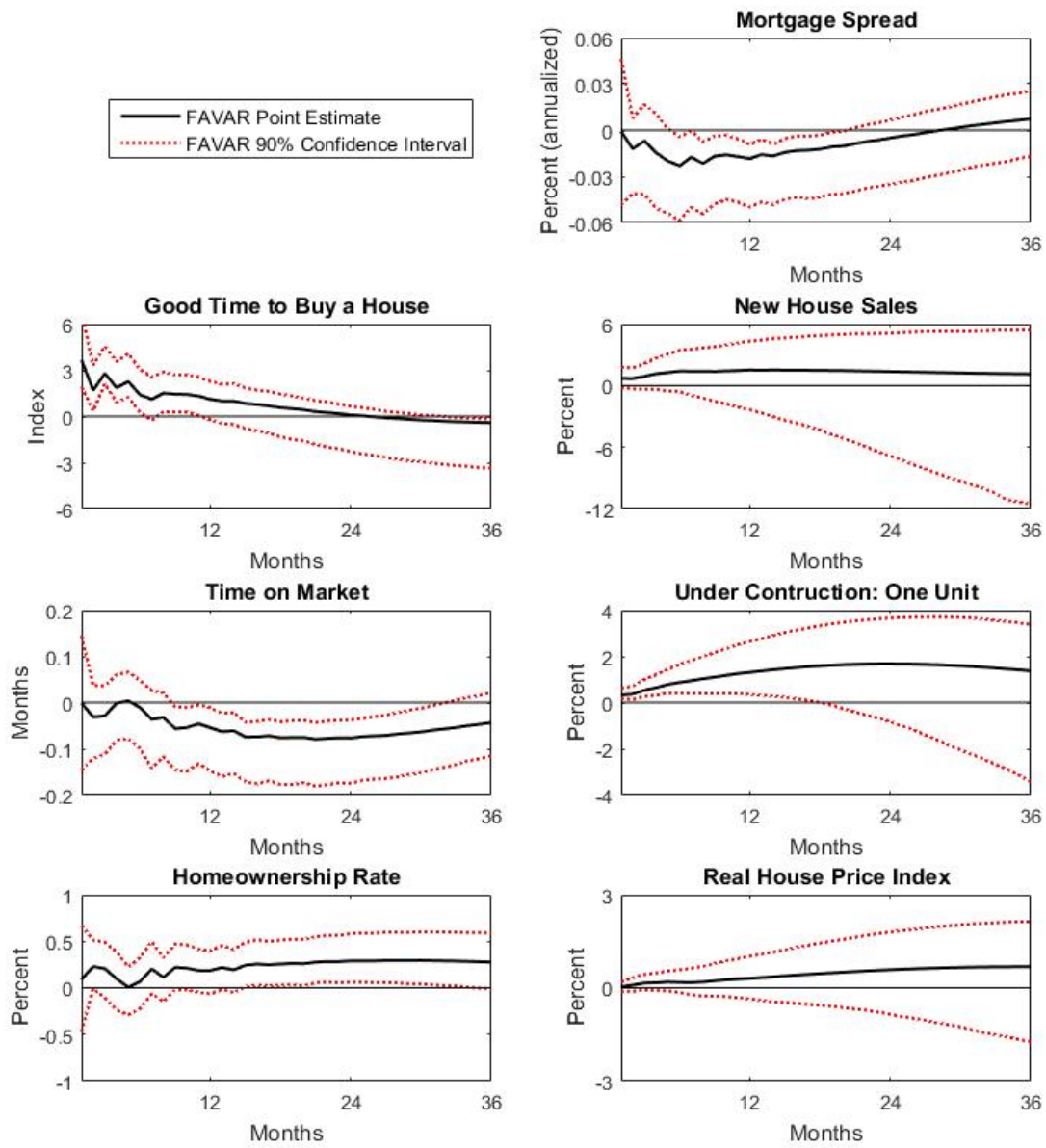


Figure 9: Impulse response functions from the FAVAR to a monetary policy shock normalized to a 0.25% cut to the risk free rate.

larger than the increase in the FAVAR depending on the IRF horizon. One explanation for this discrepancy is that the DSGE model only has one-month time to build while data from the Census Bureau indicates that new houses take about 6 months to build on average. Thus, when the DSGE model matches residential spending in the data, it does so with only one vintage of houses being built, while Census data indicates that there should be about 6 vintages of houses being built at any time. Therefore, the DSGE model needs the number of housing units in each vintage to be about 6 times larger than what is indicated from Census data. This will lead to many more new houses being available for sale and ultimately being sold in the DSGE model than in the FAVAR.

Next, Figure 9 shows that the time that new houses spend on the market after being completed falls following an expansionary monetary policy shock. This is consistent with an increase in the house selling rate, G_t , in the DSGE model. Standard macroeconomic models of housing construction cannot explain this feature of the data because their markets for new housing always clear. However, by incorporating search and matching, my DSGE model is able to provide economic theory to explain this response.

The number of housing units under construction increases in both the DSGE model and the FAVAR following an expansionary monetary policy. Further, both the DSGE and the FAVAR display hump-shaped responses that peak at 1.7%. Thus, the model does a very good job of explaining the number of housing units under construction, which is the primary driver of residential investment.

Next, Figure 9 shows that the homeownership rate rises following an expansionary monetary policy shock, which is consistent with the DSGE model. However, the size of the response in the DSGE model is nearly 4 times the response of the FAVAR after 36 months. This is due to the higher rate of house sales in the DSGE model than in the FAVAR. Thus, adding time to build would likely improve the DSGE model's fit for the homeownership rate as well as house sales. However, providing a response to the homeownership rate that is qualitatively consistent with the FAVAR is still an important contribution of the DSGE model. This is because macroeconomic models of housing typically assume that all households own some housing. Thus, homeownership is always 100% in those models, and there is no way to explain the FAVAR's increasing homeownership rate.

Finally, real house prices rise in both the DSGE model and the FAVAR.³⁰ However, the shape of the rise is different. In the DSGE model, house prices jump in response to a monetary policy shock before fading back to the steady-state. However, the FAVAR indicates that house prices should slowly rise over time. This suggests that the simple bargaining protocol used in the DSGE model does not provide enough persistence in house prices. Alternative protocols may increase the persistence, or persistence can be mechanically introduced by following Ungerer (2015).

³⁰Real house prices in the FAVAR are CoreLogic's national home price index (SFC) divided by the CPI for all items less shelter.

6 Conclusions

On average, residential investment has been a smaller share of aggregate expenditures than non-durable consumption and services, durable consumption, or non-residential investment. Further, residential investment is rarely included in theoretical models of monetary policy. However, in this paper, I show that the earliest and largest changes in output from monetary policy shocks occur in residential investment. To show this, I estimate a FAVAR and identify the monetary policy shocks with a proxy variable that is constructed in the spirit of Romer and Romer (2004). The impulse response functions from this FAVAR show that residential investment makes a larger cumulative contribution to GDP than non-durable consumption and services, durable consumption, or non-residential investment in the first 15 months following a monetary policy shock, demonstrating that residential investment is central to understanding the transmission of monetary policy.

I also document that fluctuations in residential investment are driven by fluctuations in the number of new housing units built, not by fluctuations in the size of new or existing housing units. To do this, I show that improvements to existing housing only contributes 1% of the variance in residential investment growth while investment in new structures contributes 64% of the variance in residential investment growth. In addition, I show that the number of units completed contributes 97% of the variance in the growth of new total housing square footage while average square feet per unit only contributes 3%.

Motivated by these two empirical results, I develop a new Keynesian DSGE model where houses are built in discrete units of one size and are bought and sold through a time-consuming search and matching process. The model shows that search frictions are central to generating fluctuations in residential investment and that the number of housing units under construction will not deviate from its steady-state without these frictions.

In addition to the search frictions, I assume that all houses are bought with mortgages that have administrative costs, leading to a spread between mortgage rates and risk-free long-term rates. This mortgage spread transmits monetary policy to the housing sector. An expansionary monetary shock reduces the mortgage spread, increasing the total surplus from a housing match, and incentivizing more households to search for a house and more firms to build housing units. The size of the administrative costs in the DSGE model are comparable to those of an actual financial institution. Further, the size of the drop in the mortgage spread in the DSGE model is only modestly smaller than what is observed empirically.

Finally, the DSGE model can produce the large responses in residential investment that are observed in the data, and it does not suffer from the counterfactual responses of other new Keynesian models that have flexible housing prices (Barsky, House, and Kimball, 2007). However, the DSGE model does indicate that house sales and the homeownership rate should rise much more than what is observed in the data. Further, it gives an immediate jump in house prices rather than the gradual rise observed in the data. I conjecture that future research that includes time to build in housing construction and investigates alternative bargaining protocols can improve model fit along these dimensions.

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