Heterogeneous Effects of Mortgage Rates on Housing Returns: Evidence from an Interacted Panel VAR

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Abstract

This paper develops a theoretical and empirical framework to assess the heterogeneous effects of mortgage rates on housing returns when accounting for the zero lower bound regime of the policy interest rate and local market supply and demand conditions. Based on an interacted panel VAR, estimated on a dataset comprising of 146 metropolitan statistical areas for a time period between January 1995 and December 2020, our empirical findings show that the response of housing returns to a mortgage rate shock is larger in magnitude when the federal funds rate is at its zero lower bound. Various supply and demand conditions, including housing permits, personal income, employment, and population, matter for the transmission of a mortgage rate shock to housing returns in local markets. A partial equilibrium model supports our empirical results.

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Introduction

In this paper, we build a simple partial equilibrium model of housing based upon Glaeser et al. (2008) to understand the effects of changes in mortgage rates on regional housing returns. The supply side of the model is composed of existing homeowners and developers, who sell old and new houses respectively. Housing demand is determined by new home buyers and their decision to purchase a home, which is influenced by the utility derived from living in a region and the expected capital gains from owning a home in the region. The equilibrium condition shows that mortgage rate shocks have heterogeneous effects on housing returns conditional on the expected house price growth, local supply and demand factors, and their interactions. Based on these theoretical observations, we estimate an interacted panel vector autoregression (IPVAR) model, as outlined in Towbin and Weber (2013), to empirically test the impact of various housing supply and demand determinants at the metropolitan statistical area (MSA) level, including housing permits, real personal income, employment, and population, on housing returns following a mortgage rate shock. Furthermore, the IPVAR approach allows us to account for the zero lower bound (ZLB) regime of the federal funds rate and measure its implications for a mortgage rate shock and its impact on housing returns in the presence of heterogeneous supply and demand forces.

Our empirical results show that the response of housing returns to a mortgage rate shock is amplified in the ZLB regime of monetary policy. At its maximum impact, the ZLB response is double the size of the non-ZLB response. In other words, if mortgage rates are lowered, housing returns expand by twice the amount when the policy rate is near its lower bound of zero. Furthermore, the mortgage rate shock is more persistent and its effects are longer-lasting in an environment where the federal funds rate is close to zero. These results are in line with the ongoing housing boom in the U.S. at the time of writing this paper, accompanied by declining mortgage rates throughout 2019-2020 and a cut in the federal funds rate to a range of 0-0.25 percent in early 2020, as a measure to combat the economic side effects of the Covid-19 pandemic. Allowing for supply and demand conditions and their interactions with the ZLB regime of monetary policy confirms the presence of heterogeneous effects of a mortgage rate shock on housing returns across regions. A negative mortgage rate shock triggers a larger increase in housing returns in MSAs with lower housing permits or higher personal income, employment, and population, especially

when the federal funds rate is near zero. The estimation results therefore provide strong evidence for a significant, heterogeneous response of housing returns to a mortgage rate shock and confirm the theoretical predictions derived from our simple partial equilibrium model.

Our findings can be traced back to the early contributions made by McAvinchey and Maclennan (1982) and Segal and Srinivasan (1985), both focus on the causes of remarkable cross-region variations in housing price inflation. McAvinchey and Maclennan (1982) examine the rate of housing price inflation across 11 geographic regions of the British housing market between 1967 and 1976. Performing regressions of linear functional form and allowing for supply (housing starts and completions) and demand factors (population and income growth), the study observes significant regional differences when it comes to the impact of mortgage rates. Using a sample of 51 metropolitan areas in the U.S. between 1975 and 1978, Segal and Srinivasan (1985) find that demand-side factors (income, population, and mortgage rates) have a significant influence on housing price inflation and 40% of the variations, which are unexplained by demand-side factors, can be attributed to supply-side factors (suburban growth restrictions on potentially developed land). A series of studies, including Bartik (1991), Poterba et al. (1991), Abraham and Hendershott (1996), Jud and Winkler (2002), Meese and Wallace (2003), Capozza et al. (2004), and Hwang and Quigley (2006), further investigate the dynamics of housing prices and the impact of supply and demand conditions. While these studies in the regional economics literature provide abundant evidence of heterogeneous responses of housing returns to a mortgage rate shock across geographic regions, none of them have considered the effects of the monetary policy regime, and how it interacts with local supply and demand conditions.

The zero lower bound regime of monetary policy has become a hot topic for macroeconomic research over the last decade. However, assessing the effect of monetary policy has become more challenging in the aftermath of the Great Recession (Hamilton and Wu, 2012; Wu and Xia, 2016). Even though the goal of our paper is not to evaluate the monetary policy effects in a zero lower bound environment, we still find theoretical and empirical evidence of asymmetric effects of mortgage rates on housing returns between the non-ZLB and ZLB regimes of monetary policy, and significant heterogeneity across geographic regions. Our paper is therefore related to a strand of literature which investigates the interplay between housing/real

estate developments and the heterogeneous effects of monetary policy across regions. In addition to this, our research is also linked to another strand of literature which investigates the effectiveness of monetary policy over the business cycle.

Within the first strand of literature, the housing market has been identified as an important channel through which monetary policy impacts real economic activity with differential effects across regions. Monetary policy actions affect mortgage rates, which further impact disposable income and consumption through both direct (cash flow effect) and indirect (wealth effect) channels (Elbourne, 2008; Caplin et al., 1997; Beraja et al., 2019; Bernanke and Blinder, 1988; Bernanke and Gertler, 1995). Fratantoni and Schuh (2003) find that incorporating sources of heterogeneity along with housing yields greater cross-region differences in the effect of monetary policy. Furceri et al. (2019) provide empirical evidence of how asymmetries in the impact of monetary policy shocks across U.S. states can be explained by industry mix, share of small firms, share of small banks, and housing conditions. Regarding the impact of monetary policy on regional housing markets, Christidou et al. (2011) estimate VAR models for the period 1988-2009 and their results suggest that housing markets across U.S. states respond differently to a common monetary policy shock. Füss and Zietz (2016) provide further evidence on the heterogeneous effect of monetary policy on housing returns across MSAs by interacting MSA-specific demand and supply conditions with monetary policy.

The second strand of literature examines the effectiveness of monetary policy over the business cycle. Garcia and Schaller (2002) study the asymmetric effects of monetary policy during expansions and recessions with the help of an estimated Markov switching model. Interest rate changes are found to have a stronger impact on output growth during recessions compared to periods of expansion. The results are in line with the previous findings by Weise (1999), who estimates a nonlinear VAR model to show that money supply shocks have larger output and weaker price effects, when output growth is initially low. Similarly, Lo and Piger (2005) find strong evidence that monetary policy measures applied during recessions have a stronger impact on output compared to those applied during expansions.[1] In contrast, Tenreyro and

[1] In the REITs market, Glascock and Lu-Andrews (2014) also find that macroeconomic factors have stronger effects on the pricing of REIT liquidity during recessions. Several recent studies focusing on commercial real estate and REITs also use granular data at the MSA level; see Bian et al. (2022), Feng (2021), Feng and Wu (2021), Ling et al. (2022), and Zhu and Lizieri (2022).

Thwaites (2016) reach the opposite conclusion, that is, monetary policy is less effective during recessions. Regarding the asymmetric effects of mortgage rates on housing prices over the business cycle, Kim and Bhattacharya (2009) find that mortgage rates have a stronger impact on home prices when the housing market is in an upswing rather than in a downswing. In the light of this asymmetry, the study further finds strong support for Granger causality from mortgage rates to house prices.

While our paper is related to the asymmetry in the effects of mortgages rates on housing prices over the business cycle, we focus on the ZLB and non-ZLB regimes of monetary policy rather than general business cycles. We contribute to the existing literature in three dimensions. First, we present a simple theoretical model to analyze the response of housing returns to changes in mortgage rates whilst accounting for the monetary policy regime and regional supply and demand differences. Second, we use an IPVAR approach to empirically test and further investigate the predictions of our theoretical model by interacting supply and demand conditions with changing policy interest rate environments, which allows us to analyze the heterogeneous effects of a mortgage rate shock on housing returns. Third, the sample end date of our dataset is December 2020, which means that we include important information about recent housing market fluctuations during the Covid-19 pandemic into our study and therefore our findings add to the ongoing policy debate.

Our results hold important policy implications, given that the Federal Reserve is committed to its low policy rate environment, but with current mortgage rates on the rise. In the light of our findings, this may result in negative ramifications for the housing sector. Although the U.S. housing market has been experiencing surging prices since the outbreak of Covid-19, the surge could be caused by the fiscal and monetary expansion during the Covid-19 pandemic and the prolonged effects of declining mortgage rates in both 2019 and 2020. As the economy remains in the ZLB environment and mortgage rates keep going up, we would expect a more pronounced contraction of housing returns at some point in time. Additionally, these developments unfold in a time where the U.S. economy suffers from the consequences of the Covid-19 pandemic. As a result of this, households face now a much more complex financial environment. For example, a household's financial situation may be altered due to job loss or as the mortgage forbearance ends. As more and more consumers are wondering if we are headed for a housing

market crash, our results point out the importance of avoiding a rapid climb of mortgage rates in a low policy rate environment, which for example can be achieved through large scale asset purchases, better known as quantitative easing. However, this will challenge the Fed's current plan of reducing its monthly purchases of mortgage-backed securities, given inflationary pressures, before raising the policy rate.[2]

The structure of the paper is as follows. Section 2 derives a simple partial equilibrium model to illustrate the heterogeneous effects of a mortgage rate shock on local housing returns. Section 3 presents the data used for the estimation of our IPVAR model and discusses in detail the underlying VAR methodology. Section 4 analyzes the empirical results and impulse response functions of the estimated IPVAR framework. Section 5 concludes.

Heterogeneous Effects of Mortgage Rates on Housing Returns

In order to illustrate how regional housing returns respond to a change in the mortgage rate, we tailor the simple partial equilibrium model of Glaeser et al. (2008) to incorporate heterogeneous expectations of house price growth. In this model, the house price in a region, or a MSA in our context, is jointly determined by supply and demand of the regional housing market. Housing supply is given by the total amount of old houses being sold by existing homeowners and new houses produced by developers. For the sake of simplicity, both types of housing are assumed to be physically identical. Housing demand comes from a group of potential new homebuyers, whose willingness to pay is determined by the utility gains from living in the region and the expected capital gains from owning a house in the same region.

Let $H(t)$ and $I(t)$ denote the stock of houses and the flow of new housing construction in the region at time t, respectively. The marginal cost of housing production is assumed to be a linear function of the size of construction $c_0 + c_1 I(t)$ where $c_1 > 0$. At any point in time, as long as there is new construction of housing, price and marginal cost must be equal in equilibrium, i.e. $P(t) = c_0 + c_1 I(t)$. As in Sun

[2]At the November 2021 Federal Open Market Committee meeting, the Committee decided to begin reducing the monthly pace of its net asset purchases by $10 billion for Treasury securities and $5 billion for agency mortgage-backed securities. At the December meeting, the Committee decided to further reduce the monthly pace of its net asset purchases by $20 billion for Treasury securities and $10 billion for agency mortgage-backed securities. At the January 2022 meeting, the Committee decided to continue to reduce the monthly pace of its net asset purchases, bringing them to an end in early March; see the meeting statements at https://www.federalreserve.gov/monetarypolicy/fomccalendars.htm.

and Tsang (2019), an increase in c_1 can be interpreted as a negative supply shock that reduces housing production and a decrease in c_1 captures a positive supply shock. Existing homeowners in the region are assumed to receive a Poisson-distributed shock with probability λ in each period that forces them to sell their houses, leave the region, and receive zero utility for the rest of their lives. Under this assumption, housing supply at time t is given by $S(t) = \lambda H(t) + I(t)$.

There exists a fixed number of potential home buyers at any point in time. These potential buyers are heterogeneous in terms of their utility gains from living in the region. The utility of a potential buyer i from living in the region, $u(i)$, is assumed to follow a uniform distribution on the interval $[\underline{u}, v_0]$ with density $1/v_1$, where $v_1 > 0$. Let $u^*(t)$ denote the utility of the marginal buyer at time t, potential buyers with utility above $u^*(t)$ choose to purchase a house in the region while others do not. Housing demand is therefore given by $D_t = (v_0 - u^*(t))/v_1$. Following Sun and Tsang (2019), we interpret an increase in v_1 as a negative housing demand shock and a decrease in v_1 as a positive demand shock. Given the mortgage rate r, potential buyer i's expected utility flow at time t is the sum of the utility gains from living in the region and the expected appreciation in house price:

$$\frac{u(i)}{r+\lambda} + E_t\left(\int_{x=t}^{\infty} e^{-(r+\lambda)(x-t)}\lambda P(x)dx\right) - P(t),$$

where $E_t(\cdot)$ denotes expectations as of time t. Potential buyers will keep moving into the region until the expected utility flow diminishes to zero.

The equilibrium conditions are readily available by putting the supply and demand sides of the market together; see Glaeser et al. (2008) for details. Suppose that at time t the region has reached its long-run steady state with $H(t) = \frac{v_0 - rc_0}{\lambda v_1}$ and $P(t) = c_0$. Following Glaeser et al. (2008), individuals are assumed to update their beliefs at discrete intervals. Let ϵ be the expected growth rate of house prices at time t. During a period when beliefs about the future are held constant, the expected house price follows $P(x) = P(t) + \epsilon \cdot (x - t)$. Equalizing supply and demand of the regional housing market gives rise to the house price at time $t+1$, i.e., $P(t+1) = c_0 + \frac{\epsilon\lambda c_1}{(rc_1 + v_1 + \lambda v_1)(r+\lambda)}$.

The appreciation in house price, or housing return, from t to $t+1$ is therefore given by:

$$\Delta P = \frac{\epsilon \lambda c_1}{(rc_1 + \nu_1 + \lambda \nu_1)(r + \lambda)}. \tag{1}$$

The marginal effects of mortgage rates on future housing returns can be derived as:

$$\frac{\partial \Delta P}{\partial r} = -\frac{\epsilon \lambda c_1 (2rc_1 + \lambda c_1 + \nu_1 + \lambda \nu_1)}{(rc_1 + \nu_1 + \lambda \nu_1)^2 (r + \lambda)^2}. \tag{2}$$

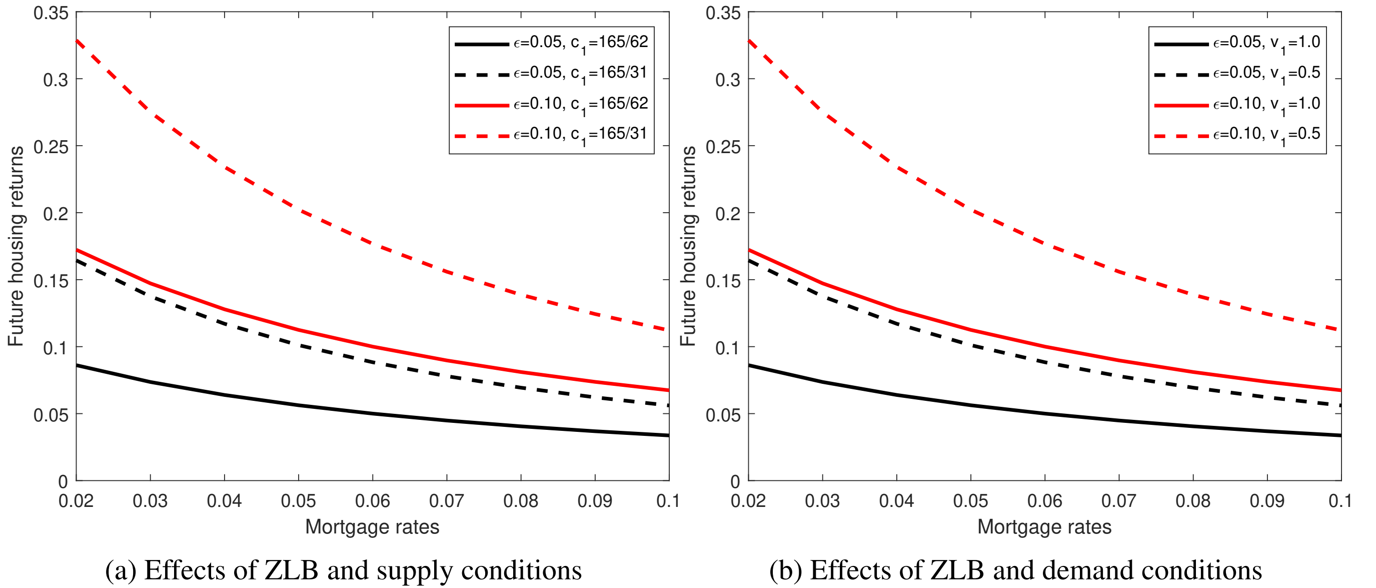
Equation (2) indicates that housing returns will increase (decrease) following a decline (rise) in the mortgage rate and the marginal effects depend on the size of the expected growth rate of house prices ϵ; they also depend on parameters c_1 and ν_1 that capture housing supply and demand conditions, as well as their interactions with ϵ. It has been shown in the literature, initially driven by the bull housing market in the 1970s, that nominal interest rates play an important role in the formation of house price appreciation expectations. The 1970s were a period of rising interest rates, accompanied by rising inflation, during which the demand for ownership was stimulated; see Frieden et al. (1977), Hendershott and Hu (1979), and Schwab (1982) among many others. As Harris (1989) points out, expectations of a future interest rate hike increase the desire for home ownership and thereby the expected growth rate of house prices. Facing potentially higher interest rates in the future, risk averse households tend to purchase a home in order to fix future housing costs and hedge against rent risk; see Kau and Keenan (1980), Sinai and Souleles (2005), and Elgin and Uras (2014). Hence, the expected growth rate of house prices ϵ strongly relates to the monetary policy regime. When nominal interest rates are near zero, households tend to expect interest rates to be higher in the future. First, being around the lower bound of zero already, nominal interest rates have little to no room to be further reduced. Second, a monetary expansion is likely to result in inflation which will cause the central bank to raise interest rates afterwards. The expected growth rate of house prices ϵ therefore tends to be higher at the ZLB of nominal interest rates.

Given higher expectations of future house price growth at the ZLB regime of monetary policy, we have the following two hypotheses:

Hypothesis 1: A mortgage rate shock has heterogeneous effects on housing returns conditional on the monetary policy regime. Other things equal, the marginal effects of a mortgage rate shock on housing returns are larger at the ZLB of nominal interest rates.

Hypothesis 2: A mortgage rate shock has heterogeneous effects on housing returns conditional on the monetary policy regime, local supply and demand conditions, and their interactions.

To better illustrate the heterogeneous effects of a mortgage rate shock on housing returns, we calibrate the model parameters to reasonable values and plot future housing returns as shown in Equation (1) against hypothetical values of the mortgage rate in Figure 1.



(a) Effects of ZLB and supply conditions

(b) Effects of ZLB and demand conditions

Figure 1: Future housing returns and mortgage rates

In the baseline scenario, we choose $\lambda = 0.05$, $r = 0.06$, $\nu_1 = 1$, and $c_1 = 165/62$.[3] We consider an expected growth rate of house prices of $\epsilon = 0.05$ during normal times and a considerably higher expectation of $\epsilon = 0.10$ when nominal interest rates are stuck at the lower bound of zero. The solid lines in black and red in both panels depict the effects of mortgage rates on future housing returns in the non-ZLB and ZLB regimes of monetary policy, respectively. In line with our expectation, the red line is

[3]These values correspond to a 5% probability of selling the house and leaving the region in each period, a 6% mortgage rate, and a density one of a potential buyer's utility. The value of c_1 is selected to equalize the future housing return in Equation (1) and the expectation ϵ in the long-run steady state.

steeper than the black line, which indicates larger marginal effects in magnitude of a mortgage rate shock on housing returns at the ZLB of nominal interest rates.

Not all regions are impacted equally. To account for regional differences, we simulate a region with lower housing supply by doubling the parameter c_1 in Panel (a) and a region with higher housing demand by halving the parameter ν_1 in Panel (b), while leaving other parameters unchanged. The dashed lines in black and red outline the effects of mortgage rates on future housing returns in the non-ZLB and ZLB regimes of nominal interest rates, respectively. As Panel (a) shows, compared to the baseline region, housing returns are more responsive to a mortgage rate shock in the region with lower housing supply, especially in the ZLB regime of monetary policy. Similarly, Panel (b) suggests higher responsiveness of housing returns to a mortgage rate shock in the region with higher housing demand, especially in the ZLB regime of monetary policy.

Data and Methodology

To empirically test the hypotheses developed in the previous section, we utilize an IPVAR model and estimate the response of housing returns to a mortgage rate shock and its dependence on the ZLB regime of the policy interest rate and local housing supply and demand conditions. On the demand side, we choose three variables, namely real personal income, nonfarm employment, and population, which have been found to directly influence housing price appreciations, while on the supply side we use the number of housing permits; see Mayer and Somerville (2000), Strauss (2013), and the references discussed in the introduction.

Data Description

We use monthly data at the MSA level from 1995 to 2020. The starting point of the sample is limited by the availability of housing permits data. Our sample covers a long period of near zero federal funds rates from 2008 to 2015 and the ongoing ZLB that started in April 2020 following the global outbreak of

Covid-19. Seasonally adjusted house price indices are obtained from Freddie Mac.[4] The federal funds rate and the 30-year fixed rate mortgage average are retrieved from the Federal Reserve Economic Data; the former rate is only used for defining the ZLB dummy variable and the latter is one of the endogenous variables in the IPVAR model. The number of housing permits is extracted from the Building Permits Survey conducted by the U.S. Census Bureau. The number of employees in the nonfarm sector is obtained from the U.S. Bureau of Labor Statistics. Personal income and population at the MSA level are only available at the annual frequency from the U.S. Bureau of Economic Analysis. We convert them into monthly data in two steps to match the frequency of other variables. In particular, we collect quarterly data on state-level personal income and generate quarterly personal income for each MSA from its annual data by assuming that all MSAs within a state have the same shares of quarterly personal income within a year as the state does. We then generate monthly personal income for each MSA by interpolating its quarterly personal income generated from the previous step. We repeat the same two steps for population, using quarterly population data at the national level instead, given that state-level population data are not available until 2010.[5] Both house price and personal income data are deflated with the chain-type price index for personal consumption expenditures obtained from the U.S. Bureau of Economic Analysis. Our final sample includes a total of 146 MSAs as listed in Table A1 in the appendix.[6]

[4]Compared to other commonly referenced house price indices, such as the Federal Housing Finance Agency and the S&P/Case-Shiller indices, the Freddie Mac House Price Index includes not only purchase transactions but also appraisal values used for refinance transactions. They also differ in terms of the choice of geographic weights, the method for identifying outliers, and the use of statistical smoothing to more efficiently estimate indices at finer geographic levels. For example, while the Federal Housing Finance Agency house price indices at the monthly frequency are available for the U.S. as a whole and census divisions, MSA-level indices are only available at the quarterly frequency. The S&P/Case-Shiller indices are only available for twenty metropolitan regions. Despite these differences, house price indices from various sources are highly correlated; their pairwise correlation coefficients are higher than 0.99. In terms of availability and coverage, the Freddie Mac house price data are the best choice for this paper. The indices have been widely used in the housing, real estate, and urban literature; see Akkoyun et al. (2013), Karamon et al. (2017), and Christiansen et al. (2019) among many others.

[5]Besides using interpolation to match the frequency of personal income and population with that of other variables, we also try to use the same annual data for each month in the year and our results stay unchanged. This is not surprising given that our focus is to capture the heterogeneity of supply and demand conditions across MSAs rather than their variation over time.

[6]While house price, employment, personal income, and population data are available for more than 380 MSAs, due to data availability and changes to MSA definitions over time, only 150 MSAs have a complete history of housing permits data over our sample period, 4 of which cannot be matched with other data. We also conduct our analyses at a more aggregated level using data of 50 U.S. states and the District of Columbia and our results stay unchanged; these results are available upon request.

IPVAR Model

In order to examine the conditional responses of housing returns to a mortgage rate shock, we estimate an Interacted Panel VAR, proposed by Towbin and Weber (2013), of the form:

$$\begin{pmatrix} 1 & 0 \\ \alpha_{0,it}^{21} & 1 \end{pmatrix} \begin{pmatrix} MR_t \\ HR_{it} \end{pmatrix} = \mu_i + \sum_{l=1}^{L} \begin{pmatrix} \alpha_l^{11} & 0 \end{pmatrix} \begin{pmatrix} MR_{t-l} \\ HR_{i,t-l} \end{pmatrix} + u_{it}, \tag{3}$$

where MR_t is the mortgage rate (i.e., the 30-year fixed rate mortgage average) in period t, which is common across MSAs, and HR_{it} is the real housing return for MSA i in period t, calculated as the log difference of real house price. The vectors μ_i and u_{it} denote MSA-specific intercepts and independent and identically distributed shocks. L is the number of lags.

An implicit assumption imposed on Equation (3) is that the 30-year fixed rate mortgage average does not depend on MSA-level housing returns, i.e., $\alpha_{l,it}^{12} = 0$ for $l = 0, ..., L$. This exogeneity assumption tends to hold for two reasons. First, the 30-year fixed rate mortgage average is a national-level variable which is impacted by conditions of any single MSA to a negligible extent. Second, the mortgage rate is affected by the Fed's monetary policy,[7] usually with a delay, and the literature has shown no evidence that the Fed responds to house price movements; see Sun and Tsang (2014). While effective mortgage rates vary across MSAs, the magnitude of regional differences is small and statistically insignificant; see Ozanne and Thibodeau (1983), Jud and Epley (1991), and Kim and Bhattacharya (2009). We use the average 30-year mortgage rates in our IPVAR model in order to properly identify an exogenous mortgage rate shock. A more detailed discussion of this topic is provided later on.

In Equation (3), $\alpha_{l,it}^{jk}$ $(l = 0, ..., L)$ are deterministically varying coefficients. To examine how responses of housing returns to a mortgage rate shock vary with the monetary policy regime and MSA-level housing supply and demand characteristics, we allow these coefficients to be linear functions of a ZLB_t dummy,

[7] Both conventional and unconventional (such as quantitative easing) monetary polices cause changes in the mortgage rate. The Fed's total assets explain about 75% of the variation in the 30-year fixed rate mortgage average.

local housing supply and demand conditions X_{it}, and their interactions, i.e.,

$$\alpha_{l,it}^{jk} = \beta_{l,1}^{jk} + \beta_{l,2}^{jk} \cdot ZLB_t + \beta_{l,3}^{jk} \cdot X_{it} + \beta_{l,4}^{jk} \cdot ZLB_t \cdot X_{it}, \tag{4}$$

where ZLB_t is the zero lower bound dummy in period t that equals one if the federal funds rate lies in the 0% to 0.25% interval and zero otherwise; the variable X_{it} captures the supply and demand characteristics of the local housing market, namely the number of housing permits, real personal income, nonfarm employment, and population for MSA i in period t.

It is worth noting that we use the ZLB indicator with a stronger focus on the potential long-lasting effects of a mortgage rate shock. The ZLB dummy captures both the state of the macroeconomy and the monetary policy environment. This indicator is different from more short-lived recession indices, such as the NBER recession indicator. The ZLB regime covers not only a severe recession but also the initial stage of an economic recovery from the recession, which better matches the period of time during which individuals raise expectations of house price growth in our partial equilibrium model presented in Section . Over our sample period, the ZLB indicator takes the value one between December 2008 and December 2015 and from April 2020 onward, which covers both the Great Recession and the ongoing Covid-19 recession. The only NBER recession excluded by the ZLB indicator is the Dot-com recession between March and November 2001, which is considerably less severe and shorter-lived than the later two recessions.

The mortgage rate variable is common to all MSAs and, over our sample period, it exhibits a significant downward trend. We remove a linear trend from the mortgage rate data and the detrended mortgage rate is stationary according to both Augmented Dickey and Fuller (1979) and Phillips and Perron (1988) unit root tests; see Table 1. For panel unit root test of real housing returns, housing permits, real personal income, employment, and population, we adopt three widely-used tests including Im, Pesaran and Shin (2003) and Fisher-type tests using ADF and PP tests (Maddala and Wu, 1999; Choi, 2001). Housing returns are stationary without any transformations. Housing permits, real personal income, employment, and population are all log transformed. One is added to the number of housing permits before taking the

natural log to accommodate zero-valued observations. The log transformed housing permits variable does not have a linear trend and it is found to be stationary. We remove MSA-specific linear trends from the log-transformed real personal income, employment, and population so that all housing demand and supply factors are stationary.[8] This stationarity condition is particularly critical for interacted VAR results to be meaningful; see Towbin and Weber (2013). Note that, in order to capture the cross-MSA heterogeneity, we do not remove the level information in the data. The summary statistics of model variables are presented in Table 2.

Table 1: Unit root test

Variable	Data transformation/Unit root test	Statistic (p-value)
Mortgage rate	Linear trend removed	
	ADF - t-stat	-3.693 (0.005)
	PP - t-stat	-3.345 (0.014)
Housing returns		
	Im, Pesaran and Shin W-stat	-40.987 (0.000)
	ADF - Fisher Chi-square	3094.700 (0.000)
	PP - Fisher Chi-square	5183.690 (0.000)
Housing permits	Log transformation of one plus the number of permits	
	Im, Pesaran and Shin W-stat	-10.513 (0.000)
	ADF - Fisher Chi-square	862.059 (0.000)
	PP - Fisher Chi-square	6067.200 (0.000)
Personal income	MSA-specific linear trend removed from log transformation	
	Im, Pesaran and Shin W-stat	-10.307 (0.000)
	ADF - Fisher Chi-square	535.181 (0.000)
	PP - Fisher Chi-square	493.125 (0.000)
Employment	MSA-specific linear trend removed from log transformation	
	Im, Pesaran and Shin W-stat	-15.349 (0.000)
	ADF - Fisher Chi-square	834.723 (0.000)
	PP - Fisher Chi-square	816.037 (0.000)
Population	MSA-specific linear trend removed from log transformation	
	Im, Pesaran and Shin W-stat	-11.229 (0.000)
	ADF - Fisher Chi-square	666.814 (0.000)
	PP - Fisher Chi-square	291.175 (0.503)

The null hypothesis is defined as the presence of a unit root (assuming individual unit root process for panel data). When removing a linear trend, we do not remove the level information in the data because we rely on the level information to capture the cross-MSA heterogeneity.

[8] All panel unit root tests reach consensus on housing permits, personal income, and employment, while for population, two of the three tests suggest stationarity.

Table 2: Summary statistics

Variable	Mean	SD	Min	Max	10th Pct	90th Pct
Mortgage rate	0.0556	0.0057	0.0429	0.0705	0.0489	0.0639
Housing returns	0.0011	0.0049	-0.0552	0.0305	-0.0041	0.0061
Housing permits	3.7651	1.4894	0	8.1438	1.7918	5.6204
Personal income	16.5863	0.8238	15.1273	19.2504	15.6749	17.6957
Employment	4.7849	0.8036	3.3382	7.2218	3.9082	5.8837
Population	12.5194	0.7726	11.1665	14.8380	11.6336	13.5921

Empirical Results

ZLB vs Non-ZLB Regimes

We start with the ZLB versus non-ZLB responses of housing returns to a negative one-standard-deviation shock to the mortgage rate by setting $\beta_{l,3}^{jk} = \beta_{l,4}^{jk} = 0$ in Equation (4). We choose one lag for the VAR, based on the Schwarz information criterion. The model parameters are estimated using the method proposed by Towbin and Weber (2013). Given the inaccuracy of analytical standard errors which rely on first-order asymptotics, we use bootstrapped standard errors instead with 50 bootstrap iterations.[9]

We evaluate the coefficients at both values of the ZLB dummy variable and then compute the impulse responses of housing returns to a negative one-standard-deviation shock, which is estimated to be 17.1745 basis points, in the mortgage rate. The impulse response functions and the bootstrapped 90% confidence intervals in both the ZLB and non-ZLB regimes are depicted in Figure 2. The horizontal axis of the impulse response functions shows the number of periods (months) that have passed after the impulse has been realized while the vertical axis measures the response of the variable of interest, i.e. housing returns. We also present the impulse responses (only in the first 20 periods to save space) and the corresponding percent deviations from the sample average of monthly housing returns in the appendix Table A2.

[9] As described in Towbin and Weber (2013), point estimates of the model parameters do not provide much information. We report the impulse response functions in this section and relegate the parameter estimates to the appendix.

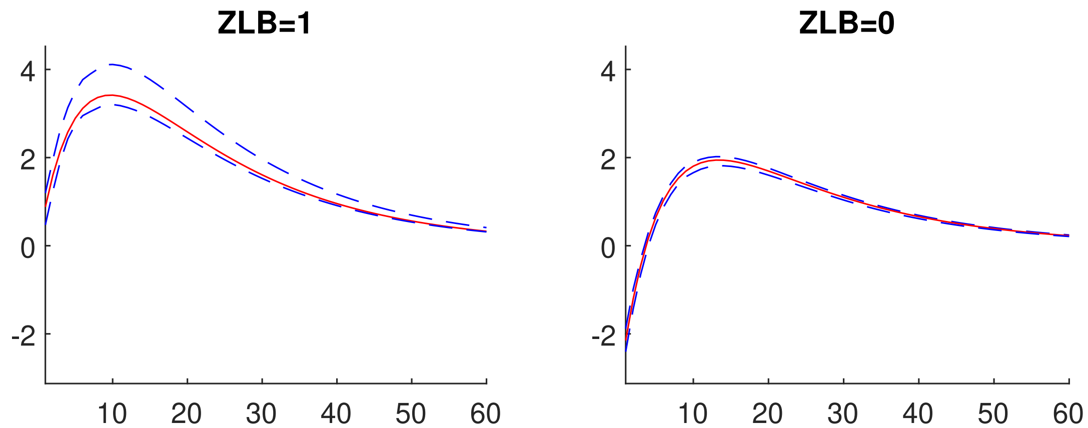


Figure 2: Responses of housing returns to a negative one-standard-deviation mortgage rate shock in ZLB and non-ZLB regimes

Figure 2 and Table A2 provide strong evidence for heterogeneous impacts of the mortgage rate shock on housing returns. The responses of housing returns to the mortgage rate shock are much stronger in the ZLB regime compared to the non-ZLB regime, a result in line with our first hypothesis. In the ZLB regime, housing returns increase right after the shock and the impact reaches its maximum about 10 months later when housing returns increase by 3.4168 basis points or about 31.22% deviation from the sample average. In the non-ZLB regime, however, the impact on housing returns is initially negative. It becomes positive a quarter later and reaches its maximum after another year. The maximum impact is only half the size of that in the ZLB regime.

The positive impact of a mortgage rate decrease on housing returns is long-lasting and large in magnitude when the policy rate is near zero. This finding is consistent with the ongoing housing market boom at the time of writing this paper, following the 2019-2020 period of falling mortgage rates and the lowering of the federal funds rate to near zero in early 2020 in response to the economic downturn caused by the global outbreak of Covid-19. Given that the federal funds rate is likely to remain low, the impact of the mortgage rate decrease in 2019 and 2020 on housing returns is expected to stay positive and outweigh the downward pressure caused by the recent surge in mortgage rates at least in the near future. As the positive impact dies down and the negative impact of rising mortgage rates, which started in February 2021, becomes more dominant at some point in time, housing returns will likely start to decline at a fast pace if the policy rate stays low. By analyzing a history of large price run-ups in U.S. state-level housing markets,

Sun and Tsang (2019) find that a sharper run-up in house prices predicts a higher probability of a crash. In light of their finding, our results point out the importance of avoiding mortgage rates from climbing too fast in maintaining healthy housing markets following the ongoing boom. This brings challenges to the Fed when it comes to the plan of reducing its monthly bond purchases, given inflationary pressures, before raising the policy rate.[10]

The Effects of Housing Supply and Demand Factors

Having illustrated the difference in the housing return responses between the two policy rate regimes, we then evaluate the effects of housing supply and demand factors, including the number of housing permits, real personal income, nonfarm employment, and population. While the ZLB regime is a dummy variable, our measures of housing permits, personal income, employment, and population are all continuous. We let the variable X be one of the these four factors at a time, estimate the model parameters, and compute the impulse response functions at a Low (10th) percentile and a High (90th) percentile value of the X variable and in both policy rate regimes.[11] The impulse responses and the bootstrapped 90% confidence intervals are depicted in Figure 3. While we observe a difference in the housing return responses evaluated at Low versus High values of each X variable in the non-ZLB regime, a greater difference stands out in the ZLB regime. In particular, housing returns increase by a larger extent following a negative mortgage rate shock in the case of fewer housing permits, higher personal income, higher employment, or larger population. We explore the role of these factors in detail one by one.

A. Housing Permits

The effects of housing permits are shown in Table A3 in the appendix, where we report the responses of housing returns in the first 20 periods following a negative one-standard-deviation shock to the mortgage rate and the corresponding percent deviations from the sample average, evaluated at the 90th and 10th percentiles of housing permits in each policy rate regime. In line with Table A2, the impact of a negative

[10]Since November 2021, the Fed has decided to begin reducing the monthly pace of its net asset purchases for Treasury securities and agency mortgage-backed securities.

[11]Given the high correlation among these factors, we are not able to include them jointly in the IPVAR model and disentangle their effects. Otherwise, we would run into a similar problem as multicollinearity in simple regression models.

mortgage rate shock on housing returns is generally larger when the policy rate is near zero. Not all MSAs are impacted equally. In particular, when the policy rate is not constrained by the ZLB, housing returns decrease in the first few months following the shock, irrespective of the level of housing permits. When the policy rate is at the ZLB, a negative mortgage shock heightens housing returns right away by 2.03 basis points (or about 18.53% deviation from the sample average) and the impact reaches its maximum at 2.44 basis points (or about 22.28% deviation from the sample average) after half a year in MSAs with High housing permits. In MSAs with Low housing permits, however, the impact is small in size initially and then increases gradually and reaches its maximum almost a year after the shock when housing returns increase by more than 4.16 basis points (or about 38% deviation from the sample average). The intuition behind this finding is straightforward. A mortgage rate decrease heats up housing demand and returns, and the effect strengthens when less housing units are allowed to be built, which restricts housing supply. These results confirm our hypothesis that a mortgage rate shock has heterogeneous effects on housing returns conditional on the state of the macroeconomy (captured by the ZLB of the policy rate), local supply conditions, and their interactions. Our results are consistent with the finding of Kishor and Morley (2015) that MSAs with less elastic housing supply are more sensitive to mortgage rate changes.[12]

B. Personal Income

Personal income also affects the response of housing returns to a negative shock to the mortgage rate; see the appendix Table A4. In the non-ZLB regime, housing returns decline in the first three or four months and increase thereafter. The impact of the mortgage rate shock on housing returns is long-lasting and reaches its maximum around 13-14 months after the shock, with a larger impact on MSAs with higher personal income than those with lower personal income. In the ZLB regime, housing returns increase almost immediately following the negative mortgage rate shock and personal income tends to matter even more. In MSAs with Low personal income, the maximum impact of the shock on housing returns is about 2.75 basis points (or 25% deviation from the sample average). In contrast, the maximum magnitude is 4.19 basis points (or 38% deviation from the sample average) in MSAs with High personal income. Given that

[12] Kishor and Morley (2015) use the geography-based measure of Saiz (2010) and the regulation-based measure from the Wharton Regulation Index of Gyourko et al. (2008) to measure supply elasticity. However, there are no time-series data on these housing supply elasticities and only the cross-sectional variation could be exploited. Instead, we use time-varying housing permits to measure supply-side conditions of housing markets.

personal income is an important determinant of housing demand in local markets, an increase in personal income reinforces the surge in housing returns caused by lowered mortgage rates.

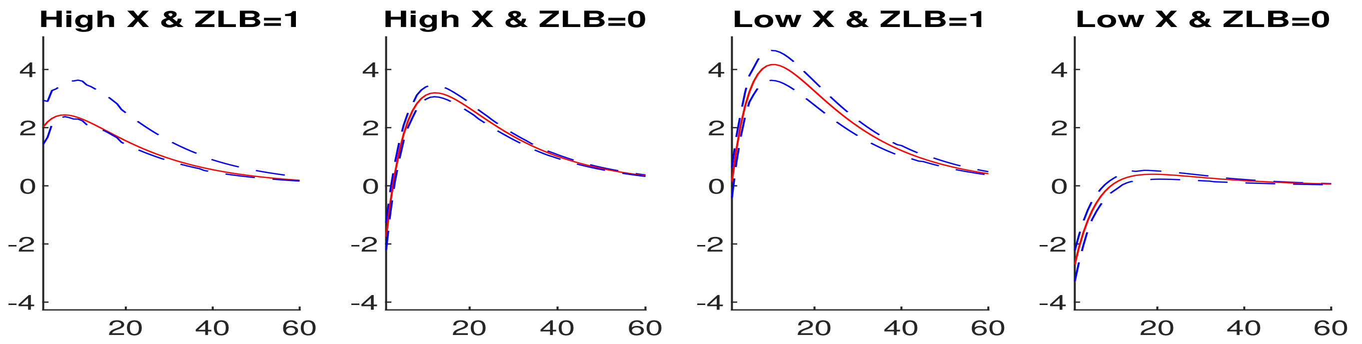
C. Employment

Table A5 in the appendix shows the effects of employment, another determinant of housing demand in local markets, on the responses of housing returns to a negative mortgage rate shock. When the federal funds rate is not near zero, housing returns decrease for 3 months and then start to increase, to a larger extent in MSAs with higher employment. It takes around 13 months for the impact of the negative mortgage rate shock to reach a peak, irrespective of the level of employment. The shock leads to larger increases in housing returns when the policy rate gets stuck at zero, especially in MSAs with High employment. In line with our expectation, an increase in employment also reinforces the surge in housing returns caused by lowered mortgage rates.

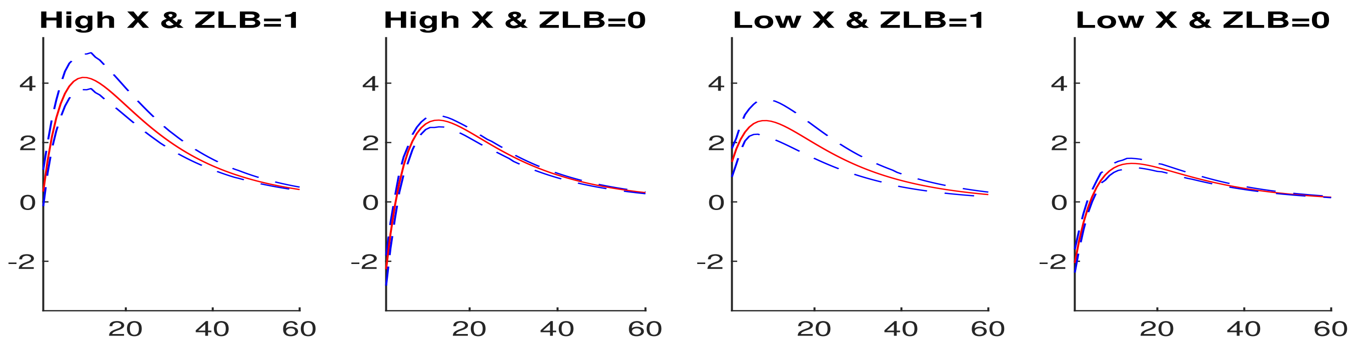
D. Population

Table A6 in the appendix shows the effects of population. Similar to personal income and employment, population also affects local housing demand positively. The table shows that a negative mortgage rate shock increases housing returns, to a larger extent in MSAs with High population and during times when the policy rate is constrained by the zero lower bound. These results confirm our hypothesis that a mortgage rate shock has heterogeneous effects on housing returns conditional on the state of the macroeconomy, local demand conditions, and their interactions.

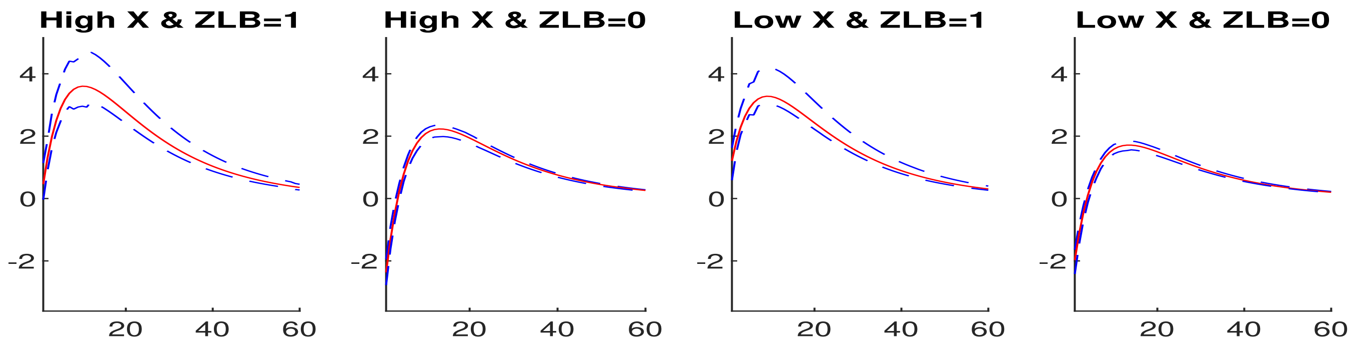
X = Housing permits



X = Personal income



X = Employment



X = Population

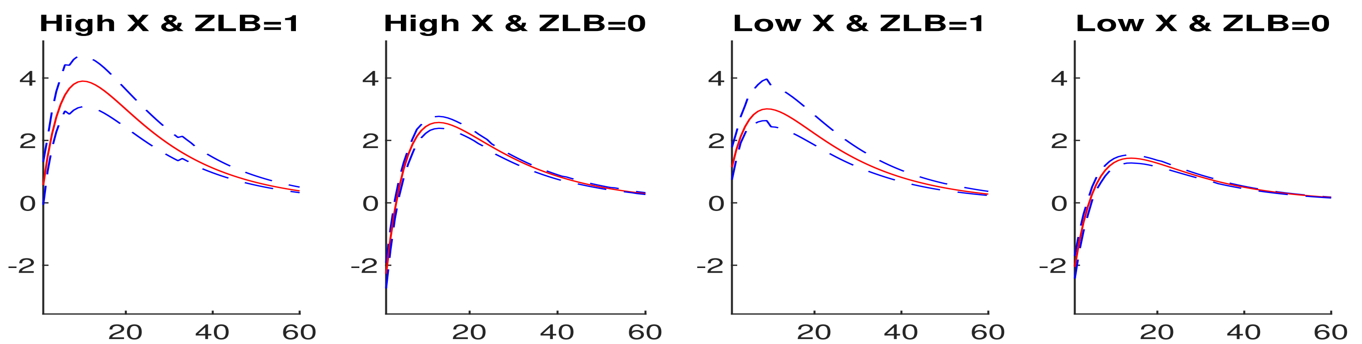


Figure 3: Impulse responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of supply and demand factors

Further Discussion: Heterogeneous Mortgage Rates across Regions

We find strong evidence for heterogeneous effects of a mortgage rate shock on housing returns across U.S. metropolitan statistical areas, conditional on the ZLB of the federal funds rate, local supply and demand factors, and their interactions. One might suspect that our results are driven by differential mortgage rates across regions, which could potentially be related to local supply and demand factors, rather than heterogeneous responses of housing returns to changes in mortgage rates. While effective mortgage rates indeed vary across MSAs, we use the 30-year fixed rate mortgage average, which is common to all MSAs and non-responsive to MSA-level housing returns, in the IPVAR model so that an exogenous shock to the mortgage rate can be properly identified. In order to rule out the possibility that our results are driven by differential mortgage rates across geographical locations, we collect and analyze the MSA-level effective mortgage rate data (available only at annual frequency) between 1995 and 2018 from the Monthly Interest Rate Survey of the Federal Housing Finance Agency (FHFA).[13] The sample ends in 2018 due to the discontinuation of FHFA's Monthly Interest Rate Survey in 2019.

First, we present the summary statistics of MSA-level effective mortgage rates in Table 3. Results show that variation in effective mortgage rates is dominated by variation within MSAs over time (i.e., the within variation) rather than that across MSAs (i.e., the between variation). In line with Ozanne and Thibodeau (1983), Jud and Epley (1991), and Kim and Bhattacharya (2009), differences in terms of mortgage rates across different regions are insignificant.

Table 3: Summary statistics of MSA-specific effective mortgage rates

	Mean	Std Dev	Min	Max
Overall	5.7708	1.3870	3.5919	8.1600
Between		0.0956	5.5066	5.9579
Within		1.3839	3.5967	8.1728

All statistics are in percent.

Second, as in a traditional VAR model, what an IPVAR identifies is the response of a variable (e.g., real housing return) to a shock, namely a change, in another variable (e.g., mortgage rate). While mortgage

[13] The MSAs covered by the Monthly Interest Rate Survey are different from the sample of 146 MSAs used in our main analysis.

rates are different in levels across MSAs, their year-to-year changes tend to closely follow those of the 30-year fixed rate mortgage average. In Table 4, we conduct mean comparison tests between MSA-specific changes in the effective mortgage rate and changes in the 30-year fixed rate mortgage average. Changes in the MSA-specific effective mortgage rate are not statistically different from changes in the 30-year fixed rate mortgage average, the measure of mortgage rate used in our IPVAR model. In other words, a shock to the MSA-specific effect mortgage rate is well captured by a shock to the national average.

Table 4: Mean comparison tests

	obs	Mean	Std Err	t value	p value
Atlanta, GA	40	0.001	0.080	0.011	0.992
Baltimore, MD	14	-0.002	0.194	-0.007	0.995
Boston, MA	40	0.013	0.059	0.212	0.833
Chicago, IL	40	0.007	0.075	0.091	0.927
Cleveland, OH	40	0.001	0.069	0.005	0.996
Columbus, OH	40	-0.002	0.068	-0.025	0.980
Dallas-Ft. Worth, TX	40	0.001	0.083	0.013	0.990
Denver, CO	40	-0.005	0.099	-0.047	0.963
Detroit, MI	40	0.009	0.074	0.129	0.898
Houston, TX	40	-0.001	0.075	-0.008	0.994
Indianapolis, IN	40	0.001	0.081	0.009	0.993
Kansas City, MO	40	0.004	0.090	0.044	0.965
Los Angeles, CA	36	-0.010	0.091	-0.112	0.911
Miami, FL	40	0.009	0.076	0.124	0.902
Milwaukee, WI	40	0.005	0.056	0.079	0.938
Minneapolis-St. Paul, MN	40	0.009	0.077	0.112	0.911
New York, NY	40	0.018	0.067	0.277	0.783
Philadelphia, PA	40	0.012	0.058	0.211	0.834
Phoenix, AR	40	0.005	0.077	0.060	0.953
Pittsburgh, PA	40	0.007	0.072	0.102	0.919
Portland, OR	40	-0.004	0.098	-0.041	0.968
San Diego, CA	40	-0.007	0.095	-0.074	0.941
San Francisco, CA	40	-0.013	0.086	-0.148	0.883
Seattle, WA	40	-0.008	0.092	-0.088	0.930
St. Louis, MO-IL	40	0.004	0.068	0.059	0.954
Tampa-St. Petersburg, FL	40	0.009	0.071	0.129	0.898
Washington-Baltimore, DC-MD	40	-0.001	0.073	-0.014	0.989

This table reports the mean comparison tests between the change in effective mortgage rate and the change in 30-year fixed rate mortgage average for each MSA in Table 16 of the Monthly Interest Rate Survey by the Federal Housing Finance Agency; see https://www.fhfa.gov/DataTools/Downloads/Pages/Monthly-Interest-Rate-Data.aspx.

It is worth noting that our goal in this section is not to explore what determines regional mortgage rates. For discussions on regional variation of mortgage rates, see for example Ostas (1977), Morrell and Saba (1983), Jameson et al. (1986), and especially Jameson et al. (1990).

Conclusion

This paper develops an empirical and theoretical framework to examine how the impact of a mortgage rate shock on housing returns is altered by local supply and demand conditions. We build a partial equilibrium model which shows that the effect of mortgage rate changes on the return of housing is dependent on the zero lower bound regime of the policy interest rate, local supply and demand conditions, and their interactions. This finding is supported by our empirical results, which originate from an IPVAR model estimated on data including 146 U.S. metropolitan statistical areas for a period ranging from January 1995 to December 2020.

Our theoretical and empirical models draw a clear and unambiguous picture. Supply and demand conditions matter for the impact of mortgage rate fluctuations. This is especially true during times when the policy interest rate hits the zero lower bound. We find that the zero lower bound on the federal funds rate intensifies the housing return responses to a mortgage rate shock, with and without accounting for demand and supply factors in local housing markets. This paper holds important policy implications for the post-Covid-19 era when the U.S. is experiencing a nationwide housing boom and a surge in mortgage rates, while the federal funds rate is expected to remain low.

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Appendix

In a bivariate IPVAR of mortgage rate (y_1) and real housing return (y_2) with one lag, the parameter matrix output takes the following form:

$$\beta = \begin{pmatrix} 0 & \beta_{(y_{012})} \\ 0 & \beta_{(y_{012} \times ZLB)} \\ \beta_{(y_{111})} & \beta_{(y_{112})} \\ 0 & \beta_{(y_{112} \times ZLB)} \\ 0 & \beta_{(y_{122})} \\ 0 & 0 \\ _cons1 & _cons2 \end{pmatrix}$$

where $\beta_{(y_{lji})}$ stands for the beta coefficient of the dependent variable i on the regressor j at lag l, $\beta_{(y_{lji}) \times ZLB}$ stands for the beta coefficient of the dependent variable i on the interaction between the regressor j and the ZLB dummy, and $_cons1$ and $_cons2$ are vectors of the intercept coefficient followed by the coefficient on the ZLB dummy. The estimates of these parameters are as follows:

Coef	Std Err	Coef	Std Err
0		0.1241	0.0083
0		-0.1750	0.0165
0.9476	0.0018	-0.1520	0.0083
0		0.1506	0.0159
0		0.8382	0.0033
0		0	
0.0029	0.0001	0.0019	0.0002
0		0.0009	0.0004

Table A1: List of MSAs

Abilene TX	Fort Smith AR-OK	Pittsburgh PA
Akron OH	Fort Wayne IN	Provo-Orem UT
Albany GA	Fresno CA	Pueblo CO
Albany-Schenectady-Troy NY	Gadsden AL	Punta Gorda FL
Albuquerque NM	Gainesville FL	Racine WI
Alexandria LA	Glens Falls NY	Rapid City SD
Allentown-Bethlehem-Easton PA-NJ	Grand Forks ND-MN	Reading PA
Altoona PA	Great Falls MT	Redding CA
Amarillo TX	Greeley CO	Rochester MN
Anchorage AK	Green Bay WI	Rochester NY
Ann Arbor MI	Greenville NC	Rockford IL
Asheville NC	Hattiesburg MS	Salem OR
Baton Rouge LA	Huntington-Ashland WV-KY-OH	Salinas CA
Beaumont-Port Arthur TX	Huntsville AL	San Angelo TX
Bellingham WA	Iowa City IA	Santa Cruz-Watsonville CA
Billings MT	Jackson MI	Santa Fe NM
Binghamton NY	Jackson MS	Savannah GA
Bismarck ND	Jackson TN	Sheboygan WI
Bloomington IN	Jacksonville FL	Shreveport-Bossier City LA
Canton-Massillon OH	Jacksonville NC	Sioux City IA-NE-SD
Casper WY	Johnstown PA	Sioux Falls SD
Cedar Rapids IA	Joplin MO	Springfield IL
Champaign-Urbana IL	Kansas City MO-KS	Springfield MO
Charleston WV	Knoxville TN	St. Cloud MN
Charlottesville VA	Kokomo IN	St. Joseph MO-KS
Chattanooga TN-GA	Lafayette LA	St. Louis MO-IL
Cheyenne WY	Lake Charles LA	State College PA
Colorado Springs CO	Lancaster PA	Sumter SC
Columbia MO	Lansing-East Lansing MI	Syracuse NY
Columbia SC	Laredo TX	Tallahassee FL
Columbus GA-AL	Las Cruces NM	Tampa-St. Petersburg-Clearwater FL
Columbus OH	Lawrence KS	Terre Haute IN
Corpus Christi TX	Lawton OK	Texarkana TX-AR
Cumberland MD-WV	Lima OH	Toledo OH
Davenport-Moline-Rock Island IA-IL	Lincoln NE	Topeka KS
Decatur AL	Lubbock TX	Tucson AZ
Decatur IL	Lynchburg VA	Tulsa OK
Dothan AL	Madison WI	Tuscaloosa AL
Dover DE	Memphis TN-MS-AR	Tyler TX
Dubuque IA	Merced CA	Utica-Rome NY
Eau Claire WI	Mobile AL	Waco TX
El Paso TX	Modesto CA	Waterloo-Cedar Falls IA
Elkhart-Goshen IN	Monroe LA	Wheeling WV-OH
Elmira NY	Montgomery AL	Wichita Falls TX
Erie PA	Muncie IN	Wichita KS
Fayetteville NC	Ocala FL	Wilmington NC
Fayetteville-Springdale-Rogers AR-MO	Oklahoma City OK	Yakima WA
Flint MI	Owensboro KY	Yuma AZ
Florence SC	Pine Bluff AR	

Table A2: Responses of housing returns to a negative one-standard-deviation mortgage rate shock in ZLB and non-ZLB regimes

	ZLB=1		ZLB=0	
Period	Change	% deviation	Change	% deviation
1	0.8809	8.05 %	-2.1508	-19.65 %
2	1.5983	14.60 %	-1.2065	-11.02 %
3	2.1545	19.69 %	-0.4462	-4.08 %
4	2.5780	23.56 %	0.1614	1.48 %
5	2.8926	26.43 %	0.6427	5.87 %
6	3.1179	28.49 %	1.0195	9.32 %
7	3.2704	29.88 %	1.3102	11.97 %
8	3.3638	30.74 %	1.5299	13.98 %
9	3.4094	31.15 %	1.6915	15.46 %
10	3.4168	31.22 %	1.8055	16.50 %
11	3.3936	31.01 %	1.8807	17.18 %
12	3.3465	30.58 %	1.9245	17.58 %
13	3.2806	29.98 %	1.9430	17.75 %
14	3.2005	29.24 %	1.9411	17.74 %
15	3.1097	28.41 %	1.9232	17.57 %
16	3.0112	27.51 %	1.8927	17.29 %
17	2.9075	26.57 %	1.8524	16.93 %
18	2.8004	25.59 %	1.8047	16.49 %
19	2.6916	24.59 %	1.7515	16.00 %
20	2.5824	23.60 %	1.6944	15.48 %

The change is expressed in basis points.

Table A3: Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of housing permits

	X = Housing permits							
	High X & ZLB=1		High X & ZLB=0		Low X & ZLB=1		Low X & ZLB=0	
Period	Change	% deviation	Change	% deviation	Change	% deviation	Change	% deviation
1	2.0280	18.53 %	-1.7512	-16.00 %	0.1492	1.36 %	-2.7026	-24.69 %
2	2.2001	20.10 %	-0.5402	-4.94 %	1.2294	11.23 %	-2.0964	-19.16 %
3	2.3178	21.18 %	0.4248	3.88 %	2.0755	18.96 %	-1.5977	-14.60 %
4	2.3913	21.85 %	1.1866	10.84 %	2.7289	24.93 %	-1.1885	-10.86 %
5	2.4292	22.20 %	1.7806	16.27 %	3.2237	29.46 %	-0.8538	-7.80 %
6	2.4385	22.28 %	2.2365	20.44 %	3.5887	32.79 %	-0.5810	-5.31 %
7	2.4250	22.16 %	2.5789	23.56 %	3.8474	35.15 %	-0.3598	-3.29 %
8	2.3936	21.87 %	2.8285	25.84 %	4.0197	36.73 %	-0.1812	-1.66 %
9	2.3483	21.46 %	3.0022	27.43 %	4.1221	37.66 %	-0.0380	-0.35 %
10	2.2922	20.94 %	3.1144	28.46 %	4.1680	38.08 %	0.0758	0.69 %
11	2.2282	20.36 %	3.1767	29.03 %	4.1688	38.09 %	0.1655	1.51 %
12	2.1583	19.72 %	3.1990	29.23 %	4.1338	37.77 %	0.2352	2.15 %
13	2.0845	19.05 %	3.1893	29.14 %	4.0707	37.19 %	0.2885	2.64 %
14	2.0081	18.35 %	3.1544	28.82 %	3.9859	36.42 %	0.3282	3.00 %
15	1.9304	17.64 %	3.0997	28.32 %	3.8845	35.49 %	0.3570	3.26 %
16	1.8522	16.92 %	3.0299	27.68 %	3.7710	34.46 %	0.3767	3.44 %
17	1.7744	16.21 %	2.9486	26.94 %	3.6487	33.34 %	0.3892	3.56 %
18	1.6976	15.51 %	2.8589	26.12 %	3.5205	32.17 %	0.3957	3.62 %
19	1.6221	14.82 %	2.7634	25.25 %	3.3887	30.96 %	0.3975	3.63 %
20	1.5484	14.15 %	2.6640	24.34 %	3.2553	29.74 %	0.3955	3.61 %

The change is expressed in basis points.

Table A4: Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of personal income

	X = Personal income							
	High X & ZLB=1		High X & ZLB=0		Low X & ZLB=1		Low X & ZLB=0	
Period	Change	% deviation	Change	% deviation	Change	% deviation	Change	% deviation
1	0.3474	3.17 %	-2.2660	-20.71 %	1.3487	12.32 %	-2.0568	-18.79 %
2	1.3883	12.69 %	-1.0764	-9.84 %	1.7802	16.27 %	-1.3066	-11.94 %
3	2.2027	20.13 %	-0.1231	-1.12 %	2.1076	19.26 %	-0.6999	-6.40 %
4	2.8304	25.86 %	0.6347	5.80 %	2.3495	21.47 %	-0.2125	-1.94 %
5	3.3046	30.19 %	1.2308	11.25 %	2.5215	23.04 %	0.1763	1.61 %
6	3.6528	33.38 %	1.6934	15.47 %	2.6366	24.09 %	0.4833	4.42 %
7	3.8981	35.62 %	2.0463	18.70 %	2.7055	24.72 %	0.7229	6.61 %
8	4.0596	37.09 %	2.3089	21.10 %	2.7372	25.01 %	0.9069	8.29 %
9	4.1533	37.95 %	2.4977	22.82 %	2.7390	25.03 %	1.0453	9.55 %
10	4.1923	38.31 %	2.6263	24.00 %	2.7172	24.83 %	1.1462	10.47 %
11	4.1876	38.26 %	2.7060	24.73 %	2.6767	24.46 %	1.2166	11.12 %
12	4.1482	37.90 %	2.7463	25.09 %	2.6218	23.96 %	1.2621	11.53 %
13	4.0816	37.29 %	2.7549	25.17 %	2.5559	23.35 %	1.2874	11.76 %
14	3.9940	36.49 %	2.7382	25.02 %	2.4819	22.68 %	1.2966	11.85 %
15	3.8905	35.55 %	2.7017	24.69 %	2.4020	21.95 %	1.2928	11.81 %
16	3.7753	34.50 %	2.6498	24.21 %	2.3181	21.18 %	1.2789	11.69 %
17	3.6516	33.37 %	2.5859	23.63 %	2.2318	20.39 %	1.2569	11.48 %
18	3.5224	32.19 %	2.5133	22.96 %	2.1443	19.59 %	1.2287	11.23 %
19	3.3899	30.97 %	2.4342	22.24 %	2.0566	18.79 %	1.1959	10.93 %
20	3.2558	29.75 %	2.3508	21.48 %	1.9695	18.00 %	1.1597	10.60 %

The change is expressed in basis points.

Table A5: Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of employment

	X = Employment							
	High X & ZLB=1		High X & ZLB=0		Low X & ZLB=1		Low X & ZLB=0	
Period	Change	% deviation	Change	% deviation	Change	% deviation	Change	% deviation
1	0.4611	4.21 %	-2.3691	-21.65 %	1.2109	11.06 %	-1.9757	-18.05 %
2	1.3187	12.05 %	-1.3039	-11.91 %	1.8186	16.62 %	-1.1275	-10.30 %
3	1.9886	18.17 %	-0.4468	-4.08 %	2.2858	20.89 %	-0.4444	-4.06 %
4	2.5038	22.88 %	0.2376	2.17 %	2.6375	24.10 %	0.1020	0.93 %
5	2.8916	26.42 %	0.7792	7.12 %	2.8943	26.45 %	0.5350	4.89 %
6	3.1751	29.01 %	1.2027	10.99 %	3.0738	28.09 %	0.8744	7.99 %
7	3.3733	30.82 %	1.5288	13.97 %	3.1902	29.15 %	1.1364	10.38 %
8	3.5021	32.00 %	1.7748	16.22 %	3.2556	29.75 %	1.3350	12.20 %
9	3.5747	32.66 %	1.9551	17.86 %	3.2799	29.97 %	1.4813	13.53 %
10	3.6019	32.91 %	2.0818	19.02 %	3.2714	29.89 %	1.5849	14.48 %
11	3.5930	32.83 %	2.1646	19.78 %	3.2369	29.58 %	1.6538	15.11 %
12	3.5555	32.49 %	2.2121	20.21 %	3.1820	29.07 %	1.6944	15.48 %
13	3.4955	31.94 %	2.2310	20.39 %	3.1114	28.43 %	1.7123	15.65 %
14	3.4182	31.23 %	2.2271	20.35 %	3.0289	27.68 %	1.7120	15.64 %
15	3.3278	30.41 %	2.2051	20.15 %	2.9377	26.84 %	1.6972	15.51 %
16	3.2277	29.49 %	2.1689	19.82 %	2.8403	25.95 %	1.6711	15.27 %
17	3.1209	28.52 %	2.1218	19.39 %	2.7389	25.03 %	1.6361	14.95 %
18	3.0095	27.50 %	2.0663	18.88 %	2.6351	24.08 %	1.5945	14.57 %
19	2.8956	26.46 %	2.0048	18.32 %	2.5303	23.12 %	1.5479	14.14 %
20	2.7805	25.41 %	1.9388	17.72 %	2.4256	22.16 %	1.4978	13.69 %

The change is expressed in basis points.

Table A6: Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of population

	X = Population							
	High X & ZLB=1		High X & ZLB=0		Low X & ZLB=1		Low X & ZLB=0	
Period	Change	% deviation	Change	% deviation	Change	% deviation	Change	% deviation
1	0.5684	5.19 %	-2.2717	-20.76 %	1.1440	10.45 %	-2.0507	-18.74 %
2	1.4830	13.55 %	-1.1309	-10.33 %	1.6951	15.49 %	-1.2649	-11.56 %
3	2.1966	20.07 %	-0.2156	-1.97 %	2.1183	19.36 %	-0.6303	-5.76 %
4	2.7445	25.08 %	0.5130	4.69 %	2.4364	22.26 %	-0.1211	-1.11 %
5	3.1562	28.84 %	1.0872	9.93 %	2.6681	24.38 %	0.2842	2.60 %
6	3.4563	31.58 %	1.5338	14.01 %	2.8295	25.85 %	0.6037	5.52 %
7	3.6651	33.49 %	1.8754	17.14 %	2.9336	26.81 %	0.8522	7.79 %
8	3.7999	34.72 %	2.1306	19.47 %	2.9913	27.33 %	1.0422	9.52 %
9	3.8745	35.40 %	2.3152	21.15 %	3.0117	27.52 %	1.1843	10.82 %
10	3.9009	35.64 %	2.4421	22.31 %	3.0023	27.43 %	1.2870	11.76 %
11	3.8887	35.53 %	2.5221	23.04 %	2.9694	27.13 %	1.3576	12.40 %
12	3.8459	35.14 %	2.5642	23.43 %	2.9180	26.66 %	1.4022	12.81 %
13	3.7793	34.53 %	2.5758	23.54 %	2.8524	26.06 %	1.4256	13.03 %
14	3.6943	33.76 %	2.5631	23.42 %	2.7760	25.37 %	1.4321	13.09 %
15	3.5954	32.85 %	2.5313	23.13 %	2.6919	24.60 %	1.4251	13.02 %
16	3.4864	31.86 %	2.4845	22.70 %	2.6021	23.78 %	1.4075	12.86 %
17	3.3702	30.79 %	2.4263	22.17 %	2.5088	22.92 %	1.3815	12.62 %
18	3.2493	29.69 %	2.3594	21.56 %	2.4134	22.05 %	1.3491	12.33 %
19	3.1256	28.56 %	2.2863	20.89 %	2.3171	21.17 %	1.3119	11.99 %
20	3.0009	27.42 %	2.2088	20.18 %	2.2209	20.29 %	1.2713	11.62 %

The change is expressed in basis points.