ABSTRACT

ABDULRAHEEM, MAYTHAM. The Macroeconomics of Housing in the US. (Under the direction of James Nason.)

This dissertation studies the macroeconomics of housing in the US. It consists of two essays. The first essay examines the role the housing market has in the US business cycle. The second essay explores more the relationship between the housing market and the mortgage market with a special focus on the 2007-2009 financial crisis.

The first essay studies the role of housing in the US economy since 1971. The focus is on the impact of the housing and mortgage markets on the business cycle and monetary transmission mechanisms. A ten variable TVP-SV-SVAR is used to address several issues. I study the effect of housing demand and supply shocks on the US business cycle and mortgage rates. Additionally, the impact of mortgage credit shocks on the US business cycle and the housing market is examined. Finally, I discuss the interactions between the US housing market and Fed monetary policy. The evidence shows: (i) housing demand shocks play only a small role in the US business cycle and in determining mortgage rates; (ii) housing supply shocks are more relevant to the 2007-2009 financial crisis than housing demand shocks; (iii) mortgage credit supply shocks have considerable effects on housing supply and inflation; (iv) monetary policy has a substantial effect on the US housing market since 1971.

In the second essay, I estimate a SVAR with housing and mortgage markets to study the 2007-2009 financial crisis along three dimensions. First, the essay examines the links between the composition of mortgage-backed securities (MBS) and the US housing market in the run-up to the financial crisis. Second, the role liquidity shocks and GSEs played in triggering the financial crisis is explored. Third, I evaluate the effectiveness of the quantitative easing (QE) programs in reducing the mortgage spread. Five main findings emerge from the estimations. First, a shock to the private-label share of MBS generates an increase in house prices, especially in 2004-2006. Second, housing demand shocks raise private MBS issues relative to securities issued by the GSEs. This response is particularly strong from 2003 to 2006. Third, liquidity shocks are the most important driver of the commercial paper spread during the 2007-2009 financial crisis. Fourth, the GSEs role in the collapse of the MBS market is limited. Finally, the effect of QE programs on the mortgage spread is minimal.

The Macroeconomics of Housing in the US

by
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DEDICATION

This dissertation is dedicated to my mother, Seryana, for her unconditional love and support. To my loving and caring father, Abdulraheem. To my beloved wife, Mariam, for sharing this journey with me and for her unlimited support. For my son Ali and my daughter Ghadeer for being adorable. Without you all, I could not have done it.

BIOGRAPHY

Maytham was born in Kuwait. He completed his high school education in Hadiya city and became a student at Kuwait University in 2009. In 2012, Maytham participated in an exchange program in Barcelona, Spain, where he attended ESADE Business School for one semester. In 2014, he received a Bachelor of Arts (BA) in Economics from Kuwait University. Later in 2014, he attended the Economics Master program at North Carolina State University. From 2016 to 2020, Maytham conducted his Doctoral research in macroeconomics. He will join the economics department at Kuwait University as an assistant professor in 2020.

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1

INTRODUCTION

I study the role of housing in the macroeconomy in my dissertation. This research has three goals. The first goal is to understand better the effects of movements in housing demand and supply on the US business cycle and mortgage market. Second, I report on the dynamic responses of the business cycle and housing market to changes in mortgage market conditions. Third, my dissertation gives more evidence about the interactions between the US housing market and Federal Reserve monetary policy.

Housing and mortgages markets have been at the center of research on the US business cycle and monetary policy for 40 years or more. Figure 1.1 shows the annual growth rate of real residential investment in single-family structures from 1972 to 2018. The plot shows that the growth in residential investment declined by 41% during the recession of 1980 and by 52% during the 2007-2009 recession. In between these recessions, aggregate US house prices most often were growing and, in fact, increased for ten years in a row from 1997 to 2006. These observations on housing markets in the US occurred at the same time there were substantial changes to the way in which mortgage markets operated. The collapse in the Savings and Loan industry in the 1980s and early 1990s was followed by the increasing use of mortgage-backed securities (MBS) in the US financial markets [Fra05]. The innovation of MBS was argued to deepen the pool of funds available to households to buy homes and to lower the cost of these loans.

My first essay studies the role housing markets have in the US business cycle. An innovation of this essay is to separate actions taken in the housing market from decisions made in mortgage markets. This separation lets me study the effects of changes in the flow of investment into the stock of single-family homes on the US housing sector and aggregate economy from responses to shifts in the prices and quantities of mortgage credit available to households. Another benefit of acknowledging the inherent differences in housing and mortgage markets is that I can identify the responses of these markets to non-systematic changes in Federal Reserve monetary policy. The results of this research are that (i) I estimate the demand for housing plays only a small role in the US business cycle and in determining mortgage rates; (ii) unexpected changes to housing supply are more important during the 2007-2009 financial crisis than are unanticipated shifts in housing demand; (iii) disturbances to the supply of mortgage credit have large effects on housing supply and inflation; and (iv) monetary policy has substantial effects on the US housing market since 1971.

I take a different approach in the second essay of my dissertation. This essay explores the relationship between US housing and mortgage markets. An important part of this relationship is the sources of funding for financial firms supplying mortgage credit to households in the US. Since the 1980s, the sources of this funding have changed because there have been ongoing innovations in the US mortgage market. As already mentioned, an important innovation is the use of MBS, which helped create an active secondary market for mortgages. The Federal National Mortgage Association (Fannie Mae) and the Federal Home Loan Mortgage Corporation (Freddie Mac) were created by Congress to broaden and deepen this secondary market and lower the cost of mortgages by buying these loans to repackage them as MBS. However, for a mortgage to qualify to be part of a MBS issued by Freddie Mac and Fannie Mae, these securities had to meet several conditions. For example, the loan to value ratio of the mortgage had to be less than 80%. The sources and character of MBS changed in the run-up to the 2007-2009 financial crisis. A key change is that an increasing share of MBS issues were by banks and other private-sector financial firms. These firms issued MBS built on subprime and Alt-A mortgages. These mortgages were riskier than conventional mortgages handled by Freddie Mac and Fannie Mae.

These changes motivate me to examine in my second essay the effects on US house prices of changes in the composition of which financial firms are issuing MBS. I also report on the sources and causes of the 2007-2009 financial crisis along with the impact of Federal Reserve policy response on US housing and mortgage markets. My second essay has five main results. First, an unexpected change to the private-label share of MBS generates an increase in house prices, especially from 2004 to 2006. Next, private-label MBS increases relative to securities issued by Freddie Mac and Fannie Mae in response to an unanticipated change in the demand for housing. This response is particularly strong from 2003 to 2006. Third, unpredictable changes to the short-term credit available to banks and firms to fund long-term risky assets are responsible for a large part of the movements in the commercial paper spread during the 2007-2009 financial crisis. Fourth, the role of Freddie Mac and Fannie Mae in the collapse of the MBS market is limited. Finally, the effect of Federal Reserve policy responses to the 2007-2009 financial crisis on the mortgage credit spread is minimal.

The essays cover more than 40 years of US economic history. Macroeconomists such as Frame & White [Fra11], Stock & Watson [Sto03], Sims & Zha [Sim06], among others, show that the housing markets, aggregate economy, and the conduct of monetary policy underwent substantial structural change since the 1970s. For example, Freddie Mac and Fannie Mae created an active secondary market, which stimulated mortgage origination and contributed to greater efficiency in housing finance. For the aggregate economy, Stock & Watson [Sto03] presents evidence on the structural change brought by the Great Moderation that started in the mid-1980s, a period of a large decline in the volatility of real activity and inflation measures. Also, there are four different chairmen of the Federal Reserve between 1970 and 2006. Sims & Zha [Sim06] identify three different regimes of monetary policy conduct during this period. They label these regimes as the Burns Regime, Volcker Regime, and Greenspan Regime. Recent developments in the empirical macroeconomic literature provide useful tools to account for time variation in the data. From that literature, I use a time-varying parameter structural vector autoregression with stochastic volatility (TVP-SV-SVAR) to account for time variation in the samples of my two essays. The TVP-SV-SVAR captures time variation in VAR models by allowing for drifting impact coefficients, intercepts, reduced form slope coefficients, and stochastic volatility.

The dissertation is organized as follows. The next chapter discusses the first essay titled Housing, Monetary Policy, and the US Economy. Chapter 3 describes the second essay titled Housing Booms and Busts. The last two sections in the dissertation provide appendices for chapters 2 and 3.

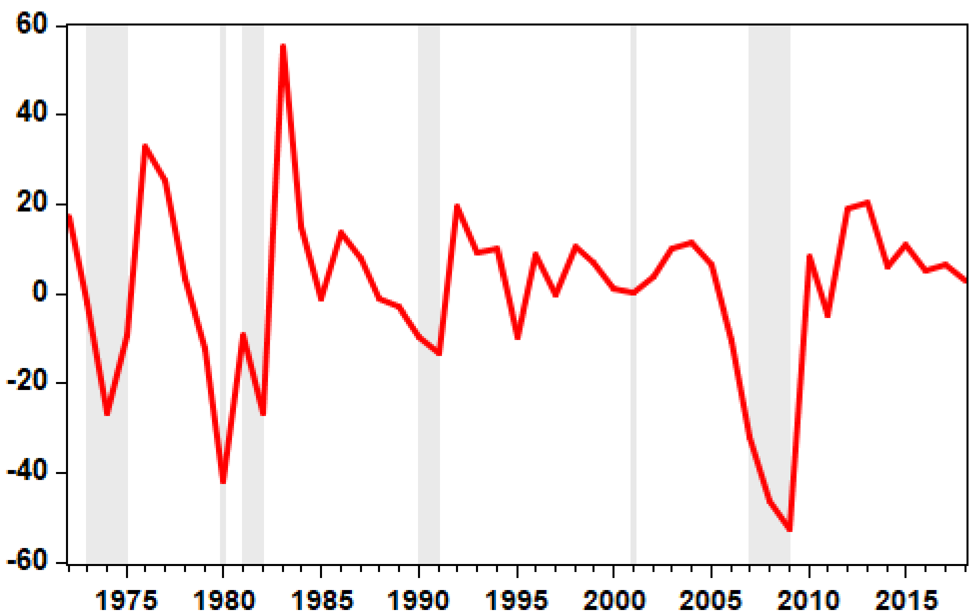

Figure 1.1 Real Residential Investment in Single Family Structures, 1972-2018

Notes: The plot shows the annual growth rate of real residential investment in single family structures. NBER recession dates appear as gray shading.

CHAPTER

2

HOUSING, MONETARY POLICY AND THE US ECONOMY: A TIME-VARYING APPROACH

2.1 Introduction

The financial crisis of 2007-2009 shed a light on the role housing and mortgage markets play in the US business cycle and monetary policy transmission. Accounts of the run-up to the crisis vary, yet most agree on a central role for housing and mortgage markets. One such account is provided by The Financial Crisis Inquiry Commission report to Congress [Com11]. According to the FCIC, “it was the collapse of the housing bubble—fueled by low interest rates, easy and available credit, scant regulation, and toxic mortgages that was the spark that ignited a string of events, which led to a full-blown crisis in the fall of 2008". By the time the FCIC report was published, more than eight million American families had either lost their homes to foreclosure, started the foreclosure process, or were failing to meet their mortgage payments. With its destructive impact on the housing market, financial markets, household wealth, and the labor market, the 2007-2009 crisis qualifies as the worst in US postwar history.

Nonetheless, the importance of the housing market for the US business cycle begins well before 2007. Investment in residential structures is a leading indicator of the US business cycle [Gre91; Dav05]. As figure 2.1 shows, real residential investment often falls prior to NBER recession dates. Further, the sharp fall in real residential investment growth in the 1980 recession is as severe as during the 2007-2009 financial crisis.

This paper studies the interplay between the US housing market, mortgage markets, and the business cycle from 1971q3 to 2018q4. I explore the role housing demand and supply shocks have in US aggregate fluctuations and on movements in mortgage rates. Second, the impact of mortgage credit supply shocks on the US aggregate economy and housing market is examined. Lastly, I discuss the interactions between the US housing market and Fed monetary policy.

I study these issues using a time-varying parameter structural vector autoregression with stochastic volatility (TVP-SV-SVAR). The TVP-SV-SVAR has ten identified shocks. The shocks are housing demand, housing supply, construction cost, mortgage credit supply, monetary policy, fiscal, liquidity, permanent income, markup, and real demand. Estimates of the TVP-SV-SVAR lead to four main conclusions. First, housing demand shocks play only a limited role in the US business cycle and no role in determining the average mortgage rate. For example, a one-percent shock to housing demand results in less than 0.15 percent increase in real consumption between the one year and the five-year horizons over the sample dates. The shock also has no statistically or economically significant effect on mortgage rates at all dates and horizons.

For the 2007-2009 financial crisis, the stochastic volatility of housing supply shocks dominates that of housing demand shocks. The stochastic volatility of housing supply shocks peaks in the 2007-2009 financial crisis. Meanwhile, the stochastic volatility of housing demand shocks is unchanged from the early 1970s until the end of the sample in 2018.

Third, the supply of mortgage credit is important for business cycle fluctuations. A negative shock to the supply of mortgage credit has a deflationary effect on the aggregate price level and causes a large contraction in real residential investment across all sample dates. At the three-quarter horizon, a one-percent credit supply shock causes a drop in inflation of 1.7 percent and in real residential investment by about 16 percent. Four to five years after the shock, inflation goes back to the steady-state, but the cumulative decline of real residential investment reaches 10 percent.

Finally, monetary policy has a substantial effect on the housing market. In this market, the effect falls mainly on real residential investment rather than the price of residential investment. A one percent monetary policy shock causes residential investment to decline by 35 percent at the five-quarter horizon across all sample dates. At the three year horizon, the monetary policy shock results in a cumulative drop of more than 50 percent in real residential investment. The negative response of residential investment persists five years after the shock, and in post-2004 the median decline exceeds 60 percent. Over the sample, the transmission of monetary policy shocks to the aggregate economy fails to display significant time variation.

The TVP-SV-SVAR is estimated on a sample that covers more than 40 years of US economic history. Several events during these years raise the issue of structural change in the data. Specifically, there is ample evidence that structural change has affected the US housing sector, mortgage market, aggregate economy, and monetary policy conduct since the start of the sample in the 1970s. Frame & White [Fra05] and Frame & White [Fra11] present evidence of structural change in the structure of US mortgage markets. They discuss the history of the mortgage market and the fundamental change it underwent since the 1970s. A list of changes includes, but are not limited to, a shift in the banks' model of funding away from deposits towards capital-market funding in the early 1980s, the abolishment of regulation Q and the introduction of laws allowing for variable-rate mortgages in the 1980s, the development of the secondary mortgage market which started in the late 1960s by the creation of Ginnie Mae and privatization of Fannie Mae, the adoption of credit scoring and automatic underwriting procedures by the banking industry in the mid-1990s, and the emergence and growth of the sub-prime mortgage market in the mid-1990s.

These developments affected the mortgage industry in several ways. First, the introduction of variable-rate mortgages transfers interest rate risk from the lender to the borrower. Second, the adoption of credit scoring and other technological advancements helped reduce the cost of mortgage underwriting. Third, GSEs guaranteed a wide array of mortgages' against credit risk and created an active secondary market, which stimulated mortgage origination and contributed to greater efficiency in housing finance. Finally, new mortgage products, such as sub-prime mortgages, reached broader segments of first-time home-buyers that were excluded from traditional fixed-rate mortgages.

For the aggregate economy, Stock & Watson [Sto03] present evidence on the structural change brought by the Great Moderation. They show that starting in 1984 there is a large decline in the volatility of real activity and inflation measures. Finally, Sims & Zha [Sim06] find evidence of changes in monetary policy behavior in the period between 1959 and 2003. Identifying regime switching with a Markov switching process, they find three different regimes of monetary policy which they label as the Greenspan Regime, Burns Regime, and Volcker Regime.

I account for structural change by using a TVP-SV-SVAR model. Time variation in VAR models was introduced in papers by Primiceri [Pri05], Cogley & Sargent [Cog01], Cogley & Sargent [Cog05], Sims & Zha [Sim06], and Canova & Pérez Forero [Can15]. To estimate the model, I use the Metropolis within Gibbs algorithm of Canova & Pérez Forero [Can15]. This model allows for time variation in the impact coefficients, intercepts, reduced form slope coefficients, and stochastic volatility.

Macroeconomists have taken various routes to incorporate the housing and mortgage markets in their models. One strand of research explores the lead-lag relationships between the business cycle and residential investment. Greenwood & Hercowitz [Gre91] and Davis & Heathcote [Dav05] construct RBC models motivated by the observation that residential investment is a leading indicator of the US business cycle. Iacoviello [Iac05] and Iacoviello & Neri [Iac10] incorporate the housing market into NK-DSGE models.

Jarocinski & Smets [Jar08] and Musso, Neri and Stracca (2011) follow another route. They construct Bayesian SVARs that include federal funds rate, inflation, aggregate consumption, residential investment, and real house prices. Jarocinski & Smets [Jar08] also have M2 in their VAR. Both papers use recursive identification schemes with short-run restrictions on the impact matrix. In addition, Jarocinski & Smets [Jar08] employ sign restrictions. The two papers examine the effects of monetary policy shocks on the housing sector. Since investment in residential structures contracts sharply following a contractionary monetary policy shock, they conclude that residential investment is sensitive to monetary policy. Innovations to residential investment are identified as housing demand shocks. Their estimates suggest housing demand shocks have only a limited impact on US aggregate growth and inflation.

In addition to the housing sector, Musso et al. [Mus11] and Walentin [Wal14] introduce mortgage market variables in their SVARs to identify a mortgage credit supply shock. Although they differ in their identification of credit supply shocks, both papers find that these shocks are important to the US housing market and the aggregate economy. They show that an adverse credit supply shock lowers real residential investment and private consumption.

My paper is closest to Walentin [Wal14], Musso et al. [Mus11] and Jarocinski & Smets [Jar08]. It fits in with the empirical SVAR literature that studies the impact on the business cycle and monetary transmission mechanism of the housing market.

The rest of the paper is organized as follows. The next section discusses the model and the identification scheme. Section 2.3 describes the data used in the analysis in addition to the priors. I present and discuss the results in section 2.4 and concludes in section 2.5.

2.2 The SVAR

This section describes the SVAR and my strategy for identifying it. The identification strategy is discussed in the context of three blocks of variables that cover the aggregate economy, the housing market, and the financial side of the economy.

2.2.1 Model

Define y_t, to be an M(= 10)×1 vector of variables. The variables are the growth rate of real non-durable goods and services consumption expenditures, $\Delta \ln C_t$, non-durable goods and services inflation, $\Delta\pi_t$, the growth rate of real disposable income, $\Delta \ln Y_t$, the growth rate of real residential investment in single-family structures, $\Delta \ln RI_t$, the growth rate of the price of residential investment in single-family structures, $\pi_{RI,t}$, the federal funds rate, $R_{ff,t}$, the yield on ten year Treasury bonds, $R_{10tr,t}$, the spread on six-month commercial paper over the 3-month Treasury bill rate, $R_{cps,t}$, the first difference of 30-year fixed mortgage rate, $\Delta R_{m,t}$, and the first difference of the growth rate of real mortgage debt, $\Delta^2 \ln MD_t$. I collect these variables into the data vector

$$y_t = \begin{bmatrix} \Delta \ln C_t & \Delta\pi_t & \Delta \ln Y_t & \Delta \ln RI_t & \pi_{RI,t} & R_{ff,t} & R_{10tr,t} & R_{cps,t} & \Delta R_{m,t} & \Delta^2 \ln MD_t \end{bmatrix}',$$

which has a p^{th} order reduced-form VAR representation

$$y_t = B_{0,t} + B_{1,t}\, y_{t-1} + ... + B_{p,t}\, y_{t-p} + u_t, \qquad u_t \sim N(0, \Omega_t), \tag{2.1}$$

where $B_{0,t}$ denotes a vector of M time-varying intercepts, $B_{j,t}$, $j = 1, \ldots, p$ are M×M matrices of time-varying slope coefficients, and Ω_t is an M×M time-varying, positive definite covariance matrix of the reduced form innovations, u_t. Let $\epsilon_t \sim N(0, I_M)$ be the vector of the structural shocks. The mapping from reduced form innovations to the structural shocks is $u_t = A_t^{-1}\Sigma_t \epsilon_t$, where A_t is the matrix of impact coefficients. Collect the off-diagonal non-zero elements of A_t into the vector α_t. The time-varying standard deviations that scale the structural shocks are in the diagonal matrix $\Sigma_t = diag\{\sigma_{m,t}\}$. The non-zero elements of Σ_t will be more conveniently referred to as the stochastic volatility of the structural shocks.

The reduced form VAR of equation (1) can be re-written as the SVAR

$$A_t y_t = A_t X_t' B_t + \Sigma_t \epsilon_t, \tag{2.2}$$

where $X_t' = I \otimes \left[1, \quad y_{t-1}' \quad ,..., \quad y_{t-p}'\right]$ and $B_t = \left[vec(B_{0,t})', \quad ..., \quad vec(B_{p,t})'\right]'$. The laws of motion for the slope coefficients, impact coefficients and standard deviations of the structural shocks are the multivariate random walks

$$B_t = B_{t-1} + \upsilon_t, \tag{2.3}$$

$$\alpha_t = \alpha_{t-1} + \varsigma_t, \tag{2.4}$$

and

$$\log(\sigma_{m,t}) = \log(\sigma_{m,t-1}) + \eta_{m,t}. \tag{2.5}$$

I set the covariance matrix of the innovations to the TVP and SV states to be block diagonal

$$\mathscr{R} = Var\left(\begin{bmatrix} \varepsilon_t \\ \upsilon_t \\ \varsigma_t \\ \eta_t \end{bmatrix}\right) = \begin{bmatrix} I_M & 0 & 0 & 0 \\ 0 & \mathscr{Q} & 0 & 0 \\ 0 & 0 & V & 0 \\ 0 & 0 & 0 & W \end{bmatrix}, \tag{2.6}$$

where $\mathscr{Q}$, V, and W are full rank matrices.

2.2.2 Identifying the Blocks and Shocks

The identification strategy is based on short-run zero restrictions imposed on the impact matrix A_t. Table 2.1 offers a summary of the restrictions. The identification is better understood by grouping the elements of y_t into three blocks. The blocks are the aggregate economy block, housing block, and financial block. I place the aggregate economy block before the housing and financial blocks. This assumption implies that shocks originating in the housing and financial blocks affect aggregate economic activity with a lag. Hence, the identification is block recursive with the aggregate economy block ordered first in the SVAR.[1]

Aggregate Economy Block

The first block represents the aggregate economy. It includes $\Delta \ln C_t$, $\Delta \pi_t$, and $\Delta \ln Y_t$. In the SVAR literature, inflation and real aggregates are categorized as the production sector; see Sims & Zha

[1]The main conclusions and results are robust to alternative identifications. See appendix A.

[Sim06] and Leeper & Roush [Lee03].

Table 2.1 shows the restrictions across and within the blocks on the impact matrix A_t. Within the aggregate economy block, the ordering is recursive with $\Delta \ln C_t$ ordered first, followed by $\Delta \pi_t$ and $\Delta \ln Y_t$. Since real income growth responds on impact to inflation shocks, the model embeds a Lucas-Sargent Philips curve relationship. Shocks to $\Delta \ln C_t$ are identified as permanent income shocks. This identification is based on the permanent-income hypothesis (PIH). The PIH predicts permanent income, rather than transitory income, is the primary driver of household consumption decisions. As a result, the PIH predicts that changes to consumption respond only to its own unanticipated shocks at impact.

I also lean on the Keynesian literature to identify shocks to $\Delta \pi_t$ and $\Delta \ln Y_t$. In this case, a shock to $\Delta \pi_t$ is identified as markup shock, while a shock to $\Delta \ln Y_t$ is identified as a real demand shock.

Housing Block

The second block uses $\Delta \ln RI_t$ and $\pi_{RI,t}$ to characterize the housing market. The key to identifying this block is that variables reflect the construction of new single-family houses rather than transactions with existing houses. The growth of residential investment captures housing construction activity, while the growth of the price of residential investment captures construction costs. Restrictions imposed on the housing block in the baseline SVAR are summarized in table 2.1. Within the block, the order is recursive with $\Delta \ln RI_t$ ordered first. This order implies that construction costs respond to supply shocks at impact and adjust to achieve market equilibrium.

The housing block is the source of two shocks. First, $\pi_{RI,t}$ reflects the cost of inputs used in house construction. Therefore, innovations to $\pi_{RI,t}$ are identified as housing construction cost shocks. Second, housing supply shocks are tied to $\Delta \ln RI_t$. A positive shock to $\Delta \ln RI_t$ generates an increase in house construction activity equivalent to a rightward shift in the housing supply curve.

Identifying innovations to $\Delta \ln RI_t$ as housing supply shocks contrasts with the literature. For the most part, the literature associates $\Delta \ln RI_t$ with housing demand; for example, see Jarocinski & Smets [Jar08] and [Mus11]. Two reasons motivate my identification. First, real residential investment measures the value of completed housing units along with the value of construction put-in-place at any point in time. Second, it takes more than three months on average for a house to sell after it enters the market. Figure 2.2 shows the median number of months on sales market for newly completed homes between 1975 and 2019. The average in that period is 5.2 months, which is almost a lag of two quarters between the time a house is finished being built (i.e., supply) and when it is sold (i.e., demand).

Financial Block

The financial side of the economy is the third block. It includes $R_{ff,t}$, $R_{10tr,t}$, $R_{cps,t}$, $\Delta R_{m,t}$, and $\Delta^2 \ln MD_t$. As part of the financial block, $\Delta R_{m,t}$, and $\Delta^2 \ln MD_t$ represent the mortgage market. This block is the source of five shocks. The shocks are monetary policy, fiscal, liquidity, mortgage credit supply, and housing demand. Table 2.1 depicts the identification within the block. The short-rate,

$R_{ff,t}$, is ordered above the long-rate, $R_{10tr,t}$, to allow for a rational-expectations term structure relationship. This implies that shocks to $R_{ff,t}$ can affect the long-rate by altering the expected path of future short-rates.

The monetary policy shock is an innovation to the federal funds rate, $R_{ff,t}$. In the baseline SVAR, monetary policymakers are assumed to follow a [Tay93] type rule when setting the policy rate. As table 2.1 shows, the monetary policy in the baseline SVAR identification is non-recursive, which is similar to Leeper & Roush [Lee03].

Shocks to the yield on ten-year treasury bonds, $R_{10tr,t}$, are identified as fiscal shocks. As discussed in Berndt et al. [Ber12], government spending shocks are financed by changes either in the primary surplus or in the yields on government debt or both. Specifically, Berndt et al. [Ber12] show that a downward (upward) shift in the yields on the treasury bonds accommodates an increase (decrease) in government spending.

The liquidity shock is an innovation to the spread of commercial paper over the 3-months Treasury bills rate, $R_{cps,t}$. A positive shock to the spread financial corporations pay over the safe short rate is interpreted as a shortage of liquidity that makes obtaining unsecured commercial paper more costly.[2]

I identify the mortgage credit supply shock as an unexpected increase in mortgage rates, $\Delta R_{m,t}$. This increase reflects a leftward shift in the mortgage supply curve. [Mus11] also identify mortgage credit supply shocks through innovations to the mortgage rate. The shock has within the quarter impact on $\Delta^2 \ln MD_t$. Hence, adjustments to credit supply shocks in the mortgage market work through changes in real mortgage debt.

Innovations to the growth of real mortgage debt, $\Delta^2 \ln MD_t$, identify the demand for housing. An unexpected increase in mortgage borrowing reflects the greater demand for house purchases by households. My identification contrasts with the way housing demand shocks are identified in the literature. Jarocinski & Smets [Jar08] and [Mus11] use innovations to residential investment to identify housing demand shocks. The previous section shows that residential investment is a measure of the flow into the supply of housing. Additionally, the construction of new houses by builders is governed by different types of loans than the mortgages that finance house purchases by households. New house construction is funded by short-term (less than a year) construction loans, while mortgages are long-term loans used by households to fund house purchases. Hence, innovations to $\Delta^2 \ln MD_t$ provide a more informative measure of unexpected changes to the demand for housing by households.

2.3 Data and Priors

This section describes the data on which the TVP-SV-SVAR is estimated. I also discuss my priors for the TVP-SV-SVAR.

[2]See Krishnamurthy & Vissing-Jorgensen [Kri12] for a detailed examination of the relationship between credit spreads and liquidity.

2.3.1 Data

The sample used to estimate the TVP-SV-SVAR covers the period from 1971q3 to 2018q4, T=190. Figure 2.3 plots the data with NBER recession dates as gray shadings. Table A.7 in the appendix gives detailed definitions and sources of the data. All variables are expressed in terms of annualized growth rates, except for the federal funds rate, ten-year yield, commercial paper spread, and the mortgage rate. The inflation rate is reported in first differences as this minimizes the price puzzle in the results.[3] I also take the first difference of the mortgage rate to avoid the multicollinearity issue that arises between mortgage rates and ten-year treasury bonds rate.[4]

The series of consumption, inflation, and disposable income exhibit low volatility during the Great Moderation from 1984 to the early 2000s. The growth rate of residential investment exhibits V-shaped declines and recoveries around the double-dip recession of the 1980s, 1990-1991 recession, and the 2007-2009 financial crisis. The federal funds rate and the yields on ten-year treasury bonds trend down from the mid-1980s and reach low levels towards the end of the sample. Also, the commercial paper spread shows spikes during the 1973-1975, 1981-1982, and 2007-2009 recessions reflecting shortages of liquidity. In the mortgage market, the change in the mortgage rate is most volatile in the late 1970s and early 1980s. This volatility reflects the impact of the Volcker disinflation.

2.3.2 Priors and Estimation

I use the Metropolis within Gibbs algorithm of Canova & Pérez Forero [Can15] to estimate the TVP-SV-SVAR. The TVP-SV-SVAR is estimated with two lags (p=2). As shown in table 2.2, the priors of the intercepts, reduced-form slope coefficients, impact matrix, and the log of the standard deviation of structural shocks are normally distributed. The covariance matrices Q, V, and W are drawn from inverse Wishart priors.

I use an empirical Bayes prior because there is no training sample. This prior employs estimates of the fixed-coefficient SVAR on the full sample period 1971q3-2018q4. I obtain OLS estimates of the slope coefficients ($\underline{\mathbf{B}}$) and their covariance matrix ($\underline{\mathbf{VB}}$), maximum likelihood estimates of the impact matrix ($\underline{\boldsymbol{\alpha}}$), its covariance matrix ($\underline{\mathbf{VA}}$) and the log of standard deviations of the structural shocks ($\underline{\boldsymbol{\sigma}}$). I set the tuning parameters $k_{\mathscr{Q}}^2 = 0.001$, $k_V^2 = 0.001$, $\mathscr{K} = 310$, and $k_W^2 = 0.0001$ to achieve a rejection rate of explosive roots' draws of around 15-35% for the reduced form slope coefficients B_τ, and an acceptance rate of 23-40% for the Metropolis step in which the impact coefficients A_τ are drawn, where $\tau = 1 : T$.

Using these settings, I generate 150,000 draws from the posterior. The first 50,000 draws are discarded. I use a thinning factor of 4 to minimize serial correlation in the posterior draws. The final number of posterior draws is 25,000.[5]

[3] See section 2.4.3 for details.
[4] The two series are highly correlated.
[5] More details on the sampling algorithm are available in Canova & Pérez Forero [Can15], pages 369-370.

2.4 Results

This section reports estimates of the baseline TVP-SV-SVAR. The TVP-SV-SVAR produces 188 sets of IRFs, FEVDs, and SVs. I pick four dates that correspond to the most important events in the sample, on which to focus the discussion: the NBER 1973q4 peak before the oil crisis's recession, the NBER 1981q3 peak before the 1981 recession, the date 1984q1 as the start of the Great Moderation, and the NBER 2007q4 peak that marks the start of 2007-2009 recession. The analysis in this section focuses on four shocks: housing demand, housing supply, mortgage credit supply, and monetary policy.

2.4.1 The Housing Demand Shock

Figure 2.4 documents the IRFs of the ten variables in the baseline model to a positive one percent housing demand shock at 1973q4, 1981q3, 1984q1, and 2007q4. Figure 2.5 reports the IRFs to the same shock at 2007q4 with 68% uncertainty bands. The first three panels of figure 2.4 depict the responses of the aggregate economy block. The shock has an overall positive effect on the aggregate economy. Real disposable income and real consumption exhibit hump shape responses. These responses are slightly larger beyond the four-quarter horizon in 2007q4. Following a housing demand shock, inflation starts to increase at the third and fourth-quarter horizons after an initial decline of 0.13% at the two-quarter horizon.

Despite the positive effects of a housing demand shock, the magnitudes of the responses are relatively small and do not exceed 0.25% for the variables in the block. Additionally, figure 2.5 shows that the uncertainty bands include zero at all horizons for the responses of real disposable income and inflation. The small effect of the housing demand shock on the aggregate economy matches the findings of Jarocinski & Smets [Jar08].

Panels 4 and 5 of figures 2.4 and 2.5 show the responses of the housing block to a housing demand shock. Real residential investment accelerates for the first two years following the housing demand shock. The increase in real residential investment reflects an increase in the construction of new houses in response to the unexpected higher demand. The greater demand for housing also puts upward pressure on the price of residential investment, which reflects the price of construction materials. Following a housing demand shock, the price of residential investment shows a slight increase of about 0.2% at the six to seven quarter horizons and stays around that level until the 20 quarter horizon.

The response of the mortgage rate to a housing demand shock in panel 9 of figures 2.4 and 2.5 is of special interest in this paper. That response turns out to be economically and statistically insignificant. The mortgage rate increases slightly at the two-quarter horizons, declines at the 3 to 4 quarter horizons, and stays slightly above zero 5 to 20 quarters after the shock. The results indicate that the largest decline in the mortgage rate does not exceed two basis points and is short-lived. In comparison, [Mus11] find a negative mortgage rate response of about five basis points at the five-quarter horizon to a housing demand shock.

The FEVDs of the housing demand shock are reported in figure 2.6. These estimates indicate that, except for the own FEVDs, the housing demand shock explains almost none of the variation in the aggregate economic activity, residential investment, financial conditions, and the mortgage market at all horizons and sample dates. These findings suggest little to no role for housing demand shocks in US business cycle fluctuations since 1971. The unimportance of housing demand shocks for the US business cycle confirms results reported by Jarocinski & Smets [Jar08], but contrasts with [Mus11]. The latter paper presents estimates that housing demand shocks explain non-negligible shares of the variations in mortgage lending rate, mortgage loans, and short-term interest rate.

Stochastic Volatility of the Housing Demand and Supply Shocks

The top left panel of figure 2.7 plots estimated SV for the housing demand shock. The median estimate of this SV shows little to no change across the sample period, which includes the 2007-2009 financial crisis.

It is illustrative here to compare the SV of the housing *demand* shock to the SV of the housing *supply* shock. The SV of housing supply shock is depicted in the top right panel of figure 2.7. In contrast to the stable pattern of housing demand shock SV, the SV of the housing supply shock shows three peaks. The first peak coincides with the double-dip recession of the early 1980s. Residential investment contracted for three consecutive years from 1980-1982. The second peak occurs around the 1990-1991 recession in which the rate of new house constructions hit its lowest level since the end of World War II [Lea92]. The third and highest peak corresponds to the 2007-2009 financial crisis. Compared to the flat SV of the housing demand shock, the SV of housing supply shock is considerably more volatile during the 2007-2009 financial crisis.

2.4.2 The Mortgage Credit Supply Shock

Figure 2.8 plots the IRFs with respect to a one percentage point mortgage credit supply shock at 1973q4, 1981q3, 1984q1, and 2007q4. The IRFs for the same shock at 2007q4 are plotted in figure 2.9. These plots include 68% uncertainty bands. The responses of the aggregate economy block are in panels 1-3. The median responses of real disposable income and real consumption to the mortgage credit supply shock show a decline of 0.4% and 1.1% respectively at the three-quarter horizon. In contrast to these small responses, inflation's response is more economically significant. Three quarters after the shock, the inflation rate falls to a trough of -1.8% followed by a jump towards the steady-state at the four-quarter horizon.

The responses of the housing block to a mortgage credit supply shock are displayed in panels 3 and 4 of figures 2.8 and 2.9. In response to the credit supply shock, the drop in real residential investment is about 17% at the one-year horizon in 2007q4. The cumulative decline in real residential investment persists into the five-year horizon. In panel 5, the credit supply shock generates an odd increase in the price of residential investment despite the decline in construction activity, but the response is statistically insignificant at all horizons.

Panels 6-10 in figures 2.8 and 2.9 depict the IRFs of the financial block to mortgage credit supply shock. Following the shock, the federal funds rate and the yield on 10-year treasury bonds show an economically and statistically significant decline, which continues for 20 quarters. The simultaneous decrease in the 10-year yield and the increase in mortgage rates (panel 9) implies that lenders are charging higher premiums on mortgage lending. Mortgage debt, which is a proxy for housing demand, also falls in response to the mortgage credit supply shock. It shows a small drop of about 0.1%, at the 20 quarter horizons across sample dates. This decline, however, is not statistically significant. Walentin [Wal14] also finds a negative, but statistically insignificant, response of real mortgage debt growth to mortgage credit supply shocks.

The FEVDs of the mortgage credit supply shock are reported in figure 2.10. These estimates attribute a more economically significant role to mortgage credit supply shocks than Walentin [Wal14] and [Mus11]. Most notably, the mortgage credit supply shock explains 30-40% of the variation in inflation at the 1- to 5-year horizons across the sample. Although still large, the share of inflation variation the shock explains is smaller after 1995. These FEVDs suggest that mortgage market conditions and financial shocks are important determinants of inflation in the short run and at the business cycle frequency.

Additionally, the mortgage credit supply shock matters for the real residential investment and the price of residential investment. The credit supply shock explains about 40% of the variation in real residential investment at the two-quarter horizon during the sample period, and 35-40% of the variation in the price of residential investment at the three-quarter horizon. The shock is less economically important to residential investment and the price level of residential investment after the three-quarter horizon. Finally, the mortgage credit supply shock is also important to explain variation in the real mortgage debt. Across sample dates, it explains about 20% of the variation in real mortgage debt at the two-quarter horizon and about 25% at the 1- to 5-year horizons.

Stochastic Volatility of the Mortgage Credit Supply Shock

The bottom left panel in figure 2.7 plots the SV of the mortgage credit supply shock. This SV reached its peak during the 1982 recession, which coincides with the Volcker disinflation. This peak dominates the SV of the shock over the sample. After the 1982 recession, the SV of the mortgage credit supply shock trends down until the sample ends in 2018.

2.4.3 The Monetary Policy Shock

Figure 2.11 plots the IRFs to a contractionary one-percentage-point monetary policy shock at 1973q4, 1981q3, 1984q1, and 2007q4. Figure 2.12 reports the same IRFs at 2007q4 along with 68% uncertainty bands. The first three panels depict the responses of the aggregate economy block to the shock. As expected, the surprise increase in the federal funds rate has a contractionary effect on real disposable income and real consumption. The shock also gives rise to a mild price puzzle. The inflation rate increases in the first five quarters following the monetary policy shock. However, the increase is less than one percent and is not statistically significant by the third quarter.[6]

[6]Furthermore, the 90% uncertainty bands of inflation response to a monetary policy shock include zero from impact to the 20 quarter horizon.

There is no evidence that the transmission of monetary policy shocks to macro aggregates changes over the sample period. This is in contrast to Mertens [Mer08]. He argues that the effect of monetary policy on the real economy is weaker after the phase-out of Regulation Q in the early 1980s.[7] My estimates, on the other hand, show no shift in the responses before or after the elimination of regulation Q.

The responses of the housing block to a contractionary monetary policy shock are displayed in panels 4 and 5 of figures 2.11 and 2.12. The response of real residential investment is large and negative over the sample period. In 2007q4, a one-percentage-point monetary policy shock results in a 25% drop in real residential investment at the one-year horizon and a 75% drop at the five-year horizon. The large contraction in real residential investment following monetary policy shocks is well documented in the literature (e.g., [Mus11], Jarocinski & Smets [Jar08], and Walentin [Wal14]). Similarly, the price of residential investment falls in response to a contractionary monetary policy. At the five year horizon, the price of residential investment declines by about 2.5%. This response, however, is statistically insignificant. In brief, monetary policy has a large effect on the housing market that falls mainly on real residential investment rather than the price of residential investment.

The responses of the mortgage market variables to a monetary policy shock are in panels 9 and 10. The shock produces changes in the mortgage rate and real mortgage debt that are statistically and economically significant. The mortgage rate increases by about 35 basis points at the one-year horizon, which rises to 65 basis points from 10 to 20 quarters after the shock. The shock generates about a 1.5% decrease in real mortgage debt growth at the five-quarter horizon, which remains negative until the five-year horizon. The upshot is monetary policy reduces the mortgage credit available to households. These results are similar to [Mus11], but differ from Walentin [Wal14].

Figure 2.13 contains the FEVDs with respect to the monetary policy shock. The results show that the monetary policy shock is especially important for the determination of the real variables in the model in the short- and long- run. The shock explains around 40% of the variation in real consumption and disposable income from a year and a half to five-year horizon. However, the importance of the monetary policy shock for consumption in the short-run falls across the sample. For instance, the shock explains 30% of the variation in consumption at the three-quarter horizons in 1986. Subsequently, the share exhibits a clear decline and hovers around 20% at the same horizons after the 2001 recession. In general, the results support the non-neutrality of monetary policy in the short-run and at the business cycle horizons.

Stochastic Volatility of the Monetary Policy Shock

The SV of the monetary policy shock is in the bottom right panel of figure 2.7. The highest peak coincides with the disinflation of the early 1980s. This peak dominates the rest of the sample. Under the Taylor-rule used in my baseline identification, these estimates imply that non-systematic

[7] Mertens uses an SVAR with two regimes. In one regime, the ceilings on deposit rates (Regulation Q) are binding. The other regime captures the periods where the ceilings are not binding. He finds that the IRFs of real GDP to monetary policy shock are stronger when the ceilings are binding.

monetary policy actions played a significant role in the early 1980s. The observed pattern in the SV of the monetary policy shock is consistent with the findings of, among others, Sims & Zha [Sim06], Primiceri [Pri05], and Canova & Pérez Forero [Can15].

2.5 Conclusions

This paper presents evidence of the effects of housing and mortgage market shocks on the US business cycle and monetary policy transmission mechanism. Using estimates of a TVP-SV-SVAR model on US data from 1971q3 to 2018q4, I draw four main conclusions. First, housing demand shocks play only a small role in the US business cycle and in determining mortgage rates at all horizons. Second, housing supply shocks are more relevant to the 2007-2009 financial crisis than housing demand shocks. The stochastic volatility of housing supply shocks peak during the 2007-2009 financial crisis. Third, mortgage credit supply shocks produce an economically important drop in residential investment and inflation. Finally, monetary policy has a strong effect on housing markets that mainly falls on real residential investment.

The findings in this paper calls for a closer examination of the role housing and mortgage markets play in the US economy. Future research should focus on building theoretical models aimed at understanding the transmission mechanism between mortgage credit supply shocks and the aggregate economy. In addition, the results warrant more study of housing demand and supply shocks. This can make a big difference for policymakers applying macroeconomic models to address policy issues related to the housing market.

Table 2.1 Baseline Identification of A_t

Variable	Block										
$\Delta \ln C_t$	Aggregate	1	0	0	0	0	0	0	0	0	0
$\Delta \pi_t$		X	1	0	0	0	0	0	0	0	0
$\Delta \ln Y_t$		X	X	1	0	0	0	0	0	0	0
$\Delta \ln RI_t$	Housing	X	X	X	1	0	0	0	0	0	0
$\pi_{RI,t}$		X	X	X	X	1	0	0	0	0	0
$R_{ff,t}$	Financial	0	X	X	0	0	1	0	0	0	0
$R_{10tr,t}$		X	X	X	X	X	X	1	0	0	0
$R_{cps,t}$		X	X	X	X	X	X	X	1	0	0
$\Delta R_{ms,t}$		X	X	X	X	X	X	X	X	1	0
$\Delta^2 \ln MD_t$		X	X	X	X	X	X	X	X	X	1

Notes: The X's represent free parameters in A_t. The zeros are short-run restrictions. The collection of $\Delta \ln C_t$, $\Delta \pi_t$ and $\Delta \ln Y_t$ represent the aggregate economy block. The housing block contains $\Delta \ln RI_t$ and $\pi_{RI,t}$, while $R_{ff,t}$, $R_{10tr,t}$, $R_{cps,t}$, $\Delta R_{ms,t}$ and $\Delta^2 \ln MD_t$ cover the financial block. Innovations to $\Delta \ln C_t$, $\Delta \pi_t$, $\Delta \ln Y_t$, $\Delta \ln RI_t$, $\pi_{RI,t}$, $R_{ff,t}$, $R_{fsc,t}$, $R_{liq,t}$, $\Delta R_{ms,t}$ and $\Delta^2 \ln MD_t$ are identified as shocks to permanent income, markup, real demand, housing supply, housing cost, monetary policy, fiscal, liquidity, mortgage credit supply, and housing demand, respectively.

Table 2.2 Priors

Parameters	Priors
B_0^{prior}	$N(\underline{\mathbf{B}}, 4 \cdot \underline{\mathbf{VB}})$
$\mathcal{Q}^{prior}$	$IW(k_{\mathcal{Q}}^2 \cdot \underline{\mathbf{VB}}, (1 + \mathcal{K}))$
α_0^{prior}	$N(\underline{\boldsymbol{\alpha}}, \underline{\mathbf{VA}})$
V^{prior}	$IW(k_V^2 \cdot \underline{\mathbf{VA}}, (1 + dim\ \alpha))$
$log(\sigma_0)^{prior}$	$N(\underline{\boldsymbol{\sigma}}, 10 \cdot I_M)$
W_i^{prior}	$IW(k_W^2, 2)$

Notes: The tuning parameters $k_{\mathcal{Q}}^2 = 0.001$, $k_V^2 = 0.001$, $\mathcal{K} = 310$, and $k_W^2 = 0.0001$. The normal distribution is denoted with N and IW denotes the inverse-Wishart distribution. The underlined symbols represent priors on the slope coefficients ($\underline{\mathbf{B}}$), the covariance matrix ($\underline{\mathbf{VB}}$) of these parameters, maximum likelihood estimates of the impact matrix (A_t), its covariance matrix ($\underline{\mathbf{VA}}$) and the log of the standard deviations of the structural shocks ($\underline{\boldsymbol{\sigma}}$).

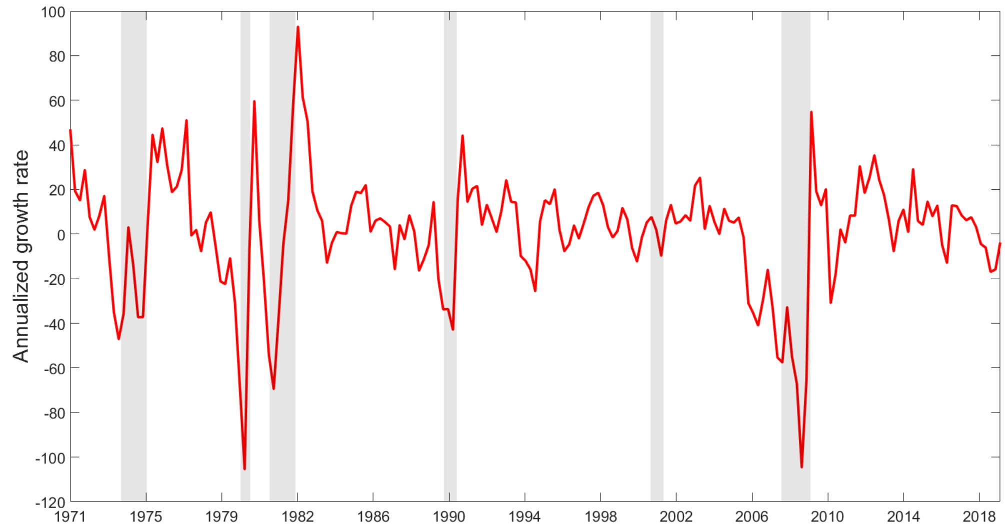

Figure 2.1 Real Residential Investment in Single Family Structures, 1971Q1-2018Q4

Notes: The plot shows the annualized quarter over quarter growth rate of real residential investment in single family structures. NBER recession dates appear as gray shading.

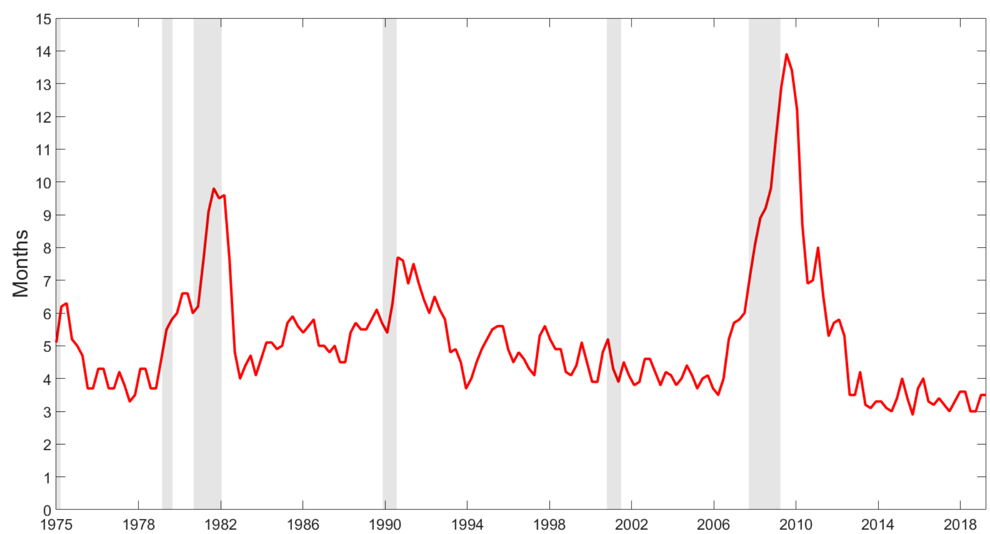

Figure 2.2 Time to Sale for a New House, 1975Q1-2019Q2

Notes: The plot is the median number of months a new house is on the market before it is sold. NBER recession dates appear as gray shading.

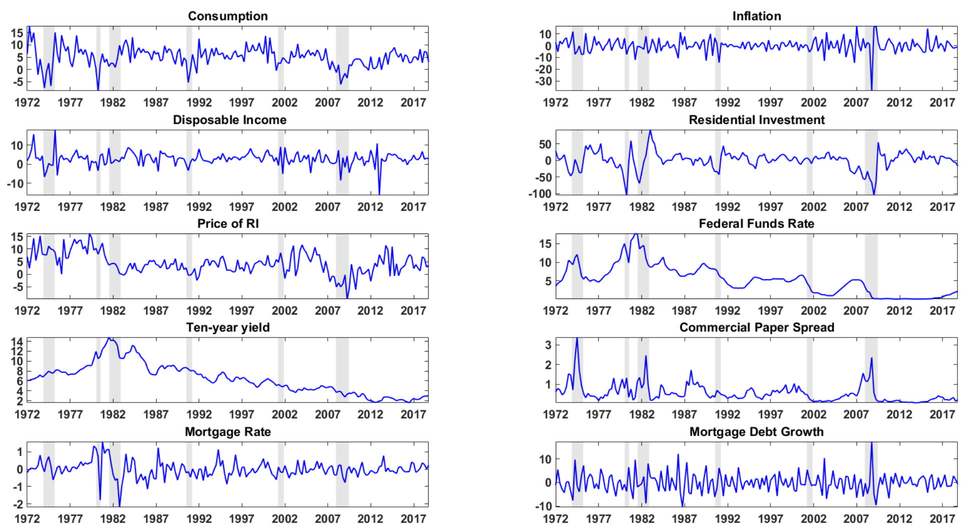

Figure 2.3 Data Plots, 1971q3 to 2018q2

Notes: All variables are expressed in terms of annualized growth rates, except for the federal funds rate, ten-year yield, commercial paper spread, and the mortgage rate. These interest rates and spreads are measured in percentage points. NBER recession dates appear as gray shading. For the details and definitions of the underlying data, see table A.7 in the appendix.

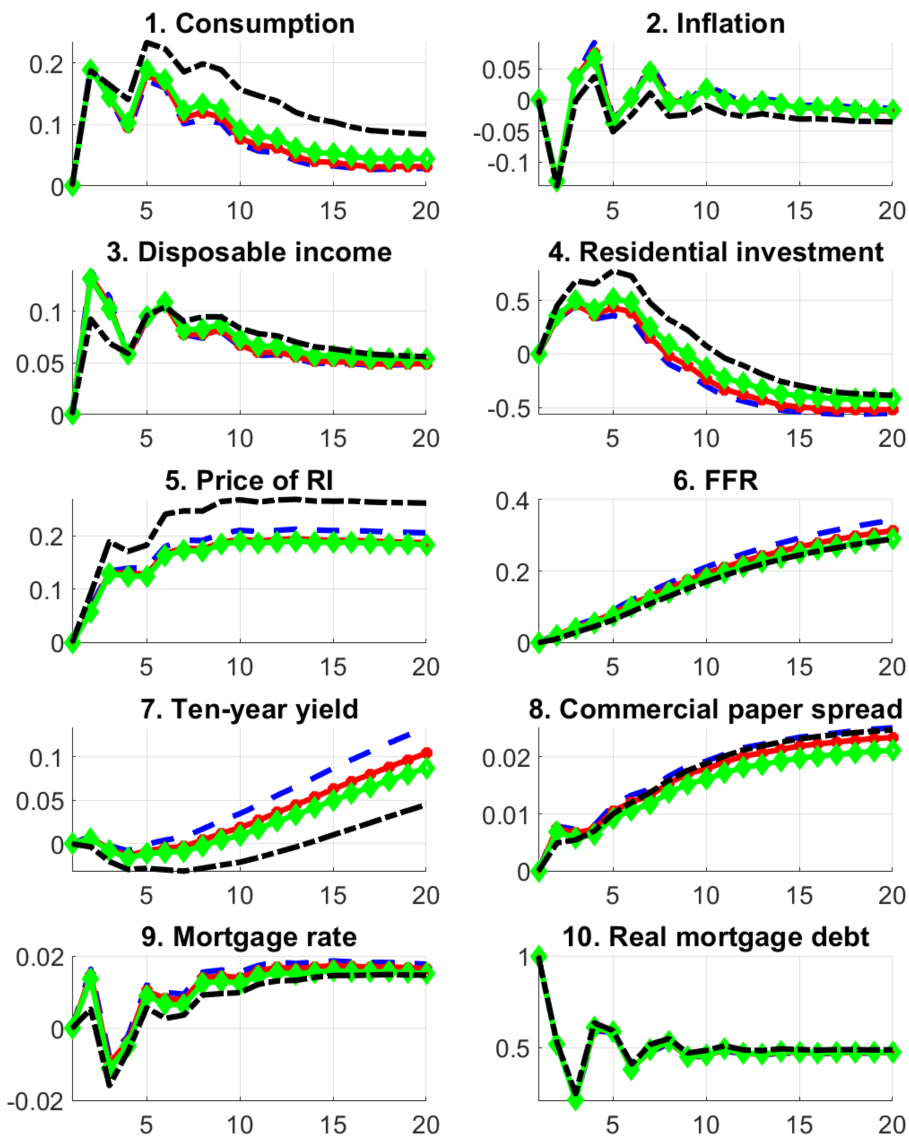

Figure 2.4 The IRFs to a Housing Demand Shock at Selected Dates

Notes: The plots show the median cumulative responses at the 1973 oil crisis (1973q4, blue dashed line); Volcker's disinflation (1981q3, red starred solid line); the Great Moderation (1984q1, green diamonds solid line); the 2007 financial crisis (2007q4, black dotted dashed line). Estimates are produced by the baseline TVP-SV-SVAR. The IRFs of consumption, inflation, disposable income, residential investment, price of residential investment, and real mortgage debt are in percentages, where the own shock of these variables are one percent changes in the structural shocks. The IRFs of the federal funds rate, the ten-year yield, the commercial paper spread, and the mortgage rate are in basis points with their own shocks representing one basis point shifts.

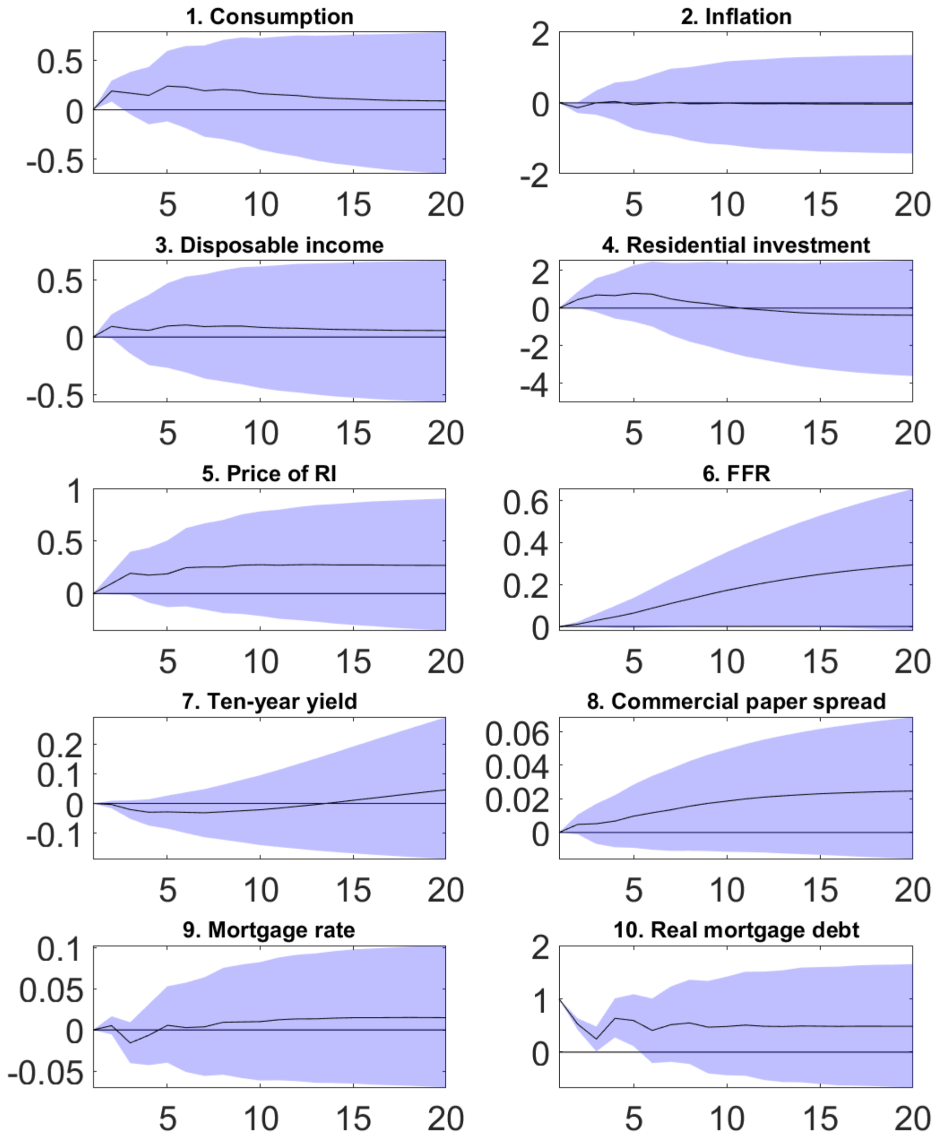

Figure 2.5 The IRFs to Housing Demand Shock at 2007q4

Notes: The plots show cumulative median and posterior 68% uncertainty bands produced by the baseline TVP-SV-SVAR. The IRFs of consumption, inflation, disposable income, residential investment, price of residential investment, and real mortgage debt are in percentages, where the own shock of these variables are one percent changes in the structural shocks. The IRFs of the federal funds rate, the ten-year yield, the commercial paper spread, and the mortgage rate are in basis points with their own shocks representing one basis point shifts.

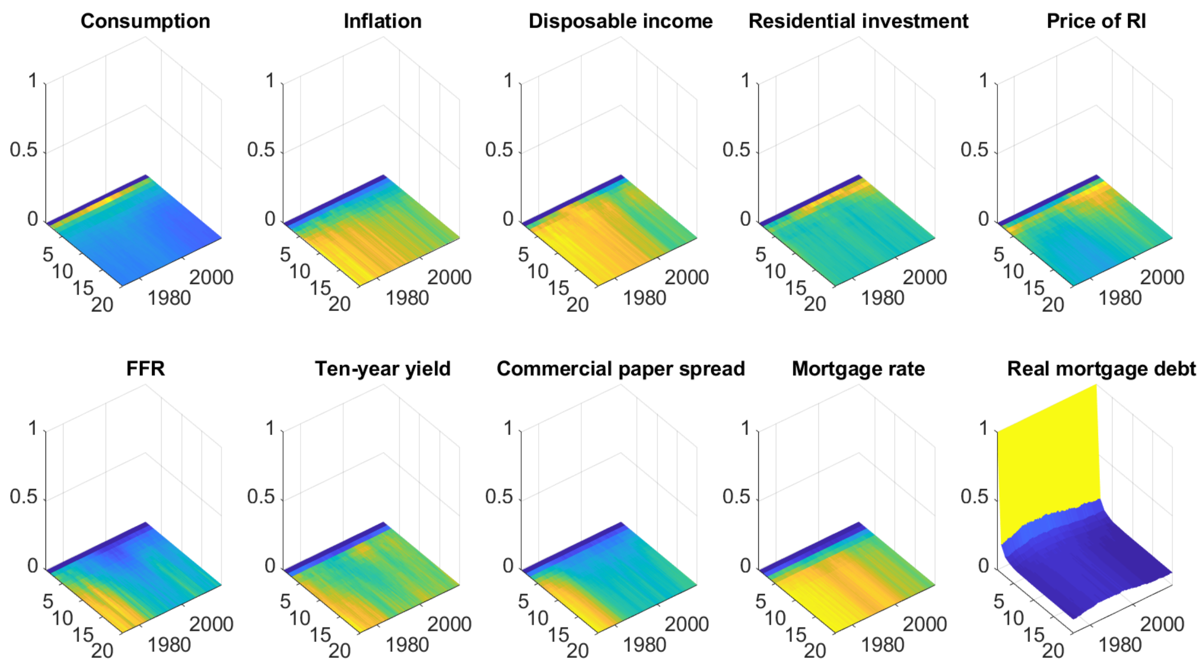

Figure 2.6 FEVDs with Respect to the Housing Demand Shock, 1972q1 to 2018q4

Notes: The plot shows the share of variation explained by the housing demand shock on the entire sample. Estimates are produced by the baseline TVP-SV-SVAR.

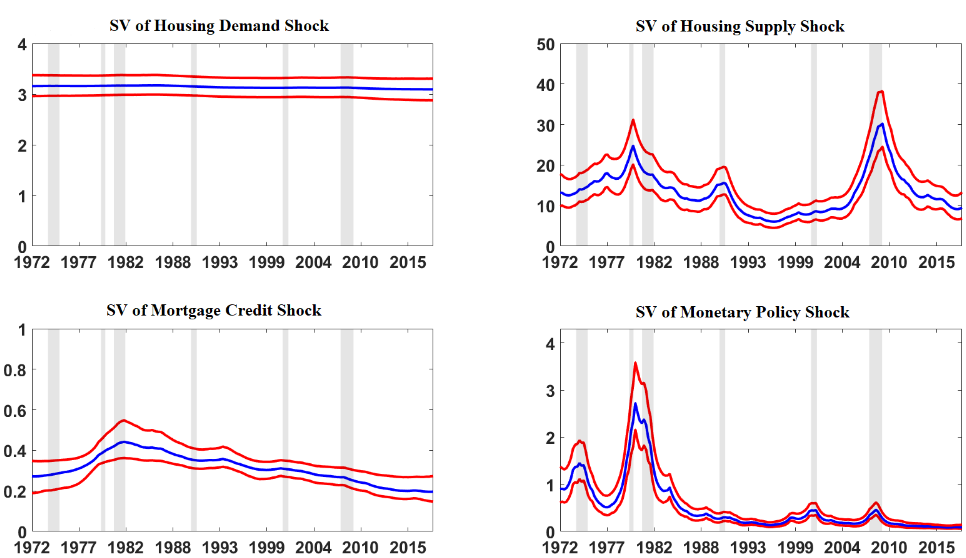

Figure 2.7 Stochastic Volatilities of Four Shocks, 1971q3 to 2018q4

Notes: The plots show median and posterior 68% uncertainty bands of SV estimates produced by the baseline TVP-SV-SVAR. NBER recession dates appear as gray shading.

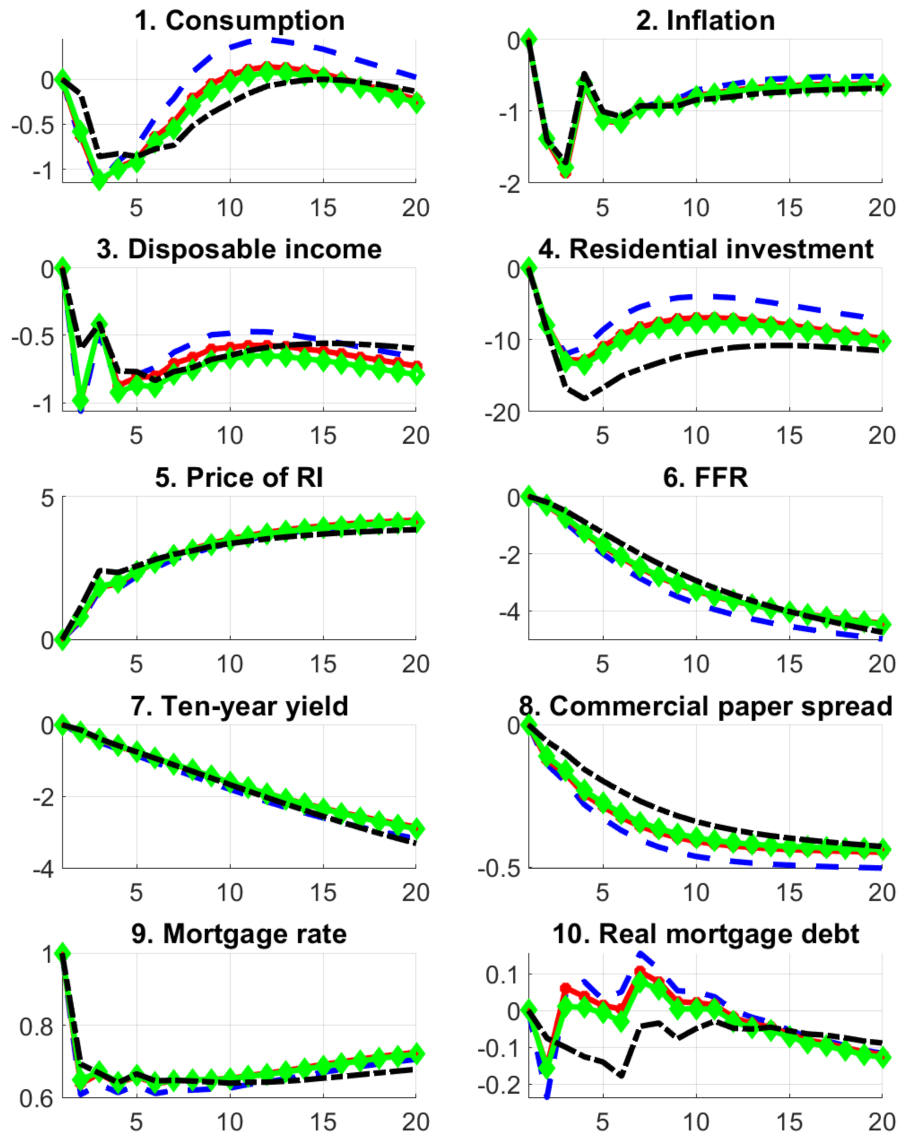

Figure 2.8 The IRFs to Mortgage Credit Supply Shock at Selected Dates

Notes: The plots show the median cumulative responses at 1973q4 (blue dashed line); 1981q3 (red starred solid line); 1984q1 (green diamonds solid line); 2007q4 (black dotted dashed line). Estimates are produced by the baseline TVP-SV-SVAR. The IRFs of consumption, inflation, disposable income, residential investment, price of residential investment, and real mortgage debt are in percentages, where the own shock of these variables are one percent changes in the structural shocks. The IRFs of the federal funds rate, the ten-year yield, the commercial paper spread, and the mortgage rate are in basis points with their own shocks representing one basis point shifts.

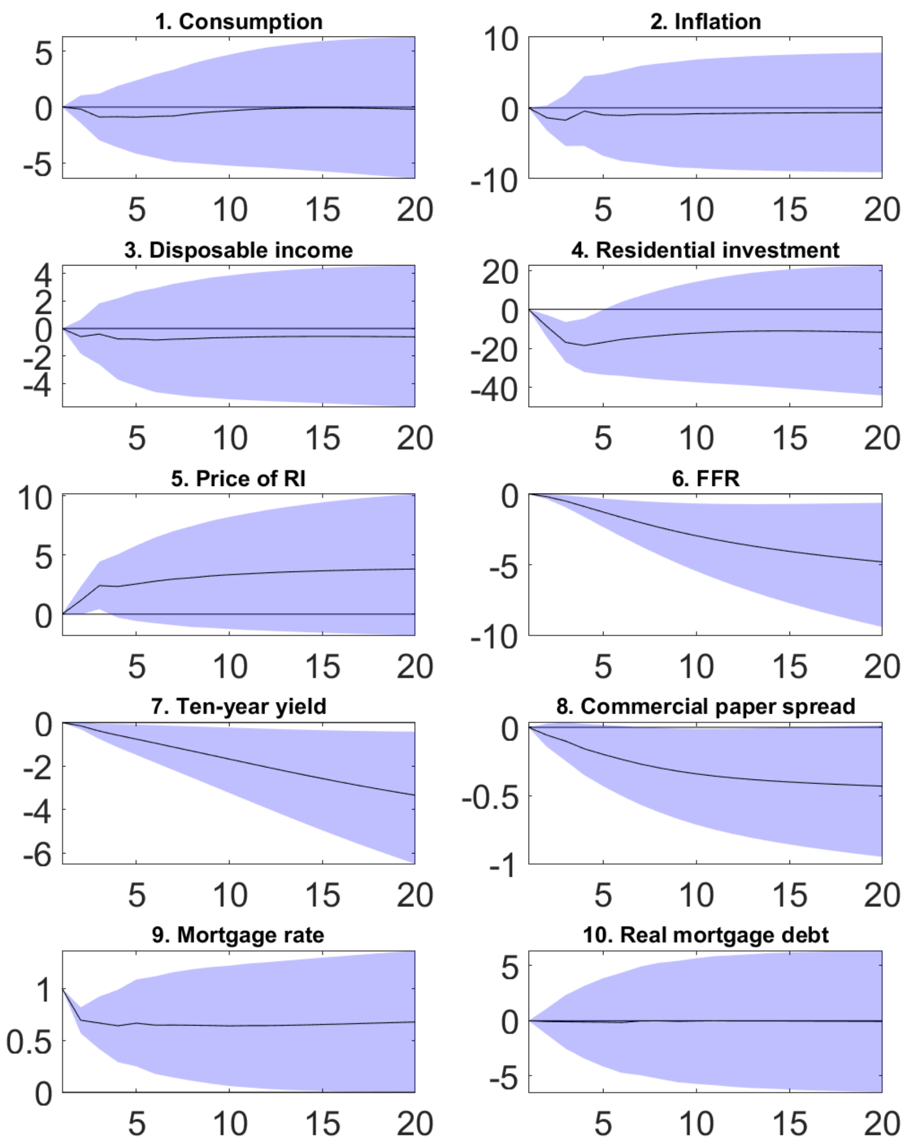

Figure 2.9 The IRFs to Mortgage Credit Supply Shock at 2007q4.

Notes: The plots show cumulative median and posterior 68% uncertainty bands produced by the baseline TVP-SV-SVAR. The IRFs of consumption, inflation, disposable income, residential investment, price of residential investment, and real mortgage debt are in percentages, where the own shock of these variables are one percent changes in the structural shocks. The IRFs of the federal funds rate, the ten-year yield, the commercial paper spread, and the mortgage rate are in basis points with their own shocks representing one basis point shifts.

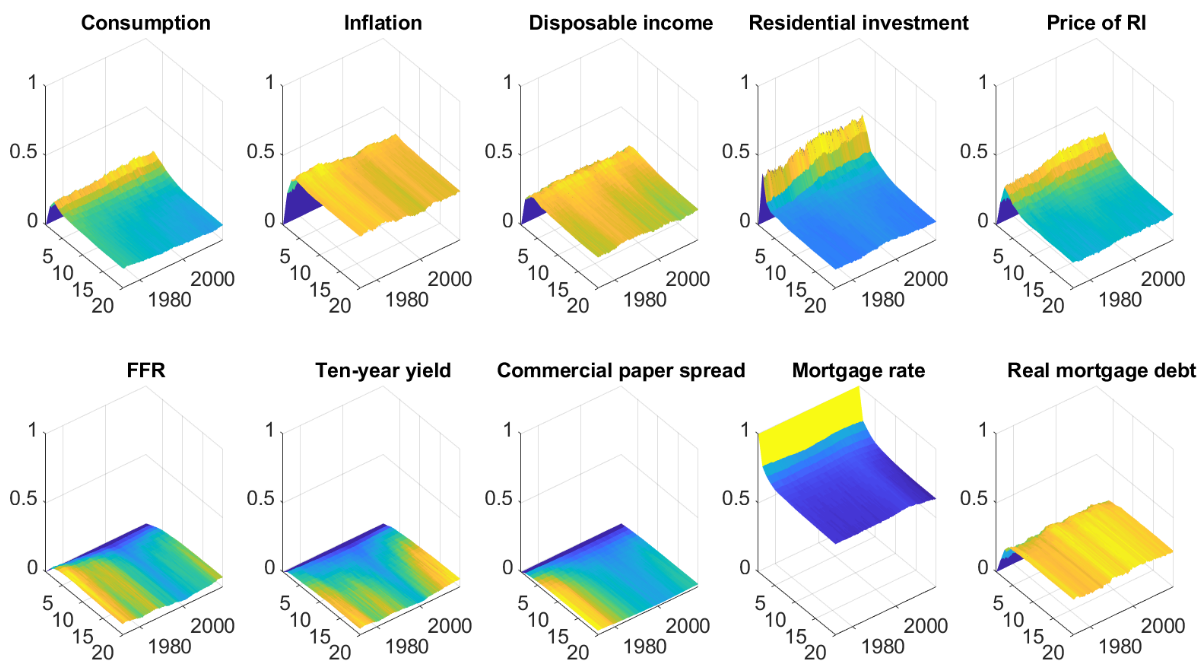

Figure 2.10 FEVDs with Respect to the Credit Supply Shock, 1972q1 to 2018q4

Notes: The plot shows the share of variation explained by the credit supply shock on the entire sample. Estimates are produced by the baseline TVP-SV-SVAR.

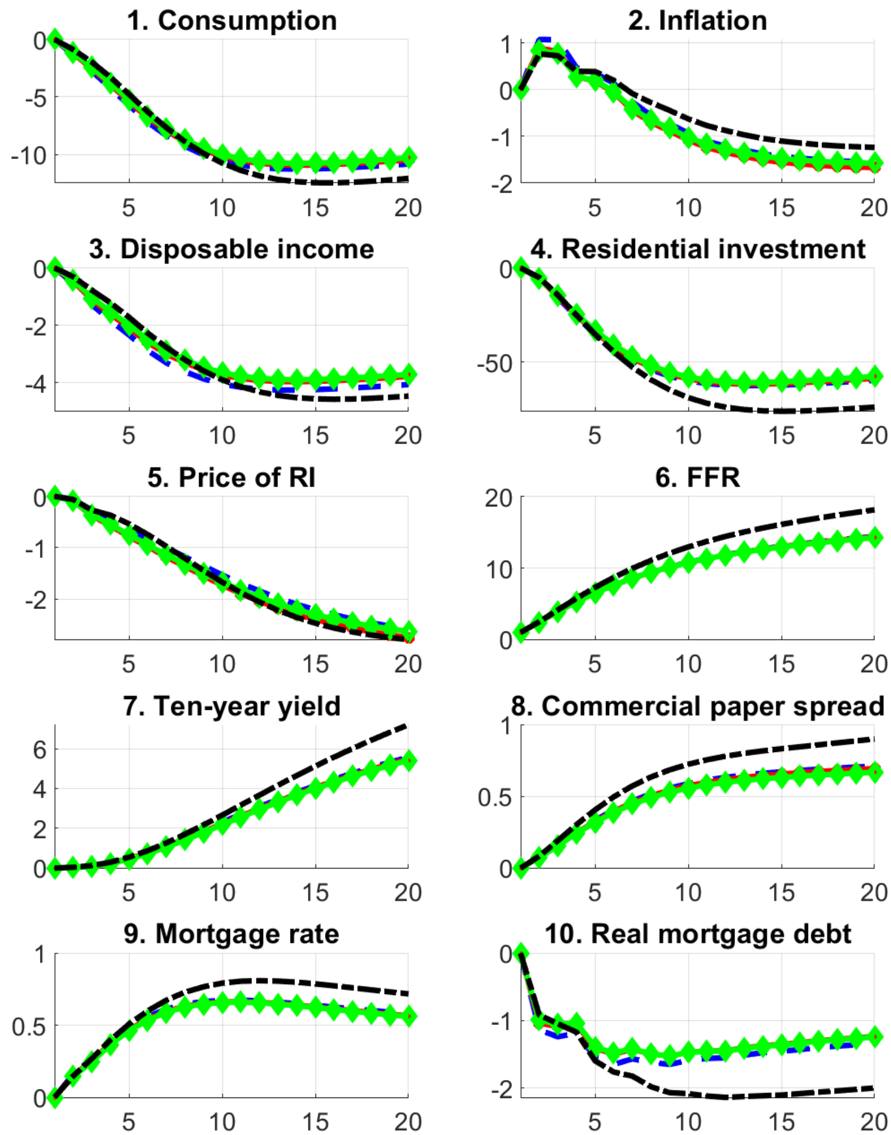

Figure 2.11 The IRFs to Monetary Policy Shock at Selected Dates

Notes: The plots show the median cumulative responses at 1973q4 (blue dashed line); 1981q3 (red starred solid line); 1984q1 (green diamonds solid line); 2007q4 (black dotted dashed line). Estimates are produced by the baseline TVP-SV-SVAR. The IRFs of consumption, inflation, disposable income, residential investment, price of residential investment, and real mortgage debt are in percentages, where the own shock of these variables are one percent changes in the structural shocks. The IRFs of the federal funds rate, the ten-year yield, the commercial paper spread, and the mortgage rate are in basis points with their own shocks representing one basis point shifts.

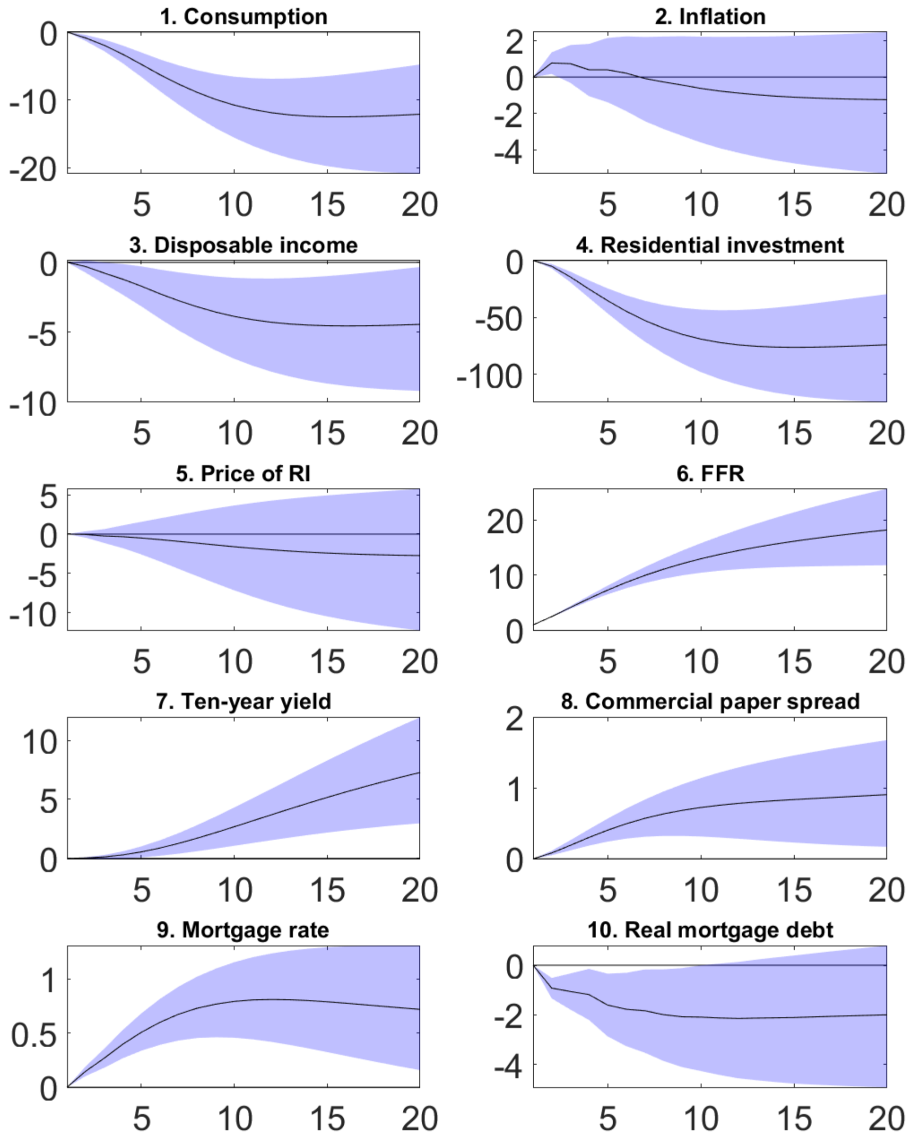

Figure 2.12 The IRFs to Monetary Policy Shock at 2007q4

Notes: The plots show cumulative median and posterior 68% uncertainty bands produced by the baseline TVP-SV-SVAR. The IRFs of consumption, inflation, disposable income, residential investment, price of residential investment, and real mortgage debt are in percentages, where the own shock of these variables are one percent changes in the structural shocks. The IRFs of the federal funds rate, the ten-year yield, the commercial paper spread, and the mortgage rate are in basis points with their own shocks representing one basis point shifts.

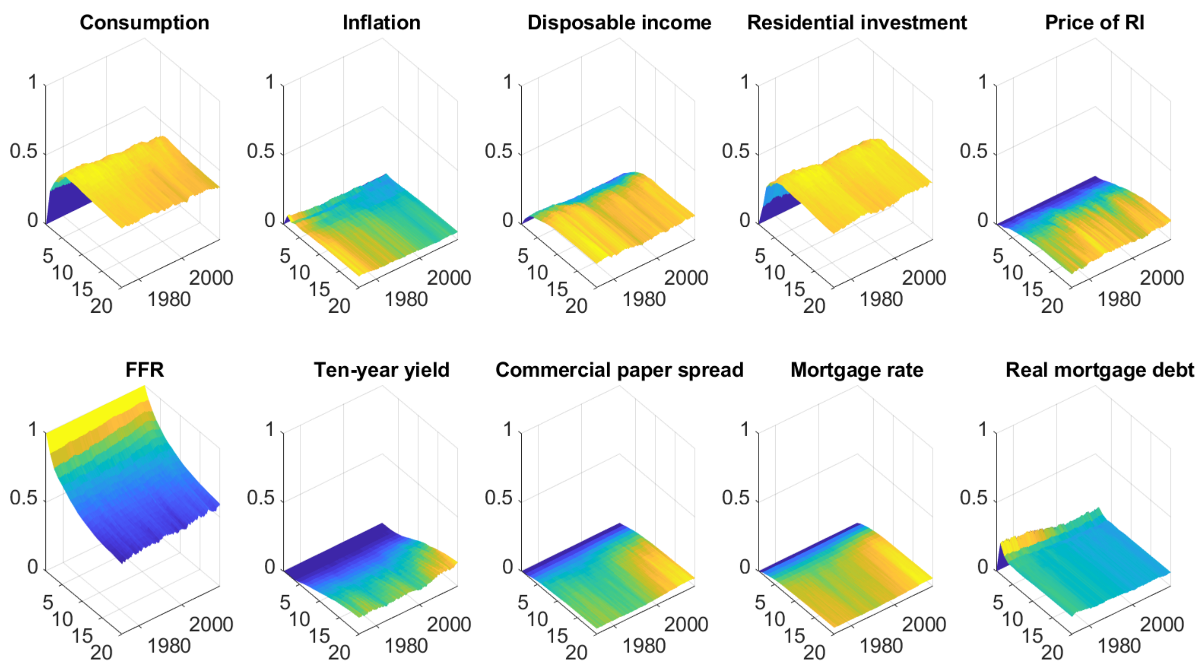

Figure 2.13 FEVDs with Respect to the Monetary Policy Shock, 1972q1 to 2018q4

Notes: The plot shows the share of variation explained by the monetary policy shock on the entire sample. Estimates are produced by the baseline TVP-SV-SVAR.

CHAPTER

3

HOUSING BOOMS AND BUSTS: WHO ISSUES MBS MATTERS

3.1 Introduction

Mortgage securitization is the process in which an issuer merges or pools several mortgage loans to generate a financial instrument called a mortgage-backed security (MBS). There are two sources of MBS. First, a mortgage loan can be insured against credit risk and securitized by a government-sponsored enterprise (GSE) such as the Federal National Mortgage Association (Fannie Mae) and the Federal Home Loan Mortgage Corporation (Freddie Mac). Loans securitized by GSEs must conform to certain standards such as large down payments and a maximum size of a loan [Fra05].[1] Second, loans that do not conform to the GSEs standards can be securitized by private firms such as commercial and investment banks. Subprime and Alt-A mortgages, generally offered to riskier borrowers with small down payments or lacking verified income, are the most important sources of non-conforming loans. Following Frame & White [Fra11], I refer to privately securitized mortgages as private-label (PL-MBS).

Figure 3.1 shows the share of PL-MBS along with the year-over-year growth rate of the US house price index from 1994q1 to 2009q4. The GSEs dominated the market for MBS with limited competition from the PL issuers from the mid-1980s until 2003. During that period, the private sector assumed the role of mortgage originator to supply conforming loans to the GSEs as raw materials. The GSEs would buy and pool these mortgages to issue new MBS.

[1] The standards evolved over time. In 2007, the maximum loan size was $417,000.

From 2003 to 2007, the composition of MBS issuance started to change. The large fees and profits generated from mortgage securitization lured commercial and investment banks to supply MBS to the market. In contrast to the GSEs, the focus of the PL issuers was on riskier non-conforming mortgages [Fra11]. These were mostly subprime mortgages. The share of PL-MBS more than doubled, growing from 15 percent in 2002 to 37 percent by the end of 2006.

House prices also appear to have played an important role in altering the composition of the MBS market. The boom in house prices starting in 1998 accelerated in 2003 before peaking in the second quarter of 2006.[2] That acceleration, coupled with the belief that house prices in the US could not fall, prompted rating agencies to grant the top PL-MBS triple-A credit ratings as documented by [Fra11]. The triple-A credit ratings became an important source of demand by investors seeking low-risk assets offering a high yield. Another source of demand for PL-MBS was commercial banks. They used PL-MBS as collateral in the interbank funding during this period [Gor12a].

[Gor08] also argues the belief that US house prices were immune to falling tipped the composition of MBS issuance towards PL-MBS. Since the structure of subprime mortgages gives lenders the option to refinance the mortgage or sell the collateral to recover the loan after two years, private lenders had incentives to take a long position on MBS. As a result, PL-MBS became more sensitive to movements in house prices than GSE-MBS. Further, [Gor12b] state that the financial panic in the 2007-2009 financial crisis was driven by sudden liquidity shortages in the money markets. The shortages were most severe in the markets that relied on short-term loans to fund subprime MBS holdings.

This paper studies the 2007-2009 housing and financial crisis from three perspectives. First, I explore the links between the MBS securitization and the housing market since 1985. These links are examined by estimating the effects of shocks to GSE-MBS and the share of PL-MBS on house prices and residential investment. In addition, this paper estimates the responses of the composition of MBS to housing demand and supply shocks. Second, the paper examines two hypotheses about the triggers of the 2007-2009 financial crisis. By identifying liquidity shocks, I develop evidence about the [Gor12b] hypothesis that the financial crisis was triggered by severe shortages in liquidity that increased the cost of short-term funding of PL-MBS. Also, the role of the GSEs securitization activity in the collapse of the MBS market is investigated by estimating the responses of the level of GSE-MBS to identified GSE-MBS shocks. Finally, I evaluate the effectiveness of the large scale asset purchasing (LSAP) or quantitative easing (QE) programs. The focus is on the impact of QE on the return of prime-rated mortgages over the yield on 10-year Treasury bonds, which is a publicly stated goal of QE by the Fed.

The study is conducted by estimating a SVAR on six housing and mortgage market variables. The SVAR consists of the growth rate of real residential investment, the growth rate of real house prices, the spread on commercial paper over 3-month Treasury bills, the spread on the prime mortgage rate over the yield on 10-year Treasury bonds, the growth rate of real GSE-MBS, and the growth rate of the share of PL-MBS. The SVAR has time-varying parameters (TVPs) and stochastic volatility

[2]As measured by S&P/Case-Shiller U.S. national home price index.

(SV). The model is estimated on a sample from 1985q1 to 2018q4 using the Metropolis within Gibbs algorithm of [Can15].

The baseline SVAR is recursive. I utilize the recursive structure to identify housing supply, housing demand, liquidity, QE, GSE-MBS, and MBS composition shocks. Innovations to residential investment and house prices are used to identify housing supply and housing demand shocks, respectively. Further, innovations to the commercial paper spread identify liquidity shocks, while innovations to the mortgage spread around QE announcement dates serve to identify as QE shocks.[3] Finally, innovations to GSE-MBS and the share of PL-MBS identify shocks in the MBS market. Potential sources of MBS shocks include: a surge in the risk-bearing capacity of the PL issuers, an increase in demand for safe assets by investors, and/or changes in regulations.

The estimation produces five main results. First, a positive housing demand shock shifts the MBS composition towards PL issuers and away from GSEs. Across all horizons, the response of the level of the share of PL-MBS to housing demand shocks is the largest between 2001 and 2006. The peak response is in 2004q2 as a one-percent shock to housing demand raises the level of the share of PL-MBS by 2.2, 4.1, and 4.6 percent at 4, 10, and 20 quarter horizons, respectively. These responses are consistent with the argument of [Gor08] that PL-MBS are more sensitive to movements in house prices than GSE-MBS. Second, a positive shock to the share of PL-MBS generates higher house prices. House prices are found to be more sensitive to MBS composition shocks from 2003 to 2006. In 2004q2, a ten-percent shock to the composition of MBS increases the level of house prices by 1.3, 3.6, and 4.2 percent at 4, 10, and 20 quarter horizons, respectively. Hence, shocks to MBS composition have an economically important effect on the level of house prices.

Third, liquidity shocks are an important trigger of the 2007-2009 financial crisis. In 2008q4, the shock to liquidity causes the commercial paper spread to increase by 170 basis points, 280 basis points, and 500 basis points at the 2, 4, and 20 quarter horizons, respectively. Furthermore, liquidity shocks explain more than 90% of the variation in the commercial paper spread from the one- to eight-quarter horizons across the sample. Fourth, the estimates show only a small effect of GSE-MBS shocks on the level of GSE-MBS, especially during the 2007-2009 financial crisis. The GSE-MBS responses to GSE-MBS shocks are small and do not exceed 1.25 percent across all the horizons and dates. These responses are even smaller around the 2007-2009 financial crisis. Furthermore, GSE-MBS shocks fail to explain any economically significant share of the variation in the level of GSE-MBS beyond the one-quarter horizon across the sample. This result attributes only a marginal role to the GSEs in the collapse of the MBS market and in triggering the 2007-2009 financial crisis.

Finally, QE programs' effect on the mortgage spread is limited. The QE shocks reduce the mortgage spread by 2 percent, 3 percent, and 4.4 percent at the 2, 4, and 20 quarter horizons, respectively. However, the responses of the mortgage spread to these shocks are smaller from 2009 to 2013 compared to the rest of the sample. For example, in 1986q1, the mortgage spread shock reduces the mortgage spread by 2 percent, 3.3 percent, and 5.5 percent at the 2, 4, and 20 quarter horizons, respectively. I interpret these results as evidence the Fed QE programs were not able to significantly

[3] See also [Kri11], [Chu12], and [Kil18] for the use of event studies in identifying QE shocks.

reduce the spread in the mortgage market.

The outline of the paper is as follows. The next section discusses the SVAR and the identification scheme. Section 3.3 describes the data used in the analysis in addition to the priors. Section 3.4 examines the SV results. The IRFs to housing supply and demand, GSE-MBS, and MBS composition shocks are discussed in section 3.5. I examine the role of liquidity and GSE-MBS shocks in triggering the 2007-2009 financial crisis in section 3.6. Section 3.7 evaluates the effectiveness of the Fed QE programs. Section 3.8 concludes.

3.2 The SVAR and Identification

This section describes the SVAR and my identification strategy. Identification is discussed in the context of two blocks of variables that cover the housing and mortgage markets.

3.2.1 Model

Define y_t, to be an M(= 6)×1 vector of variables. The variables are the growth rate of real residential investment in single-family structures, $\Delta \ln RI_t$, the growth rate of the real house price index, $\Delta \ln HP_t$, the commercial paper spread over 3-months treasury bills, S_t, the thirty-year fixed mortgage spread over ten year Treasury bonds, MS_t, the growth rate of real GSE-MBS, $\Delta \ln GSE_t$, and the growth rate of the share of PL-MBS, $\Delta \ln PLS_t$.[4] This sets

$$y_t = \begin{bmatrix} \Delta \ln RI_t & \Delta \ln HP_t & S_t & MS_t & \Delta \ln GSE_t & \Delta \ln PLS_t \end{bmatrix}'$$

A maintained assumption is that y_t has a p^{th} order reduced-form VAR representation

$$y_t = B_{0,t} + B_{1,t} y_{t-1} + ... + B_{p,t} y_{t-p} + u_t, \qquad u_t \sim N(0, \Omega_t), \tag{3.1}$$

where $B_{0,t}$ denotes a vector of M time-varying intercepts,$B_{j,t}$, $j = 1, \ldots, p$ are M×M matrices of time-varying slope coefficients, and Ω_t is an M×M time-varying, positive definite and full rank covariance matrix of the reduced form innovations u_t. Let $\epsilon_t \sim N(0, I_M)$ be the vector of the structural shocks. The mapping from reduced form innovations to the structural shocks is $u_t = A_t^{-1}\Sigma_t \epsilon_t$, where A_t is the matrix of impact coefficients. Collect the off-diagonal non-zero elements of A_t into the vector α_t. The time-varying standard deviations that scale the structural shocks are in the diagonal matrix $\Sigma_t = diag\{\sigma_{m,t}\}$. The non-zero elements of Σ_t will be more conveniently referred to as the stochastic volatility of the structural shocks.

The reduced form VAR of equation (1) can be re-written as the SVAR

$$A_t y_t = A_t X_t' B_t + \Sigma_t \epsilon_t, \tag{3.2}$$

where $X_t' = I \otimes \begin{bmatrix} 1, & y_{t-1}' & ,..., & y_{t-p}' \end{bmatrix}$ and $B_t = \begin{bmatrix} vec(B_{0,t})', & ..., & vec(B_{p,t})' \end{bmatrix}'$. The laws of motion for the slope coefficients, impact coefficients and standard deviations of the structural shocks are

[4]See table 3.1 for more details on the sources and definitions of the data.

the multivariate random walks

$$B_t = B_{t-1} + v_t, \tag{3.3}$$

$$\alpha_t = \alpha_{t-1} + \varsigma_t, \tag{3.4}$$

and

$$\log(\sigma_{m,t}) = \log(\sigma_{m,t-1}) + \eta_{m,t}. \tag{3.5}$$

Given $\eta_{m,t} = \begin{bmatrix} \eta_{1t}, & ..., & \eta_{M,t} \end{bmatrix}$, I set the covariance matrix of the innovations to the TVP and SV states to be block diagonal

$$\mathscr{R} = Var\left(\begin{bmatrix} \varepsilon_t \\ v_t \\ \varsigma_t \\ \eta_t \end{bmatrix}\right) = \begin{bmatrix} I_M & 0 & 0 & 0 \\ 0 & \mathscr{Q} & 0 & 0 \\ 0 & 0 & V & 0 \\ 0 & 0 & 0 & W \end{bmatrix} \tag{3.6}$$

where $\mathscr{Q}$, V and W are full rank matrices.

3.2.2 Identification of the Blocks and Shocks

My identification strategy imposes short-run zero restrictions on the impact matrix A_t. Table 3.2 offers a summary of the restrictions. I group the elements of y_t into a housing block and a mortgage market block. The inter-block ordering is recursive. The housing block is ordered first because it contains real residential investment growth, $\Delta \ln RI_t$. In this case, financial shocks affect real residential investment with a one-quarter lag.[5]

Housing Block

The housing market includes $\Delta \ln RI_t$ and the growth rate of house prices, $\Delta \ln HP_t$. Within the block, $\Delta \ln RI_t$ is ordered first. Residential investment adds new units on the margin to housing supply. This ordering implies that on impact, house prices adjust to housing supply shocks. Housing demand shocks are identified as innovations to $\Delta \ln HP_t$ under this identification. A shock to housing demand represents a rightward shift in the demand curve for houses.

Mortgage Block

The mortgage market consists of the short rate spread, S_t, the mortgage yield spread, MS_t, the growth of GSE-MBS, $\Delta \ln GSE_t$, and the growth rate of the share of PL-MBS in total MBS, $\Delta \ln PLS_t$. I order S_t first in the mortgage block. This identifies innovations to S_t as liquidity shocks. Liquidity shocks alter the costs banks incur to finance holdings of risky long-term assets, which includes MBS, with short-term funds.[6]

[5] The main conclusions and results are not altered by estimating TVP-SV-SVARs under alternative identifications. See the appendix.

[6] See Krishnamurthy & Vissing-Jorgensen [Kri12] for more on the relationship between credit spreads and liquidity.

Also, a shock to MS_t reflects unanticipated changes in the conditions of the mortgage market. An unanticipated increase in the prime mortgage rate over the yield on 10-year Treasuries implies a higher risk premium and worsening conditions for the mortgage market participants. An innovation to $\Delta \ln PLS_t$ represents a shock to the composition of MBS. The source of this shock can be a change in the willingness of PL issuers to hold risky assets, an increase in investors' demand for safe assets, and/or changes in regulations.

3.3 Data and Priors

The sample used to estimate the model runs from 1985q1 to 2018q4 for a total of T=132 observations. This period includes notable events in the housing and mortgage markets such as the savings and loan crisis of the 1980s, 1990s financial deregulation, the 1998-2006 boom in housing prices, and the 2007-2009 financial crisis.

Table 3.1 provides detailed definitions and sources of the data. I focus the analysis on single-family homes whenever the data allows. For example, the residential investment series measures the flow of new single-family structures. Data on PL-MBS and GSE-MBS is available only for mortgages on multi-family homes up to four units. The mortgage spread, MS_t, is constructed on the average "prime" mortgage rate. This is the benchmark rate for mortgages underlying GSE-MBS, but is not relevant for PL-MBS. There is no available data on subprime mortgage rates that cover my sample.

Figure 3.2 plots the data with NBER recession dates as gray shadings. All variables are expressed in terms of annualized growth rates, except for the commercial paper spread and mortgage spread. The growth rate of residential investment exhibits V-shaped declines and recoveries around the 1990-1991 recession and the 2007-2009 financial crisis. The growth rate of house prices is positive from the late 1990s to its peak in 2006q2. House prices drop sharply from 2006q3 to the end of the financial crisis in 2009q2. It is slow to recover afterward.

The commercial paper spread peaks during the 2007-2009 financial crisis, as shown in figure 3.2. This peak is a reflection of the liquidity squeeze during the financial crisis. The mortgage spread also shows a peak during the 2007-2009 financial crisis in addition to another peak in 1986. The third row of figure 3.2 shows the plots of the growth rate of GSE-MBS and the growth rate of the share of PL-MBS. The aftermath of the federal government takeover of the two largest GSEs (Fannie Mae and Freddie Mac) causes the GSE-MBS and MBS composition series to show a spike in 2009.

Priors and Estimation

I use the Metropolis within Gibbs algorithm of [Can15] to estimate the TVP-SV-SVAR of equations (2)-(6). The TVP-SV-SVAR is estimated with two lags (p=2).

Table 3.3 presents my priors on the TVP-SV-SVAR. The variances of the errors of the laws of motion given in equations (3)-(5) have inverse Wishart priors. The priors on the impact matrix, intercepts, reduced-form slope coefficients, and the log of the standard deviation of structural shocks are normally distributed. An empirical Bayes prior is used to avoid forfeiting observations on a training sample. This prior utilizes estimates of the fixed-coefficients version of the SVAR on the full sample that runs from 1985q1 to 2018q4. Estimating this SVAR by OLS produces the parameters of the priors of the slope coefficients, $\underline{\mathbf{B}}$, and covariance matrix, $\underline{\mathbf{VB}}$. Given these priors, I employ maximum likelihood to obtain the prior mean of the impact coefficients, $\underline{\boldsymbol{\alpha}}$, covariance matrix, $\underline{\mathbf{VA}}$, and the log of standard deviations of the structural shocks, $\underline{\boldsymbol{\sigma}}$. The tuning parameters are $k_{\mathscr{Q}}^2 = 0.001$, $k_V^2 = 0.001$, $\mathscr{K} = 0$, and $k_W^2 = 0.0001$. These choices achieve a rejection rate of explosive roots' draws of around 15-35% for the reduced form slope coefficients B_τ, and an acceptance rate of 23-40% for the Metropolis step in which the impact coefficients A_τ are drawn, where $\tau = 1 : T$.

Using these settings, I generate 500,000 draws from the posterior. The first 150,000 draws are discarded, and a thinning factor of 14 is applied to minimize serial correlation in the posterior draws. The final number of posterior draws is 25,000.[7]

3.4 SV Results

Figure 3.3 reports the SVs of housing supply, housing demand, liquidity, the mortgage spread, GSE-MBS, the MBS composition shocks from 1985q3 to 2018q4 with 90% uncertainty bands. The top two panels of figure 3.3 depict the SV of housing supply and housing demand shocks. Around the 1990-1991 recession, the uncertainty bands surrounding the SV of the housing supply shock are wider relative to the housing demand shock. There is considerable uncertainty surrounding the SV of the housing supply shock estimates between 2006 and 2011. Similarly, the uncertainty bands around the SV of the housing demand shock show a small hump-shape that peaks in 2012. These years were a period of turmoil in the housing market. However, the median SVs of the housing supply and demand shocks are mostly unchanged from 1985 to 2005.

The SVs of liquidity and mortgage spread shocks appear in the second row of figure 3.3. There are two peaks in the plot of the SV of the liquidity shock. The first is around 1987, which coincides with the 1987 financial panic known as the Black Monday. The largest peak occurs during the 2007-2009 financial crisis. The SV of the mortgage spread shock is mostly flat across all sample dates.

The SV estimates of the GSE-MBS shock is reported in the bottom left panel of figure 3.3. The estimates are flat from 1985 to 2008, which includes the run-up to the 2007-2009 financial crisis. There is a spike in the SV of the GSE-MBS shock from 2009 to 2011. It stays elevated through 2011. The 2009-2011 period of heightened volatility in the GSE-MBS shock corresponds to the aftermath of the US government takeover of Fannie Mae and Freddie Mac in September 2008.

The bottom right panel in figure 3.3 displays the SV of the MBS composition shock. The plot shows three peaks. The first two peaks are in the late 1980s and coincide with the cleanup and winding down of the Savings and Loan industry. According to Corporation & Corporation [Cor98], the government sale of $25 billion of failed S&Ls' assets "...helped expand the securitization of mortgages ineligible for GSE guarantees" in the late 1980s. The collapse of the PL-MBS market coincides with the 2007-2009 financial crisis and the federal government takeover of the two largest

[7]More details on the sampling algorithm are available in Canova and Perez Forero (2015), pages 369-370.

GSEs (Fannie Mae and Freddie Mac) in 2008.

3.5 The Housing Market and the MBS Composition

This section examines the links between the MBS and housing markets in the run-up to the 2007-2009 financial crisis. Estimates of the baseline TVP-SV-SVAR outlined in section 3.2 produce a set of 130 IRFs. I pick six dates related to the 1998-2006 boom and bust in the US housing market and the subsequent financial crisis when discussing the IRFs. The first date is 1998q1. It marks the start of the 1998-2006 boom in house prices. Second, 2002q1 captures the end of the 2001 recession and the fast growth of the PL-MBS share. The next date is 2006q2, which coincides with the sample peak of house prices. I pick 2007q3 because this date marks an early sign of trouble in the PL-MBS market because the investment bank PNB-Paribus halted support for three funds holding more than $2 billion worth of PL-MBS. Finally, 2008q1 and 2008q3 are the dates on which the failures of Bear Stearns and Lehman Brothers occur. The source of these failures was argued to be a substantial exposure to the subprime mortgage market.

3.5.1 Housing Supply Shock

The top row of figure 3.4 presents the responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to housing supply shocks across the entire sample. In the housing block, the housing supply shock has a positive effect on the levels of residential investment and house prices at all horizons and dates. These responses are slightly larger after 2003. In the mortgage market block, the responses of the levels of GSE-MBS and the share of PL-MBS exhibit substantial time variation. The level of GSE-MBS declines at all horizons following a housing supply shock between 2000 and 2013. The 1988-1993 period is the only other period that shows a negative response of GSE-MBS to a housing supply shock. The shock also causes an increase in the share of PL-MBS at all horizons and dates. Between 2002 and 2008, the responses of the share of PL-MBS to a housing supply shock are larger than before 2002.

Next, I take a close up look at the effects of the housing supply shock. Figure 3.5 shows the responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to housing supply shocks at 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. The responses of the levels of residential investment and house prices show only minimal time variation at the selected dates. In 2006q2, a one-percent housing supply shock causes a 1.5 percent increase in the level of residential investment at the two-quarter horizon, and a permanent 2.2 percent increase at the two-year horizon. Also, the price of existing houses increases slightly following a housing supply shock in the run-up to the 2007-2009 financial crisis. In 2007q3, the level of house prices increase by 0.2 percent at the one-year horizon, and 0.4 percent at the two-year horizon.[8]

[8]Despite being counter-intuitive, this increase in house prices can be due to the way they are measured. According to Davis & Heathcote [Dav07], house prices also reflect the price of land. Given an inelastic supply of land, any increase in residential investment can cause the price of land to increase. Therefore, viewing land as an input with respect to residential investment explains the positive response of house prices to housing supply shocks.

The bottom row of figure 3.5 plots the responses of the levels of GSE-MBS and the share of PL-MBS to a housing supply shock at 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. In 1998q1, the housing supply shock causes the level of GSE-MBS to increase by 0.1 percent from the five-quarter to the five-year horizon. However, the GSE-MBS responses are negative at the same horizons starting 2002q1. In 2002q1, 2006q2, 2008q1, and 2008q3, a housing supply shock causes a 0.2 percent drop in the level of GSE-MBS after the five-quarter horizon. This result implies the GSEs are not increasing their MBS issuance in response to the increased supply of housing from 2002 to 2008. Finally, following a housing supply shock, the level of the PL-MBS share increases by 0.36 percent at the two-year horizon in 2006q2, compared to less than 0.2 percent prior to 2002q1 at the same horizon. Although the magnitudes are small, this result suggests surges in housing supply drive up the share of PL-MBS. This relationship is evident in the run-up to the 2007-2009 financial crisis.

3.5.2 Housing Demand Shock

The bottom row of figure 3.4 contains the responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to housing demand shocks across the entire sample. The greater demand for houses stimulates residential investment and house prices. The responses of the levels of residential investment and house prices to a housing demand shock are positive across the entire sample and at all horizons. These responses get slightly smaller after the 2001 recession. Following a housing demand shock, the level of GSE-MBS declines at all horizons between 2000 and 2009. Also, starting in the late 1990s, the response of the level of the PL-MBS share to a housing demand shock displays a more pronounced hump shape. The responses of the PL-MBS share are statistically significant at each date after 2000, and the hump shape reaches a maximum between 2001 and 2006. After 2006, the IRFs exhibit less hump-shaped responses, but larger responses than pre-2000.

To dive into the details of these IRFs, figure 3.6 plots the responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to a housing demand shock at 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. In the housing block, the responses of residential investment to a housing demand shock are statistically significant up to one year after the shock. The bulk of responses are at the one to eight quarter horizons and are slightly smaller after 1998q1. In 2006q2, 2007q3, 2008q1, and 2008q3, the housing demand shock causes the level of residential investment to increase by 1.4 percent at the five- to the eight-quarter horizon. The positive response of the level of residential investment is consistent with the Tobin-q relationship. Greater demand for houses makes it profitable to invest in new housing. The housing demand shock also raises house prices. The shock increases the level of house prices by about 2 percent from the five-quarter to five-year horizon in 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3.

The bottom two panels in figure 3.6 plot the responses of the levels of GSE-MBS and the share of PL-MBS to a housing demand shock. In 1998q1, the level of GSE-MBS increases slightly from impact to the one-year horizon following a housing demand shock. However, the level of GSE-MBS shows a clear decline in 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. That decline is statistically and economically significant from impact to the 5-year horizon. The bulk of these responses accumulates within a year after the housing demand shock. For instance, in 2006q2, the GSE-MBS level declines by 1 percent at the one-year horizon and stays at that level until the 5-year horizon. This result indicates that the GSEs are not financing surges in housing demand in the run-up to the 2007-2009 financial crisis.

Also, the housing demand shock causes the share of PL-MBS to increase at all horizons in 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. The responses are smaller in 1998q1. For example, at the five-year horizon, a one-percent shock to housing demand raises the level of the share of PL-MBS by 1.7 percent in 1998q1 compared to 3.9 percent in 2002q1. The strong positive responses of the level of PL-MBS share between 2002q1 and 2007q3 are consistent with [Gor08]. Gorton argues that subprime mortgages securitized by PL issuers are more sensitive to fluctuations in house prices than GSE securitized mortgages.

3.5.3 GSE-MBS Shock

The top row of figure 3.7 has the responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to a one-percent GSE-MBS shock across the entire sample. In the housing block, the GSE-MBS shock causes a positive, yet statistically insignificant, increase in the level of residential investment at all horizons across the sample. Also, across the sample, the levels of house prices increase at all horizons following a GSE-MBS shock. The increase in the level of house prices is larger and statistically significant post-2000. Interestingly, the level of the share of PL-MBS increases following the GSE-MBS shock over all horizons and sample dates. The response of the level of the PL-MBS share peaks between 2002 and 2006.

Next, I discuss the effects of the GSE-MBS shock in the context of the 1998-2006 boom and bust in the US housing market and the 2007-2009 financial crisis. Figure 3.8 shows the responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to a GSE-MBS shock at 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. In the housing market, the levels of residential investment and house prices rise after the GSE-MBS shock at all selected dates. The magnitude of the rise is smaller in 1998q1. The magnitude of the level of residential investment response is small and does not exceed 0.4 percent at any date or horizon. Similarly, the response of the level of house prices is small overall. For example, the largest response occurs in 2007q3, where a GSE-MBS shock causes the level of house prices to increase by 0.2 percent at the 5-year horizon. These small effects suggest the GSEs' contribution to the 1998-2006 boom in house prices is limited.

The bottom two panels in figure 3.8 depict the responses of the levels of GSE-MBS and the share of PL-MBS to a GSE-MBS shock at 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. The responses of the level of GSE-MBS and the share of PL-MBS to GSE-MBS shock are positive at all of the selected dates and horizons. In 1998q1, the response of the share of PL-MBS is smaller than 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. For example, the GSE-MBS shock causes a 2 percent increase in the level of the share of PL-MBS in 2008q1 at the five-year horizon compared to a 1.3

percent increase in 1998q1 at the same horizon. This result implies that the PL-MBS grows faster than GSE-MBS following a surge in the GSEs activity.

3.5.4 MBS Composition Shock

The responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to MBS composition shock are shown in the bottom row of figure 3.7 across the entire sample. In the housing block, the MBS composition shock triggers hump-shaped responses in the level of residential investment. The peak of the hump is higher after the early 2000s. Across all horizons and dates, the level of house prices increases following a shock to the composition of MBS. The peak response of house price levels to a shock to the composition of MBS is in the 2004 to 2006 period. Further, between 1992 and 2003, any shock to the MBS composition not only increased the share of PL-MBS but also stimulated the growth of GSE-MBS. Interestingly, this relationship is reversed between 2003-2006.

Figure 3.9 plots the responses of the levels of residential investment, house prices, GSE-MBS, and the share of PL-MBS to MBS composition shock at 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. The MBS composition shock has a positive effect on residential investment. In 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3, the level of residential investment increases by about 0.4 percent at the 4-year horizon following an MBS composition shock. However, this is a small increase in relation to the growth rates of residential investment observed in the data; see the first panel of figure 3.2. Along with the lack of economically compelling IRFs, the uncertainty bands of these IRFs cover zero at all horizons. On the other hand, the response of the level of house prices to the MBS composition shock is economically and statistically significant at 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3 up to the 4-year horizon. For example, a one-percent shock to the MBS composition in 2006q2 increases the level of house prices by 0.1, 0.3, and 0.35 at the 4, 10, and 20 quarter horizons, respectively. These effects may seem modest at first because of the small size of the shock. The share of PL-MBS more than doubled between 2003 and 2006. A larger MBS composition shock of say 10 percent in 2006q2 can generate a 3.5 percent increase in house price levels at the five-year horizon. This increase is almost two times as large as the median growth rate of house prices in the data from 1985q1 to 2018q4. These estimates show the effect of MBS composition shocks on house price levels is larger and more economically important after 2000. Notably, from 2004 to 2006, the GSEs share of the MBS market declined and gave way to the emergence of subprime lending and securitization [Com11]. These responses are consistent with a view of subprime lending and securitization as a more important driver of house prices than GSEs securitization during the 2007-2009 financial crisis.

The bottom two panels in figure 3.9 show the responses of the levels of GSE-MBS, and the share of PL-MBS to the MBS composition shock at 1998q1, 2002q1, 2006q2, 2007q3, 2008q1, and 2008q3. In 1998q1 and 2002q1, the share of PL-MBS increases in response to its own shock along with producing an expansion in GSE-MBS. In 1998q1, the shock increases the level of GSE-MBS by 0.3 percent after the three-year horizon. However, this response is reversed in 2006q2, 2007q3, 2008q1, and 2008q3. For example, the MBS composition shock causes a 0.1 percent drop in the level of GSE-MBS after the three-year horizon in 2007q3. These responses reflect the increasing dominance of PL-MBS in the MBS market in the years before the 2007-2009 financial crisis.

3.6 The 2007-2009 Financial Crisis

This section investigates two hypotheses about the sources and causes of the 2007-2009 financial crisis. First, I explore the effect of liquidity shocks on the commercial paper spread. The motivation is [Gor12b]. They argue the financial crisis was caused by a shortfall in liquidity that raised the cost of short-term debt on which banks and other financial institutions relied to fund longer maturity risky assets. Others, such as [Swa09], attribute the 2007-2009 financial crisis to the GSEs. They argue the GSEs' expansion into riskier MBS is the main reason the MBS market collapsed in the 2007-2009 financial crisis.

I evaluate these explanations for the 2007-2009 financial crisis using liquidity and GSE-MBS shocks to generate IRFs and FEVDs. The FEVDs are reported on the entire sample. The IRFs focus on five dates that represent key moments in the financial crisis. The first date is 2007q3. It marks the BNP Paribas decision to freeze three funds heavily invested in PL-MBS. Second, 2007q4 captures the peak date of the 2007-2009 NBER recession. Additionally, 2008q1 and 2008q3 represent the dates of Bear Stearns and Lehman Brothers failures. Finally, I pick 2008q4, which coincides with the US government placing Fannie Mae and Freddie Mac in conservatorship.

IRFs of Liquidity and GSE-MBS Shocks

The left panel in figure 3.10 shows the IRFs of the commercial paper spread to one-percent liquidity shocks across the entire sample. Liquidity shocks cause an increase in the commercial paper spread at all horizons and dates. The magnitude of the increases is economically significant, and the responses are larger after 2007.

The left panel of figure 3.11 shows the responses of the commercial paper spread to liquidity shocks at 2007q3, 2007q4, 2008q1, 2008q3, and 2008q4. The responses of the commercial paper spread to liquidity shocks are economically important during the 2007-2009 financial crisis. For example, when the federal government took over the GSEs in 2008q4, liquidity shocks cause the commercial paper spread to increase by 170 basis points, 280 basis points, and 500 basis points at the 2-quarter, 4-quarter, and 20-quarter horizons, respectively. These increases in the commercial paper spread suggest banks and other financial firms faced liquidity shortages during the financial crisis. These results are consistent with [Gor12b]. Their estimates support the view that a prime source of the financial crisis were liquidity shocks that constrained the ability of banks and other financial firms to fund MBS and other securitized assets.

The responses of the GSE-MBS level to GSE-MBS shocks are displayed in the right panel in figure 3.10. At all horizons and dates, the level of GSE-MBS increases following the GSE-MBS shock. From 2002 to 2009, the responses are smaller relative to the rest of the sample. The right panel of figure 3.11

reports the responses of the level of GSE-MBS to its own shock at 2007q3, 2007q4, 2008q1, 2008q3, and 2008q4. The largest effect of the shock occurs in 2008q1 as the level of GSE-MBS increases by 1 percent at the one-year horizon. Overall, these responses are small and do not exceed 1.1 percent across all the horizons. These weak responses of GSE-MBS to GSE-MBS shocks suggest the GSEs played only a limited role in the collapse of the mortgage market.

FEVDs of Liquidity and GSE-MBS Shocks

Figure 3.12 shows the FEVDs of the commercial paper spread and the level of GSE-MBS with respect to liquidity and GSE-MBS shocks. Across the sample, liquidity shocks are the most important factor in explaining variation in the commercial paper spread. The shock to liquidity explains more than 90 percent of the variation in commercial paper spread at horizons of less than two years.

On the other hand, GSE-MBS shocks fail to explain any economically significant share of the variation in the level of GSE-MBS beyond impact. From the one-quarter to the 5-year horizons, GSE-MBS shocks do not account for more than 0.1 percent of the variation in the level of GSE-MBS. The inability of the GSE-MBS shock to generate economically interesting IRFs and FEVDs is evidence that it was not a source or a cause of the 2007-2009 financial crisis.

3.7 QEs and the Mortgage Spread

The 2007-2009 financial crisis prompted the Fed to intervene in the mortgage markets. These interventions are more commonly known as LSAPs or QE programs. Under these programs, the Fed engages in large-scale purchases of Treasury debt and MBS issued by the GSEs. The Fed purchases MBS with the goal of reducing the mortgage spread. The maintained assumption is that shrinking the mortgage spread lowers the cost of financing in the credit markets. According to the Fed Chairman at the time, Ben Bernanke, the QE program aims at “reducing those spreads [credit spreads] and improving the functioning of private credit markets more generally.” [Ber09].

I investigate whether the Fed was able to achieve its explicit objective of reducing the mortgage spread through the QE programs. The QE shock is identified as a negative shock to the mortgage spread one quarter after the policy action was announced.

Figure 3.13 depicts the responses of the mortgage spread to QE shocks at 2009q1, 2011q1, 2012Q4, 2013q2, and 2018q4, which represent QE1, QE2, QE3, QE4, and the end of sample dates, respectively. Following all four QE shocks, the mortgage spread declines by 2 percent, 3 percent, and 4.4 percent at the 2, 4, and 20 quarter horizons, respectively. It‘s illustrative to examine the time variation in these responses across the entire sample. Figure 3.14 shows the response of the mortgage spread to a one-percent negative mortgage spread shock across the entire sample. The response of the mortgage spread to its own shock is economically and statistically significant at all dates and horizons, including the 2009-2013 QE programs. These responses are stable from impact to the two-year horizon across the sample. This stable relationship across the sample between the mortgage spread and its own shock makes it difficult to attribute the drop in the mortgage spread solely to the QE programs. Additionally, after 2004, the response of the mortgage spread to its own shock is significantly smaller after the two-year horizon. For example, the shock reduces the mortgage spread by 5.5 percent at the five-year horizon in 1986q1, compared to 4.3 percent from 2004q1 to 2013q2 at the same horizon. To illustrate the difference between these magnitudes, the sample data of the mortgage spread shows a peak of 2.6 percent at the height of the 2007-2009 financial crisis. Hence, even if the drop in the mortgage spread is attributed to the QE programs, the effect is significantly smaller between 2009 and 2013.

Figure 3.15 shows the FEVDs of the mortgage and housing markets with respect to the mortgage spread shock at all sample dates. The bottom left panel shows the FEVD of the mortgage spread with respect to its own shock. At all horizons and dates, the shock explains almost all of the variation in the mortgage spread. There is limited to no time variation in these estimates. This result shows it's difficult to attribute the variation in the mortgage spread entirely to the QE programs.

The mortgage spread shock is also important for the determination of residential investment and house prices. The shock explains around a third and two-thirds of the variation in the levels of residential investment and house prices from the six-quarter to the five-year horizon. The importance of the mortgage spread shock extends to the MBS market as well. For example, in 2009, the mortgage spread shock explains 80% of the variation in the level of GSE-MBS from the two-quarter to the five-year horizon. The shock is less important after 2010, but still explains about half of the variation in the level of GSE-MBS at the five-year horizon.

3.8 Conclusions

This paper relies on a structural VAR to examine three main issues. First, it examines the effect of housing supply and demand shocks on the share of PL-MBS and GSE-MBS. I find that positive housing supply and demand shocks shift the MBS composition towards PL issuers and away from GSEs, especially between 2001 and 2006. For example, in 2004q2, a one-percent shock to housing demand raises the level of the share PL-MBS by 2.2, 4.1, and 4.6 percent at 4, 10, and 20 quarter horizons, respectively. Also, a positive shock to the share of PL-MBS leads to higher house prices. House prices are more sensitive to a PL-MBS share shock from 2003 to 2006. In 2004q2, a ten-percent shock to the composition of MBS increases the level of house prices by 1.3, 3.6, and 4.2 percent at 4, 10, and 20 quarter horizons, respectively.

Second, I examine the role liquidity shocks and GSEs played as sources of the 2007-2009 financial crisis. In 2008q4, the shock to liquidity causes the commercial paper spread to increase by 170 basis points, 280 basis points, and 500 basis points at the 2, 4, and 20 quarter horizons, respectively. Additionally, the liquidity shock explains more than 90% of the variation in the commercial paper spread from the one- to eight-quarter horizon across the sample. Hence, liquidity shocks are an important trigger of the 2007-2009 financial crisis. On the other hand, the role of the GSEs in triggering the 2007-2009 financial crisis is limited. In 2008q1, the level of GSE-MBS increases by 1 percent at the one-year horizon following a one-percent GSE-MBS shock. The response of the level of GSE-MBS to its own shock is small during the 2007-2009 financial crisis and does not exceed 1.1 percent across all horizons. Furthermore, The GSE-MBS shock does not explain any economically meaningful variation in the level of GSE-MBS.

Finally, the effectiveness of QE programs in reducing the mortgage spread is evaluated. Evidence indicates the effect of QE programs on the mortgage spread is limited. The response of the mortgage spread to its own shock is smaller from 2004 to 2013 compared to the rest of the sample. For example, following QE shocks, the mortgage spread declines by 2 percent, 3 percent, and 4.4 percent at the 2, 4, and 20 quarter horizons, respectively. However, in 1986q1, the mortgage spread shock reduces the mortgage spread by 2 percent, 3.3 percent, and 5.5 percent at the 2, 4, and 20 quarter horizons, respectively.

To conclude, I hope this paper spurs new research on these topics along with contributing a better understanding of the US housing market before and after the 2007-2009 financial crisis.

Table 3.1 Data Definitions and Sources

Variable	Definition	Source
Real residential investment	Investment in single family structures, chain-type quantity index (2012=100)	U.S. Bureau of Economic Analysis.
Real house price index	U.S Office of Housing Enterprise Oversight repeat sales index, 1985Q1-1987Q1. From 1987Q1 to 2018Q4 it's Case/Shiller Index (1890=100).	Constructed and provided by Robert Shiller www.econ.yale.edu/~shiller/data.htm.
Six-month commercial paper rate	Average for financial and non-financial firms with AA or equivalent bond rating, Percent, 1985Q1-1997Q2. Spliced with 3-Month AA Financial Commercial Paper Rate, Percent, 1997Q1-2018Q4.	Board of Governors of the US Federal Reserve System.
Three-month Treasury bill rate	Secondary market rate, Percent.	Board of Governors of the US Federal Reserve System.
Yield on ten year Treasury bonds	10-year yields on actively traded non-inflation-indexed issues adjusted to constant maturities, Percent.	Board of Governors of the US Federal Reserve System.
Thirty-year fixed mortgage rate	Average of 30-year fixed mortgage rates in the United States, Percent.	Freddie Mac.
Agency and GSEs MBS issues	Home mortgages (one-to-four family mortgages) that have been removed from the originator's balance sheet and securitized by government agencies and GSEs.	Board of Governors of the US Federal Reserve System.
Private-label MBS issues	Home mortgages (one-to-four family mortgages) that have been removed from the originator's balance sheet and securitized by the private sector (excluding GSEs). Reported as assets of special purpose vehicles that hold private-label mortgage pools, Millions.	Board of Governors of the US Federal Reserve System.

Table 3.2 Baseline Identification of A_t

Variable	Block						
$\Delta \ln RI_t$	Housing	1	0	0	0	0	0
$\Delta \ln HP_t$		X	1	0	0	0	0
S_t	Mortgage	X	X	1	0	0	0
MS_t		X	X	X	1	0	0
$\Delta \ln GSE_t$		X	X	X	X	1	0
$\Delta \ln PLS_t$		X	X	X	X	X	1

Notes: The X's represent free parameters in the off-diagonal elements of A_t while zeros are short-run restrictions. Two variables, $\Delta \ln RI_t$ and $\Delta \ln HP_t$, represent the housing block. The mortgage market block contains S_t and MS_t, $\Delta \ln GSE_t$ and $\Delta \ln PLS_t$.

Table 3.3 Priors

Parameters	Priors
B_0^{prior}	$N(\underline{\mathbf{B}}, 4 \cdot \underline{\mathbf{VB}})$
$\mathcal{Q}^{prior}$	$IW(k_{\mathcal{Q}}^2 \cdot \underline{\mathbf{VB}}, (1 + \mathcal{K}))$
α_0^{prior}	$N(\underline{\boldsymbol{\alpha}}, \underline{\mathbf{VA}})$
V^{prior}	$IW(k_V^2 \cdot \underline{\mathbf{VA}}, (1 + dim\ \alpha))$
$log(\sigma_0)^{prior}$	$N(\underline{\boldsymbol{\sigma}}, 10 \cdot I_M)$
W_i^{prior}	$IW(k_W^2, 2)$

Notes: The tuning parameters $k_{\mathcal{Q}}^2 = 0.001$, $k_V^2 = 0.001$, $\mathcal{K} = 0$, and $k_W^2 = 0.0001$. The normal distribution is denoted with N and IW denotes the inverse-Wishart distribution. The underlined symbols represent priors on the slope coefficients ($\underline{\mathbf{B}}$), the covariance matrix ($\underline{\mathbf{VB}}$) of these parameters, maximum likelihood estimates of the impact matrix (A_t), its covariance matrix ($\underline{\mathbf{VA}}$) and the log of the standard deviations of the structural shocks ($\underline{\boldsymbol{\sigma}}$).

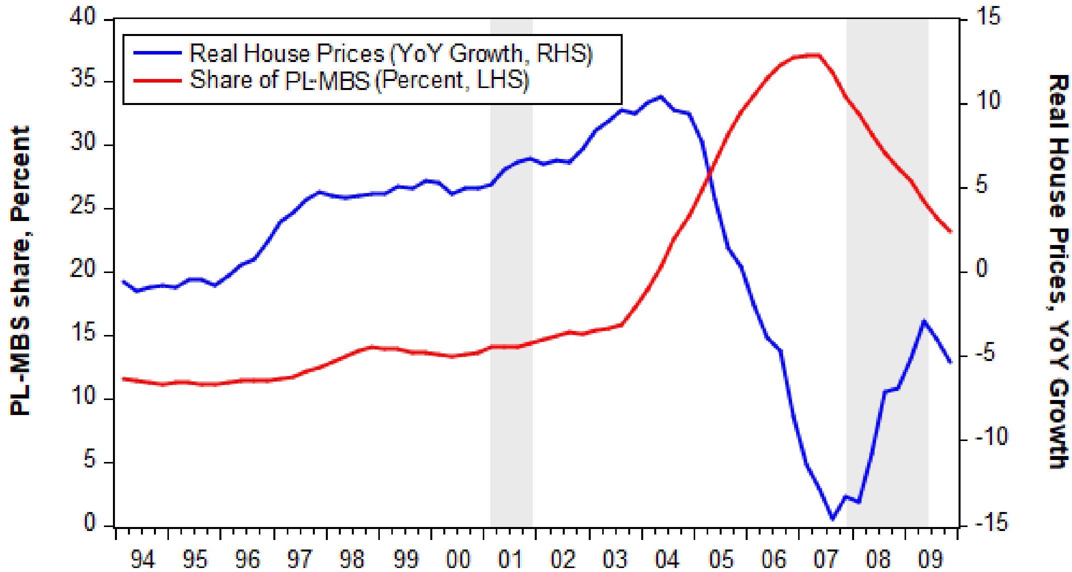

Figure 3.1 Real House Price Index and PL-MBS Share, 1994Q1 to 2009Q4

Notes: NBER recession dates appear as gray shading.

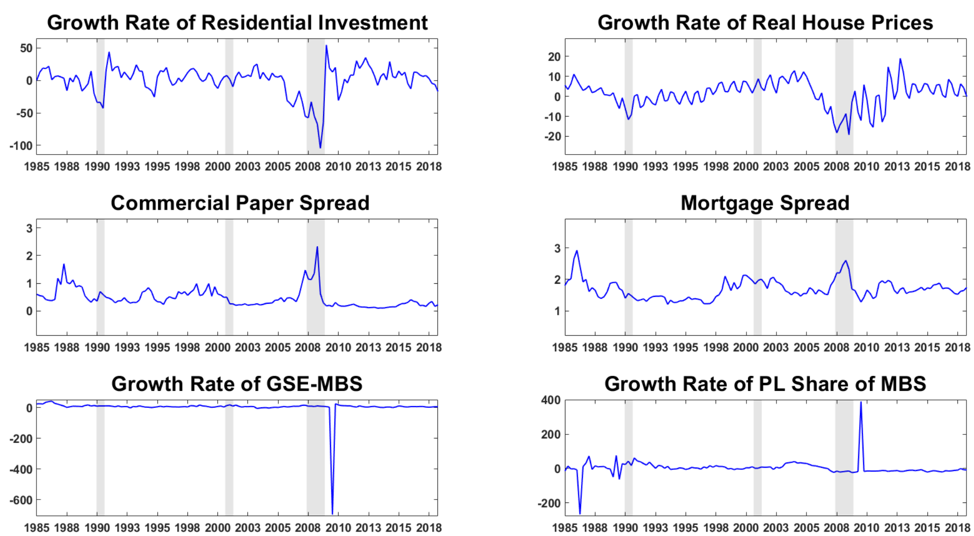

Figure 3.2 Sample Data, 1985q3 to 2018q4

Notes: All variables are expressed in term of annualized growth rate, except for the commercial paper and mortgage spreads. NBER recession dates appear as gray shading. For the details and definitions of the underlying data, see Table 3.1.

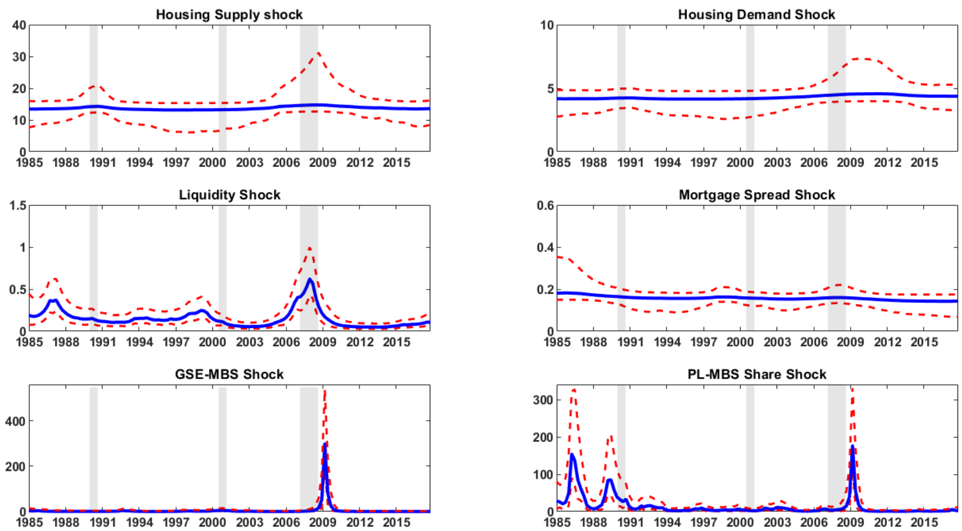

Figure 3.3 SV Estimates, 1985q3 to 2018q4

Notes: The plots show median as solid (blue) lines and posterior 90% uncertainty bands as dotted (red) lines. NBER recession dates appear as gray shading.

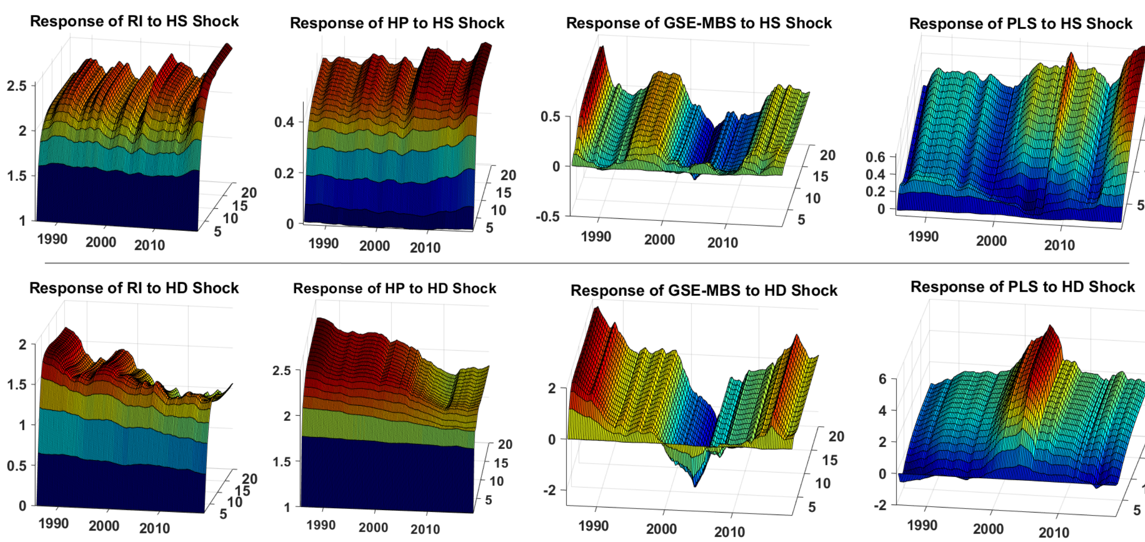

Figure 3.4 Selected IRFs to Housing Supply (HS) and Demand (HD) Shocks, 1985q3 to 2018q4

Notes: Median IRFs of the levels of residential investment (RI), housing prices (HP), GSE-MBS, and the share of PL-MBS to HS (top row) and HD (bottom row) shocks produced by the baseline TVP-SV-SVAR. The IRFs of residential investment, house prices, GSE-MBS, and PL-MBS share in total MBS are in percentages while their own shocks are shifts of one percent.

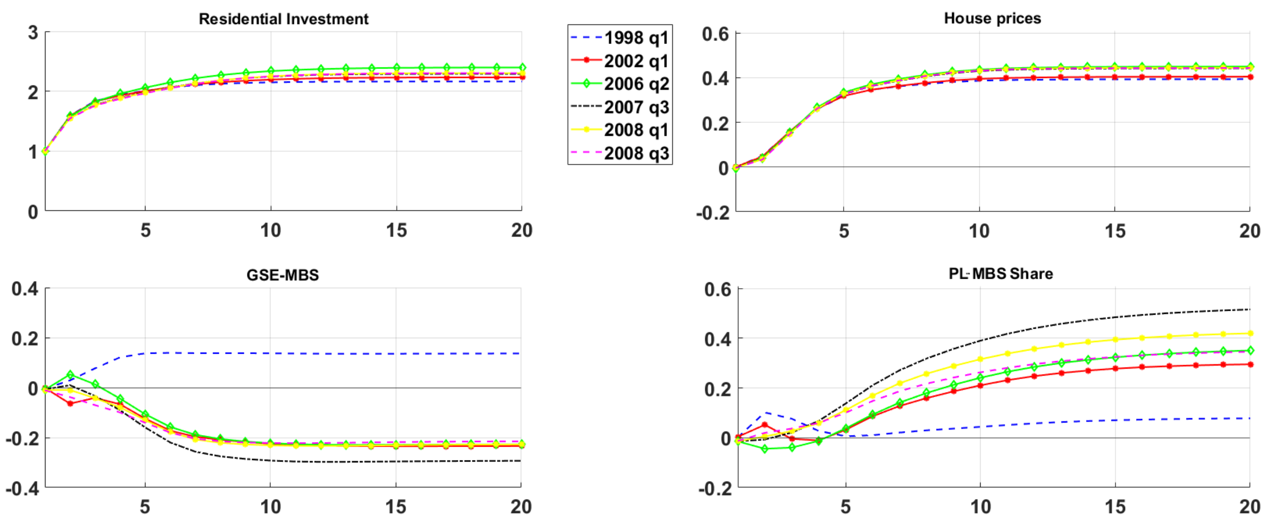

Figure 3.5 Selected IRFs to Housing Supply Shocks, Selected Dates

Notes: Median cumulative IRFs to a one-percent housing supply shock at six selected dates. The 1998q1 (blue) marks the start of the 1998-2006 boom in house prices. The 2002q1 (red) captures the end of the 2001 recession and the period of fast growth of PL-MBS share. The 2006q2 (green) coincides with the sample peak of house prices. The 2007q3 (black) marks the freeze of three BNP Paribas PL-MBS funds. The 2008q1 (yellow) and 2008q3 (magenta) represent the failure of Bear Stearns and the bankruptcy of Lehman Brothers, respectively. The IRFs of residential investment, house prices, GSE-MBS, and PL-MBS share in total MBS are in percentages while their own shocks are shifts of one percent.

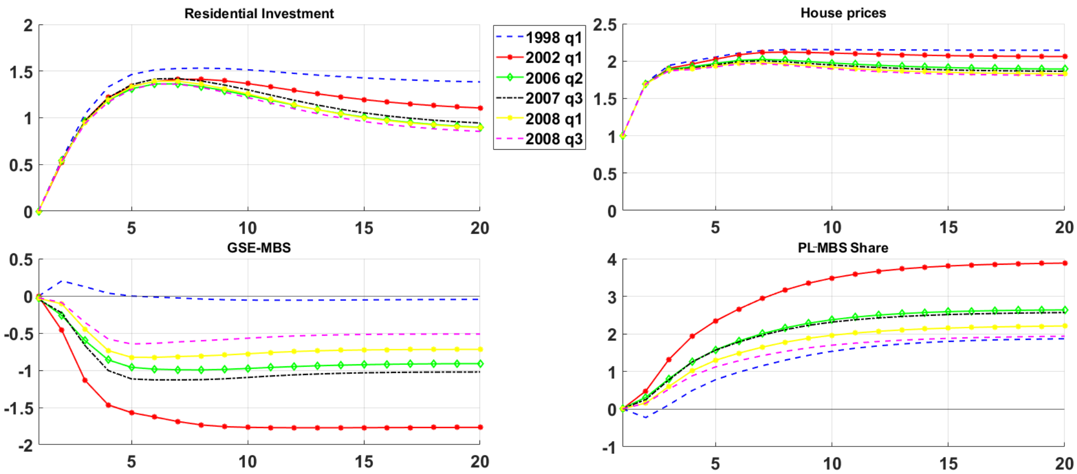

Figure 3.6 Selected IRFs to Housing Demand Shocks, Selected Dates

Notes: Median cumulative IRFs to a one-percent housing demand shock at six selected dates. The 1998q1 (blue) marks the start of the 1998-2006 boom in house prices. The 2002q1 (red) captures the end of the 2001 recession and the period of fast growth of PL-MBS share. The 2006q2 (green) coincides with the sample peak of house prices. The 2007q3 (black) marks the freeze of three BNP Paribas PL-MBS funds. The 2008q1 (yellow) and 2008q3 (magenta) represent the failure of Bear Stearns and the bankruptcy of Lehman Brothers, respectively. The IRFs of residential investment, house prices, GSE-MBS, and PL-MBS share in total MBS are in percentages while their own shocks are shifts of one percent.

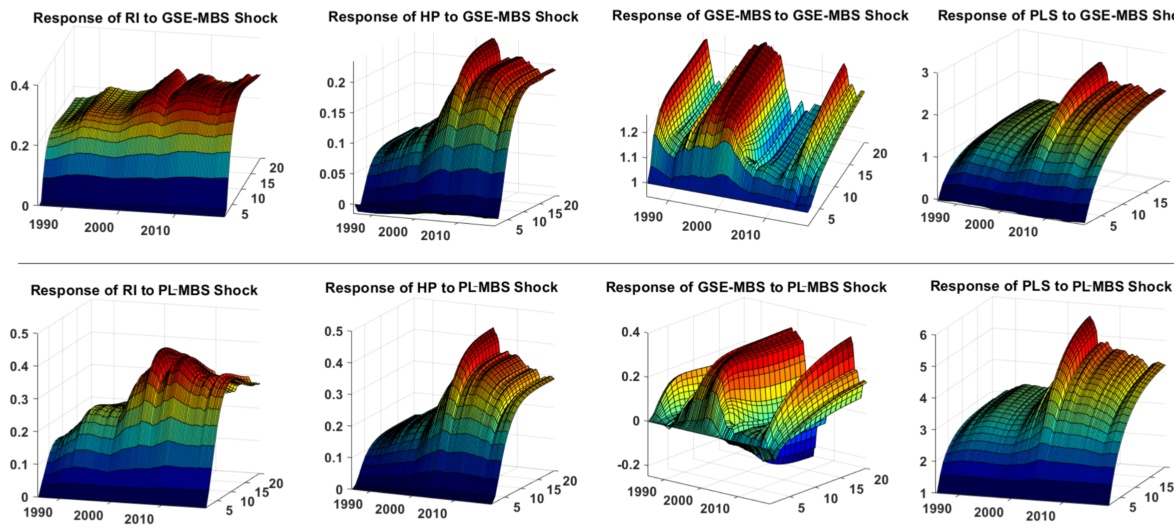

Figure 3.7 Selected IRFs to the GSE-MBS and PL-MBS Shocks, 1985q3 to 2018q4

Notes: Median IRFs of the levels of residential investment (RI), housing prices (HP), GSE-MBS, and the share of PL-MBS to GSE-MBS (top row) and PL-MBS (bottom row) shocks produced by the baseline TVP-SV-SVAR. The IRFs of residential investment, house prices, GSE-MBS, and PL-MBS share in total MBS are in percentages while their own shocks are shifts of one percent.

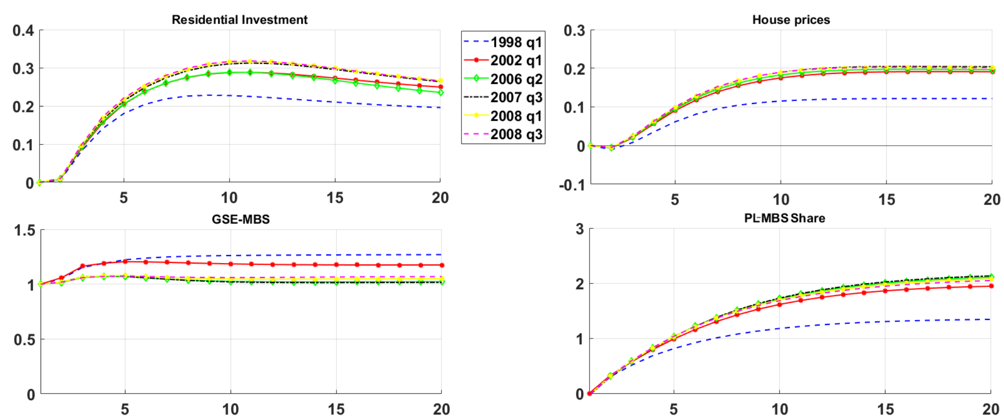

Figure 3.8 Selected IRFs to GSE-MBS Shocks, Selected Dates

Notes: Median cumulative IRFs to a one-percent GSE-MBS shock at six selected dates. The 1998q1 (blue) marks the start of the 1998-2006 boom in house prices. The 2002q1 (red) captures the end of the 2001 recession and the period of fast growth of PL-MBS share. The 2006q2 (green) coincides with the sample peak of house prices. The 2007q3 (black) marks the freeze of three BNP Paribas PL-MBS funds. The 2008q1 (yellow) and 2008q3 (magenta) represent the failure of Bear Stearns and the bankruptcy of Lehman Brothers, respectively. The IRFs of residential investment, house prices, GSE-MBS, and PL-MBS share in total MBS are in percentages while their own shocks are shifts of one percent.

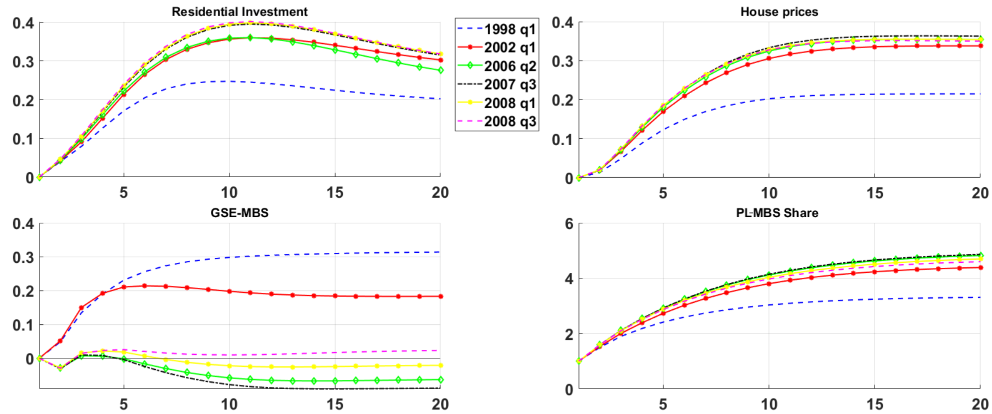

Figure 3.9 Selected IRFs to MBS Composition Shocks, Selected Dates

Notes: Median cumulative IRFs to a one-percent PL-MBS share shock at six selected dates. The 1998q1 (blue) marks the start of the 1998-2006 boom in house prices. The 2002q1 (red) captures the end of the 2001 recession and the period of fast growth of PL-MBS share. The 2006q2 (green) coincides with the sample peak of house prices. The 2007q3 (black) marks the freeze of three BNP Paribas PL-MBS funds. The 2008q1 (yellow) and 2008q3 (magenta) represent the failure of Bear Stearns and the bankruptcy of Lehman Brothers, respectively. The IRFs of residential investment, house prices, GSE-MBS, and PL-MBS share in total MBS are in percentages while their own shocks are shifts of one percent.

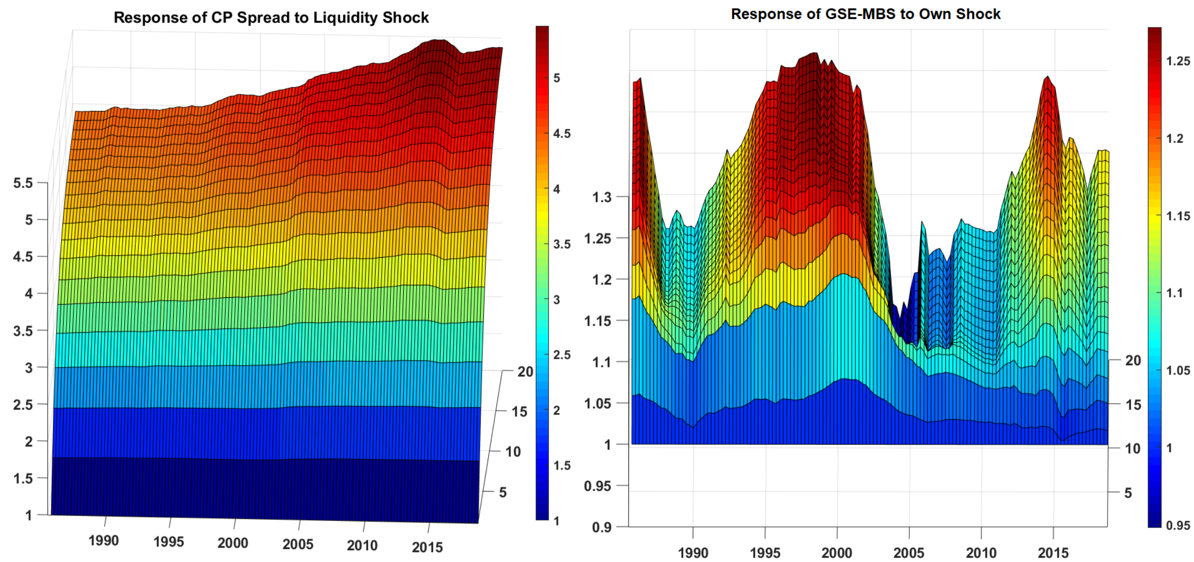

Figure 3.10 Selected IRFs to Liquidity and GSE-MBS Shocks, 1985q3 to 2018q4

Notes: The left panel shows the median IRFs of commercial paper spread to a liquidity shock. The right panel shows the median IRFs of GSE-MBS to own shock. The IRFs of GSE-MBS are in percentages while its own shock is a shift of one percent. The IRFs of the commercial paper spread are in basis points, where its own shock represents a one basis point change.

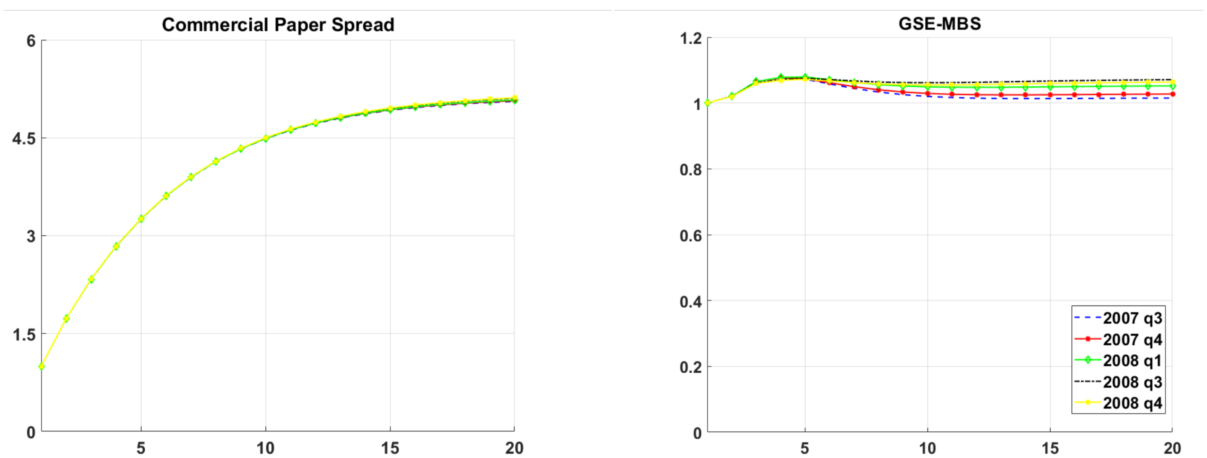

Figure 3.11 Selected IRFs to Liquidity and GSE-MBS Shocks, Selected Dates

Notes: Median cumulative IRFs to one-percent liquidity and GSE-MBS shocks at five selected dates. The 2007q3 (blue) marks the freeze of three BNP Paribas PL-MBS funds. The 2007q4 (red) captures the NBER peak date of the 2007-2009 recession. The 2008q1 (green) coincides with the failure of Bear Stearns. The 2008q3 (black) the bankruptcy of Lehman Brothers. The 2008q4 (yellow) represent the US government takeover of Fannie Mae and Freddie Mac. The IRFs of GSE-MBS are in percentages while its own shock is a shift of one percent. The IRFs of the commercial paper spread are in basis points, where its own shock represents a one basis point change.

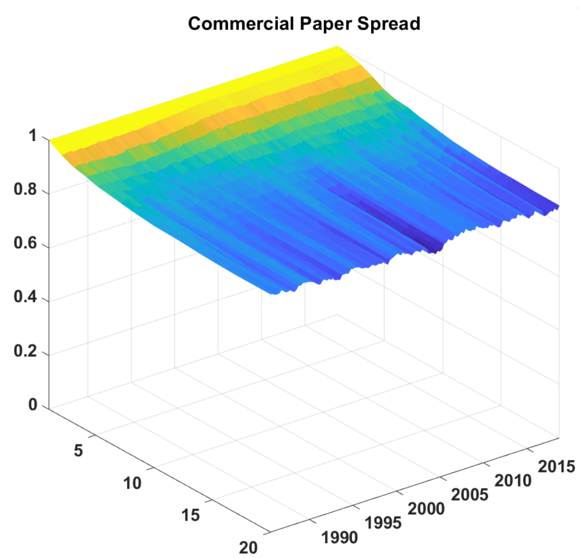

Figure 3.12 Selected FEVDs of Liquidity and GSE-MBS Shocks, 1985q3 to 2018q4

Notes: The left panel shows accumulated FEVDs of the commercial paper spread to liquidity shocks. The right panel depicts the accumulated FEVDs of the GSE-MBS to own shocks.

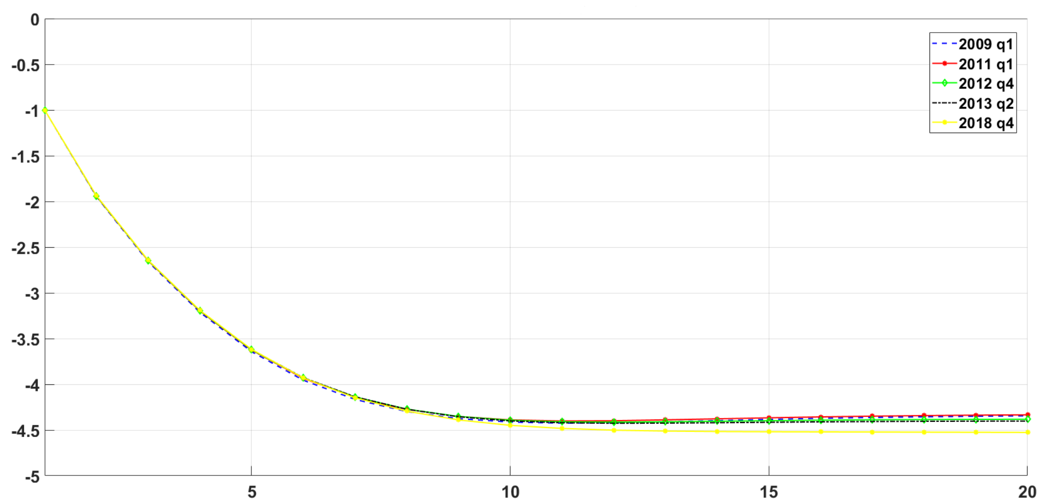

Figure 3.13 The IRFs of Mortgage Spread to QE Shocks at Selected Dates

Notes: The median cumulative IRFs of the mortgage spread to a negative one-percent shock to mortgage spread at five selected dates. The dates 2009q1, 2011q1, 2012Q4, 2013q2, and 2018q4 represent QE1, QE2, QE3, QE4, and the end of sample, respectively. The IRFs of the mortgage spread are in basis points, where its own shock represents a one basis point change.

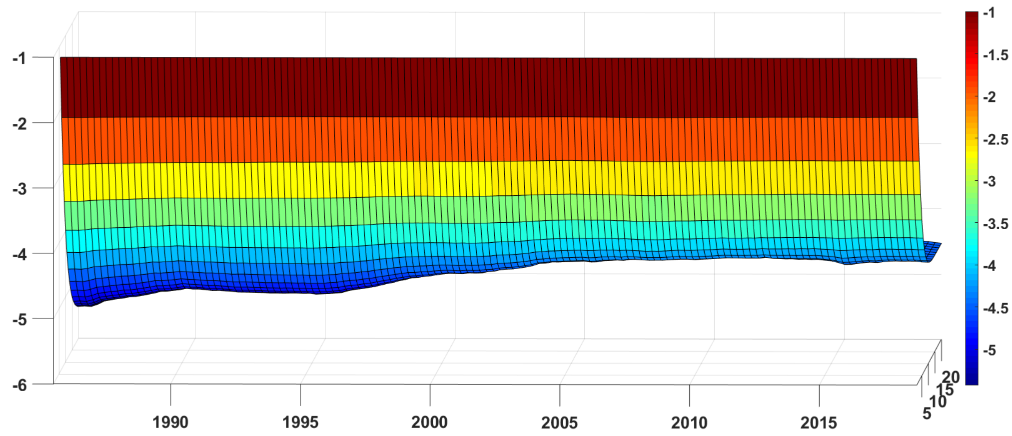

Figure 3.14 The IRFs of Mortgage Spread to a Negative Mortgage Spread Shock, 1985q3 to 2018q4

Notes: Median IRFs of the mortgage spread to a negative one-percent mortgage spread shock produced by the baseline TVP-SV-SVAR. The IRFs of the mortgage spread are in basis points, where its own shock represents a one basis point change.

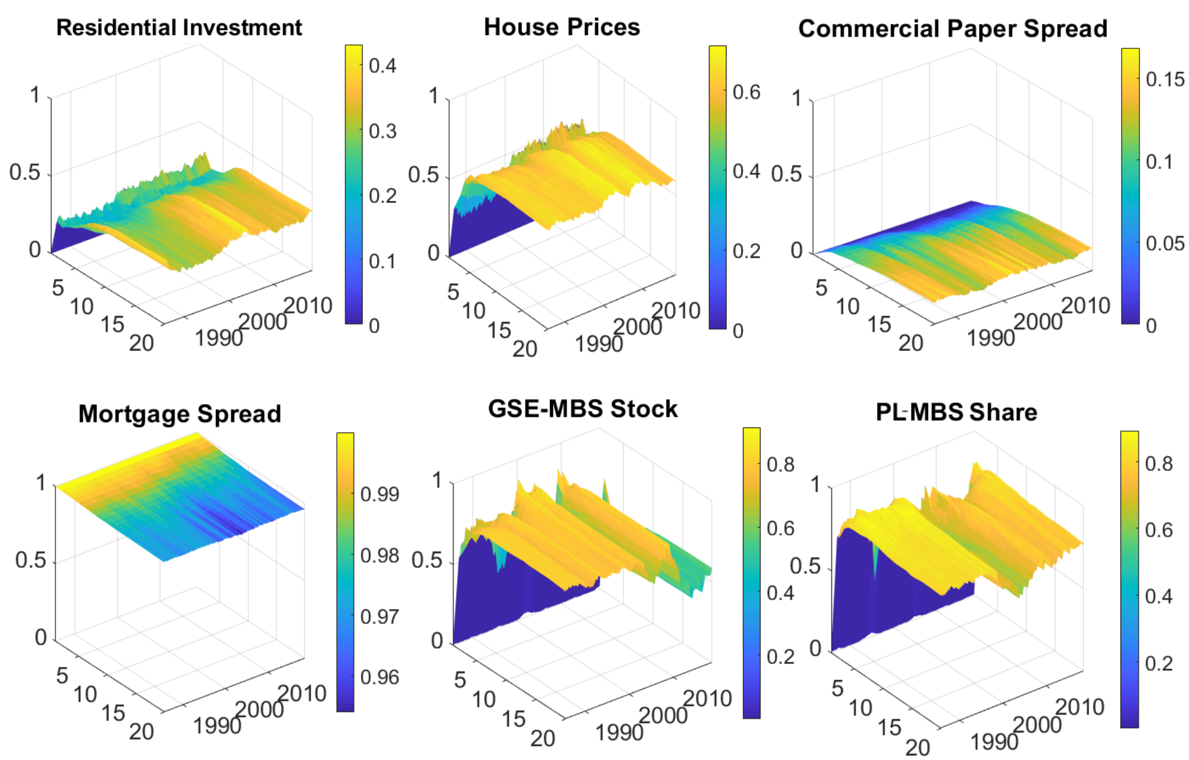

Figure 3.15 FEVDs of Mortgage Spread Shocks, 1985q3 to 2018q4

Notes: The plots are the share of variation explained by mortgage spread shocks for all the variables in the baseline TVP-SV-SVAR across the entire sample.

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APPENDICES

APPENDIX

A

APPENDIX FOR CHAPTER 2

A.1 Alternative Identifications of the SVAR

This section considers different short-run restrictions on the impact matrix, A_t, in the baseline SVAR described in section 2.2. The aim is to test for the robustness of the results in alternative identification schemes.

A.1.1 Residential Investment as the Driver of the Business Cycle

Table A.1 Identification of A_t

Variable	Block										
$\Delta \ln RI_t$	Housing	1	0	0	0	0	0	0	0	0	0
$\pi_{RI,t}$		X	1	0	0	0	0	0	0	0	0
$\Delta \ln C_t$		0	0	1	0	0	0	0	0	0	0
$\Delta \pi_t$	Aggregate	X	X	X	1	0	0	0	0	0	0
$\Delta \ln Y_t$		X	X	X	X	1	0	0	0	0	0
$R_{ff,t}$	Financial	0	0	0	X	X	1	0	0	0	0
$R_{fsc,t}$		X	X	X	X	X	X	1	0	0	0
$R_{liq,t}$		X	X	X	X	X	X	X	1	0	0
$\Delta R_{ms,t}$		X	X	X	X	X	X	X	X	1	0
$\Delta^2 \ln MD_t$		X	X	X	X	X	X	X	X	X	1

Notes: The X's represent free parameters in A_t. The zeros are short-run restrictions.

Leamer [Lea07] claims residential investment is the main driver of the US business cycle. Table A.1 presents an identification that is an experiment to examine the idea residential investment is a key driver of the US business cycle. This identification orders the housing market before the aggregate and financial blocks. By placing the housing market first, shocks in this block affect all other variables on impact except for consumption and the federal funds rate. Consumption does not respond to any shock at impact to preserve the identification that it only responds to the PIH shock. The monetary policy follows a Taylor rule by responding only to inflation and disposable income shocks at impact.

A.1.2 Housing Demand Shock as the Driver of the Business Cycle

Table A.2 Identification of A_t

Variable	Block										
$\Delta^2 \ln MD_t$		1	0	0	0	0	0	0	0	0	0
$\Delta R_{ms,t}$	Mortgage and Housing	X	1	0	0	0	0	0	0	0	0
$\pi_{RI,t}$		X	X	1	0	0	0	0	0	0	0
$\Delta \ln RI_t$		X	X	X	1	0	0	0	0	0	0
$\Delta \ln C_t$		0	0	0	0	1	0	0	0	0	0
$\Delta \pi_t$	Aggregate Economy	X	X	X	X	X	1	0	0	0	0
$\Delta \ln Y_t$		X	X	X	X	X	X	1	0	0	0
$R_{ff,t}$		0	0	0	0	0	X	X	1	0	0
$R_{fsc,t}$	Financial	X	X	X	X	X	X	X	X	1	0
$R_{liq,t}$		X	X	X	X	X	X	X	X	X	1

Notes: The X's represent free parameters in A_t. The zeros are short-run restrictions. Innovations to $\Delta^2 \ln MD_t$ are the source of housing demand shocks.

In section A.1.1, I experiment with an identification that makes housing supply shocks a key driver of the US business cycle. This section proposes an identification in which housing demand shocks are a fundamental source of business cycle fluctuations in the US. Table A.2 summarize this alternative scheme.

The identification in table A.2 combines the mortgage and housing markets into one recursive block. As discussed in section 2, housing demand shocks are identified by innovations to mortgage debt growth, $\Delta^2 \ln MD_t$. Within the mortgage and housing block, housing demand shocks drive the mortgage rates, the price of residential investment, and investment in residential structures. Furthermore, housing demand shocks affect the inflation rate, disposable income, the ten-year Treasury bonds rate, and the commercial paper spread at impact.

Similar to section A.1.1, consumption only responds to its own shocks, which are identified as PIH shocks. The monetary policy follows a Taylor rule by responding only to inflation and disposable income shocks within the quarter. The commercial paper spread absorbs all the shocks. In this identification, it is the element of the financial block that contains information for the other variables in the SVAR.

A.1.3 Putting “M" Back in Monetary Policy

Table A.3 Identification of A_t

Variable	Block										
$\Delta \ln C_t$	Aggregate Economy	1	0	0	0	0	0	0	0	0	0
$\Delta\pi_t$		X	1	0	0	0	0	0	0	0	0
$\Delta \ln Y_t$		X	X	1	0	0	0	0	0	0	0
$\Delta \ln RI_t$	Housing	X	X	X	1	0	0	0	0	0	0
$\pi_{RI,t}$		X	X	X	X	1	0	0	0	0	0
$R_{ff,t}$	Financial	0	0	0	0	0	1	X	0	0	0
$\Delta \ln M2$		0	X	X	0	0	X	1	0	0	0
$R_{tr10,t}$		X	X	X	X	X	X	X	1	0	0
$\Delta R_{m,t}$		X	X	X	X	X	X	X	X	1	0
$\Delta^2 \ln MD_t$		X	X	X	X	X	X	X	X	X	1

Notes: The X’s represent free parameters in A_t. The zeros are short-run restrictions.

The baseline identification equates monetary policy with a Taylor rule. This Taylor rule does not include a monetary aggregate. The omission of a monetary aggregate assumes money is supplied elastically to clear the money market at prevailing prices and has no effect beyond that captured by the federal funds rate [Lee03]. Leeper & Roush [Lee03] argue for the inclusion of a monetary aggregate like M2 in monetary policy VARs. However, my baseline identification includes ten variables, and adding more variables exacerbates the over-parametrization issue. The baseline VAR has four interest rates. This provides the opportunity to include money supply growth, $\Delta \ln M2$, by discarding the spread on commercial paper over 3-month Treasury bills, $R_{cps,t}$.

Table A.3 presents an identification in the spirit of Leeper & Roush [Lee03]. In this identification, I identify a money demand equation by allowing the growth rate of money supply to be a function of disposable income, inflation, and the federal funds rate. The revised Taylor rule specification adds the money supply variable to the Fed’s information set. The growth of real mortgage debt remains the financial information variable of the SVAR as it respond to all the shocks in the model.

A.1.4 Alternative Identification of the Housing Block

Table A.4 Identification of A_t

Variable	Block										
$\Delta \ln C_t$	Aggregate	1	0	0	0	0	0	0	0	0	0
$\Delta \pi_t$		X	1	0	0	0	0	0	0	0	0
$\Delta \ln Y_t$		X	X	1	0	0	0	0	0	0	0
$\pi_{RI,t}$	Housing	X	X	X	1	0	0	0	0	0	0
$\Delta \ln RI_t$		X	X	X	X	1	0	0	0	0	0
$R_{ff,t}$	Financial	0	X	X	0	0	1	0	0	0	0
$R_{fsc,t}$		X	X	X	X	X	X	1	0	0	0
$R_{liq,t}$		X	X	X	X	X	X	X	1	0	0
$\Delta R_{ms,t}$		X	X	X	X	X	X	X	X	1	0
$\Delta^2 \ln MD_t$		X	X	X	X	X	X	X	X	X	1

Notes: The X's represent free parameters in A_t. The zeros are short-run restrictions.

Within the housing block, there are two alternative recursive orderings. If residential investment, RI_t, is ordered above the price of residential investment, $\pi_{RI,t}$, the price of residential investment responds to housing supply shocks at impact. Otherwise, at impact housing construction, RI_t, adjusts to housing cost shocks.

The first case is covered by the baseline identification described in section 2. This section creates an identification for the second case. By placing the price of residential investment above residential investment, table A.4 shows housing construction reacts to the cost shock at impact. The aggregate and financial blocks are identical to the baseline identification.

A.1.5 Recursive Identification of the Impact Matrix

In the baseline identification, the federal funds rate responds on impact to inflation and disposable income shocks. Table A.5 presents an alternative in which monetary policy does not respond instantly to changes in inflation and income variables. Also, this identification differs from the baseline in being inter- and intra-block recursive. The fourth row identifies a consumption function in which consumption growth reacts to inflation, income growth, and the policy rate at impact. The growth of real mortgage debt remains the financial information variable of the SVAR.

Table A.5 Identification of A_t

Variable	Block									
$R_{ff,t}$	1	0	0	0	0	0	0	0	0	0
$\Delta\pi_t$	X	1	0	0	0	0	0	0	0	0
$\Delta \ln Y_t$	X	X	1	0	0	0	0	0	0	0
$\Delta \ln C_t$	X	X	X	1	0	0	0	0	0	0
$\Delta \ln RI_t$	X	X	X	X	1	0	0	0	0	0
$\pi_{RI,t}$	X	X	X	X	X	1	0	0	0	0
$R_{fsc,t}$	X	X	X	X	X	X	1	0	0	0
$R_{liq,t}$	X	X	X	X	X	X	X	1	0	0
$\Delta R_{ms,t}$	X	X	X	X	X	X	X	X	1	0
$\Delta^2 \ln MD_t$	X	X	X	X	X	X	X	X	X	1

Notes: The X's represent free parameters in A_t. The zeros are short-run restrictions.

A.1.6 Bayesian Model Selection Criteria

This section computes the log marginal likelihood (Log-ML) of the baseline SVAR and the alternatives discussed in sections A.1.1 to A.1.5. The marginal likelihood, $p(y)$, is the normalizing factor of the posterior distribution of the model,

$$p(y) = \frac{p(y|\Theta^*)p(\Theta^*)}{p(\Theta^*|y)},$$

where y is the data vector and Θ^* contains the SVAR estimated parameters. Using Canova & Pérez Forero [Can15] code, I implement Geweke [Gew99] harmonic mean estimator of Log-ML and report the results in table A.6.

Table A.6 Estimates of Log Marginal Likelihoods

Model in	Baseline	A.1.1	A.1.2	A.1.3	A.1.4	A.1.5
Log M-L	-16.4437	-16.4436	-16.4435	-16.4435	-16.4437	-16.444

Notes: Baseline refers to the TVP-SV-SVAR discussed in section 2. A.1.1,2,3,4, and 5 refer to the alternative identifications mentioned in this appendix. Estimates of the log marginal likelihoods are obtained using the harmonic mean estimator of Geweke [Gew99].

The Log-ML estimates are essentially identical for the baseline and the alternative models. The IRFs, FEVDs, and the SVs results are also identical.[1] Therefore, the main findings in the paper are robust to the discussed alternative identifications.

[1] Provided upon request.

A.2 Global Identification of the Baseline SVAR

This section shows the baseline identification in section 2 is globally identified using tools developed by Rubio-Ramirez, Waggoner & Zha [RR10]. I start by writing the constant coefficients homoskedastic version of the SVAR in section 2. Using Rubio-Ramirez et al. [RR10] notations, define $A_0 \equiv \Sigma^{-1}A$ to find

$$y_t' A_0 = \sum_{L=1}^{2} y_t' A_L + \epsilon_t',$$

where A_L is a function of the impact matrix, A, and the reduced form slope coefficients, B. Next, construct the matrices Q_j, $j = 1, \ldots, 10$ as in Theorem 1 of Rubio-Ramirez et al. [RR10].

$$Q_1 = \begin{bmatrix} 0&1&0&0&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0&0&0\\ 0&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&1&0&0&0&0&0\\ 0&0&0&0&0&1&0&0&0&0\\ 0&0&0&0&0&0&1&0&0&0\\ 0&0&0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&0&0&0&0 \end{bmatrix}, Q_2 = \begin{bmatrix} 0&0&1&0&0&0&0&0&0&0\\ 0&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&1&0&0&0&0&0\\ 0&0&0&0&0&1&0&0&0&0\\ 0&0&0&0&0&0&1&0&0&0\\ 0&0&0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$Q_3 = \begin{bmatrix} 0&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&1&0&0&0&0&0\\ 0&0&0&0&0&1&0&0&0&0\\ 0&0&0&0&0&0&1&0&0&0\\ 0&0&0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0 \end{bmatrix}, Q_4 = \begin{bmatrix} 0&0&0&0&1&0&0&0&0&0\\ 0&0&0&0&0&1&0&0&0&0\\ 0&0&0&0&0&0&1&0&0&0\\ 0&0&0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$
Q_5 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}, \quad
Q_6 = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

$$
Q_7 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}, \quad
Q_8 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

$$
Q_9 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}, \quad
Q_{10} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}.
$$

The sum of the restrictions exceeds 45. As a result, this TVP-SV-SVAR meets the necessary condition for identification. To test for the sufficient condition, I construct the rank matrices defined as $M_j = \begin{bmatrix} Q_j\, A_0 \\ [I_j \;\; 0_{j\times(10-j)}] \end{bmatrix}$, $j = 1, \ldots, 10$,

$$M_1 = \begin{bmatrix} 0 & x & x & x & x & x & x & x & x & x \\ 0 & 0 & x & x & x & x & x & x & x & x \\ 0 & 0 & 0 & x & x & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & x & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & x & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, M_2 = \begin{bmatrix} 0 & 0 & x & x & x & x & x & x & x & x \\ 0 & 0 & 0 & x & x & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & x & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & x & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$M_3 = \begin{bmatrix} 0 & 0 & 0 & x & x & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & x & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & x & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, M_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & x & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & x & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & x & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$
M_5 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & x & x & x & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & x & x & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}, M_6 = \begin{bmatrix}
x & x & x & x & x & 0 & x & x & x & x \\
0 & 0 & 0 & x & x & 0 & x & x & x & x \\
0 & 0 & 0 & 0 & x & 0 & x & x & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & x & x & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

$$
M_7 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0
\end{bmatrix}, M_8 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0
\end{bmatrix}
$$

$$M_9 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, M_{10} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

All M_j have a full column rank. Therefore the SVAR is globally identified.

A.3 Data Sources

Table A.7 presents the sources and definitions of the data. Note that the residential investment series measures the flow of new single-family structures, while data on mortgage debt is available only for mortgages on multi-family homes up to four units. The nominal mortgage debt is deflated by the non-durable goods and services price index. I construct this index using the Fisher index formula; Whelan [Whe02] provides a guide on the use of Fisher's "ideal chain index" in the US National Income and Product Accounts (NIPA).

Table A.7 Data Sources and Definitions

Variable	**Definition**	**Source**
Non-durable goods and services consumption expenditures	Personal consumption expenditures on non-durable goods and services. Chain-type quantity index.	U.S. Bureau of Economic Analysis
Non-durable goods and services inflation	Personal consumption expenditures on non-durable goods and services. Chain-type price index.	
Real disposable income	Real disposable personal income. Chained dollars.	
Real residential investment	Investment in single family structures, chain-type quantity index.	
Price of residential investment	Investment in single family structures, chain-type price index.	
Federal funds rate	Effective federal funds rate.	Federal Reserve Board
Yield on ten year Treasury bonds	Yield on constant maturity bond.	
Term commercial paper rate	Average six-month commercial paper rate for financial and non-financial firms with AA or equivalent bond rating, 1985Q1-1997Q2. Spliced with 3-month AA financial commercial paper rate, 1997Q1-2018Q4.	
3-month Treasury bill rate	Secondary market rate.	
Mortgage debt	Multifamily mortgage debt. Deflated by by non-durable goods and services price index.	
Thirty-year fixed mortgage rate	30-Year fixed rate prime mortgage average in the United States.	Freddie Mac
Number of Months on Sales Market for New Homes	Median number of months for sale since the completion of the home.	U.S. Census Bureau

APPENDIX

B

APPENDIX FOR CHAPTER 3

B.1 Alternative Identifications

This section tests for the robustness of the SVAR estimates to alternative identification schemes. The alternatives consider different short-run restrictions on the impact matrix, A_t, relative to the baseline case in section 3.2.

B.1.1 Reversing the Ordering within the Housing Block

Table B.1 Identification of A_t

Variable	Block						
$\Delta \ln HP_t$	Housing	1	0	0	0	0	0
$\Delta \ln RI_t$		X	1	0	0	0	0
S_t	Mortgage	X	X	1	0	0	0
MS_t		X	X	X	1	0	0
$\Delta \ln GSE_t$		X	X	X	X	1	0
$\Delta \ln PLS_t$		X	X	X	X	X	1

Notes: The X's represent free parameters in A_t. The zeros are short-run restrictions.

In the baseline identification of section 3.2, house prices adjust on impact to housing supply shocks. Table B.1 offers an alternative identification with different dynamics in the housing block. A shock to the market value of houses, $\Delta \ln HP_t$, is an incentive to invest in housing. Therefore, the shock to house prices affect housing investment, $\Delta \ln RI_t$, on impact. The ordering of the mortgage market block is identical to the baseline identification in section 3.2.

B.1.2 House Prices Drive PL-MBS

Table B.2 Identification of A_t

Variable	Block						
$\Delta \ln RI_t$	Housing	1	0	0	0	0	0
$\Delta \ln HP_t$		X	1	0	0	0	0
S_t	Mortgage	X	X	1	0	0	0
MS_t		X	X	X	1	0	0
$\Delta \ln GSE_t$		0	0	X	X	1	0
$\Delta \ln PLS_t$		X	X	X	X	X	1

Notes: The X's represent free parameters in A_t. The zeros are short-run restrictions.

An argument of the paper is that PL-MBS share is more sensitive to changes in house prices than is GSE-MBS. In this alternative identification scheme, I embed the assumption that house prices shocks drive the issuance of PL-MBS rather than GSE-MBS. Table B.2 summarize this identification. I impose two zero restrictions on the impact responses of $\Delta \ln GSE_t$ to shocks from the housing market. The implication is only the share of PL-MBS reacts on impact to house price shocks. Under this identification, the issuance of GSE-MBS responds to changes in housing market conditions with a one-quarter lag. In the housing market, house prices adjust to housing supply shocks to clear the market.

B.1.3 Bayesian Model Selection Criteria

This section reports the log marginal likelihood (Log-ML) of the baseline SVAR and the alternatives discussed in sections B.1.1 and B.1.2. The marginal likelihood, $p(y)$, is the normalizing factor of the posterior distribution of the model,

$$p(y) = \frac{p(y|\Theta^*)p(\Theta^*)}{p(\Theta^*|y)},$$

where y_t is the data vector and Θ^* is a vector of the SVAR estimated parameters. Using Canova & Pérez Forero [Can15] code, I implement Geweke [Gew99] harmonic mean estimator of Log-ML and report the results in table B.3.

Table B.3 Estimates of Log Marginal Likelihoods

Model in	Baseline	B.1.1	B.1.2
Log M-L	-12.0000	-12.0012	-12.0015

Notes: Baseline refers to the TVP-SV-SVAR discussed in section 3.2. B.1.1 and B.1.2 refer to the alternative identifications mentioned in this appendix. Estimates of the log marginal likelihoods are obtained using the harmonic mean estimator of Geweke [Gew99].

The Log-ML estimates are nearly identical for all the models with a marginal advantage for the baseline identification. The main IRFs and stochastic volatility results are also identical. In conclusion, the main findings are robust to the discussed alternative identification schemes.

B.2 Additional Figures

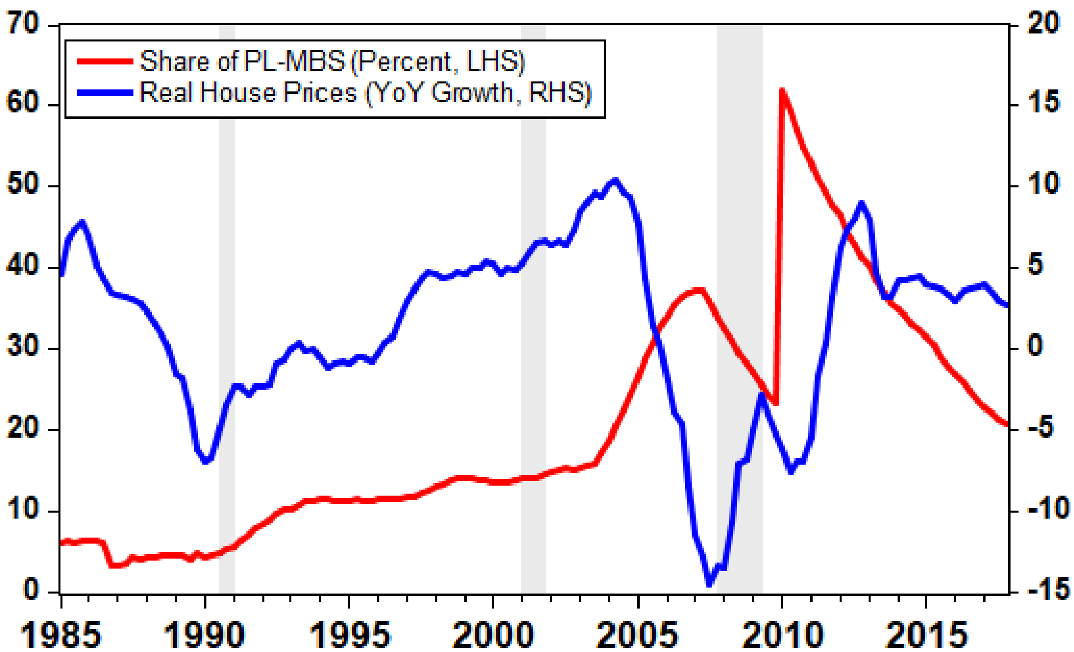

Figure B.1 Real House Price Index and PL-MBS Share, 1985Q1 to 2017Q4

Notes: NBER recession dates appear as gray shading.