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.

Keywords Housing returns · Mortgage rates · Supply and demand conditions · Zero lower bound

JEL Classification R10 · C32 · C33 · E52

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 & Hendershott, 1996; Jud & Winkler, 2002; Meese & Wallace, 2003; Capozza et al., 2004; Hwang
& 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 & Wu, 2012; Wu & 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 & Blinder, 1988; Bernanke & Gertler, 1995). (Fratantoni & 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 non-linear 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. In contrast, Tenreyro and 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

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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).
the Fed’s current plan of reducing its monthly purchases of mortgage-backed securities, given inflationary pressures, before raising the policy rate.\textsuperscript{2}

The structure of the paper is as follows. “Heterogeneous Effects of Mortgage Rates on Housing Returns” section derives a simple partial equilibrium model to illustrate the heterogeneous effects of a mortgage rate shock on local housing returns. “Data and Methodology” section presents the data used for the estimation of our IPVAR model and discusses in detail the underlying VAR methodology. “Empirical Results” section analyzes the empirical results and impulse response functions of the estimated IPVAR framework. “Conclusion” section 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 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 $\lambda$ 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 $[u, v_0]$ with density $1/\nu_1$, where $\nu_1$

\textsuperscript{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.
> 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 \( D_t = (\nu_0 - u^*(t))/\nu_1 \). Following Sun and Tsang (2019), we interpret an increase in \( \nu_1 \) as a negative housing demand shock and a decrease in \( \nu_1 \) 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 \( H(t) = \frac{\nu_0 - rc_0}{\nu_1} \) and \( P(t) = c_0 \). Following Glaeser et al. (2008), individuals are assumed to update their beliefs at discrete intervals. Let \( \epsilon \) 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., \( P(t + 1) = c_0 + \frac{\epsilon \lambda c_1}{(rc_1 + \nu_1 + \lambda \nu_1)(r + \lambda)} \).

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 \( \epsilon \); they also depend on parameters \( c_1 \) and \( \nu_1 \) that capture housing supply and demand conditions, as well as their interactions with \( \epsilon \). 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, riskaverse 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 $\epsilon$ 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 $\epsilon$ 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 Eq. 1 against hypothetical values of the mortgage rate in Fig. 1.

In the baseline scenario, we choose $\lambda = 0.05$, $r = 0.06$, $\nu = 1$, and $c_1 = 165/62$. 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

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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 Eq. 1 and the expectation $\epsilon$ in the long-run steady state.

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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 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 \( \nu_1 \) 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) and 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

\(^4\) 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.
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. 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 5 in the Appendix.

**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:

\[
\begin{pmatrix}
1 & 0 \\
\alpha_{21}^{t} & 1
\end{pmatrix}
\begin{pmatrix}
MR_t \\
HR_{it}
\end{pmatrix}
= \mu_i + \sum_{l=1}^{L} \left( \begin{pmatrix}
\alpha_{11}^{t-l} & 0 \\
0 & 1
\end{pmatrix}
\begin{pmatrix}
MR_{t-l} \\
HR_{it-l}
\end{pmatrix}
\right) + u_{it},
\]

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 \( \mu_i \) and \( u_{it} \) denote MSA-specific intercepts and independent and identically distributed shocks. \( L \) is the number of lags.

An implicit assumption imposed on Eq. 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 \( l = 0, \ldots, L \).

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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.
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, 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 Eq. 3, $a_j^k (l = 0, \ldots, L)$ 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 dummy, local housing supply and demand conditions $X_{it}$, and their interactions, i.e.,

$$a_j^k = \beta_{j,1} \cdot ZLB_t + \beta_{j,2} \cdot X_{it} + \beta_{j,3} \cdot ZLB_t \cdot X_{it},$$ (4)

where ZLB 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 “Heterogeneous Effects of Mortgage Rates on Housing Returns” 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 & Fuller, 1979) and (Phillips & Perron, 1988) unit root tests;

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7 Both conventional and unconventional (such as quantitative easing) monetary policies 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.
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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 et al., 2003) and Fisher-type tests using ADF and PP tests (Maddala & 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

| 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.

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 et al., 2003) and Fisher-type tests using ADF and PP tests (Maddala & 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

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.
cross-MSA heterogeneity, we do not remove the level information in the data. The summary statistics of model variables are presented in Table 2.

**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 $\beta_{1,3} = \beta_{1,4} = 0$ in Eq. 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 Fig. 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 6.

Figure 2 and Table 6 provide strong evidence for heterogeneous impacts of the mortgage rate shock on housing returns. The responses of housing returns to the

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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.
The heterogeneous effects of mortgage rates on housing returns 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

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**Fig. 2** Responses of housing returns to a negative one-standard-deviation mortgage rate shock in ZLB and non-ZLB regimes
its monthly bond purchases, given inflationary pressures, before raising the policy rate.\textsuperscript{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 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.\textsuperscript{11} The impulse responses and the bootstrapped 90% confidence intervals are depicted in Fig. 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 7 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 6, the impact of a negative 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

\textsuperscript{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.

\textsuperscript{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.
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.

Fig. 3 Impulse responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of supply and demand factors
(2015) that MSAs with less elastic housing supply are more sensitive to mortgage rate changes.\textsuperscript{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 8. 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 2.74 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 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 9 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 10 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.

\textsuperscript{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.
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 make sure that mortgage rate shocks in local markets can be captured by changes in the 30-year fixed rate mortgage average, 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). 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) and Jud and Epley (1991), and Kim and Bhattacharya (2009), differences in terms of mortgage rates across different regions are insignificant.

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 rates are, to a limited extent, 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. Namely, when there is a shock of one percentage point to the

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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

13 The MSAs covered by the Monthly Interest Rate Survey are different from the sample of 146 MSAs used in our main analysis.
national average, the effective mortgage rate in any single region will also change by nearly one percentage point.

In sum, we use the 30-year fixed rate mortgage average in the IPVAR model to properly identify an exogenous shock to the mortgage rate. Despite the heterogeneity in mortgage rates across regions, there is an almost one-to-one change between the 30-year fixed rate mortgage average and the effective mortgage rate.

### Table 4 Mean comparison tests

| City, State       | 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](https://www.fhfa.gov/DataTools/Downloads/Pages/Monthly-Interest-Rate-Data.aspx).
in each MSA. A shock to the MSA-specific effective mortgage rate is well captured by a shock in the national average.\textsuperscript{14}

**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.

**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:

$$
\beta = \begin{pmatrix}
0 & \beta_{(y_1)2}
0 & \beta_{(y_1)2\times ZLB}
\beta_{(y_2)1}
0 & \beta_{(y_1)2}
0 & \beta_{(y_1)2\times ZLB}
0 & \beta_{(y_2)1}
0 & 0
\end{pmatrix}
$$

where $\beta_{(y_i)j}$ stands for the beta coefficient of the dependent variable $i$ on the regressor $j$ at lag $l$, $\beta_{(y_i)j\times ZLB}$ 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

\textsuperscript{14} 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 & Saba, 1983; Jameson et al., 1986), and especially (Jameson et al., 1990).
| Table 5  | 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 | Jackson ville 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 |
Table 5 (continued)

| City 1 | City 2 | City 3  |
|--------|--------|--------|
| 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 6  Responses of housing returns to a negative one-standard-deviation mortgage rate shock in ZLB and non-ZLB regimes

| Period | ZLB=1 | ZLB=0 |
|--------|-------|-------|
|        | 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.

are vectors of the intercept coefficient followed by the coefficient on the ZLB dummy. The estimates of these parameters are as follows:
Table 7  Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of housing permits

| 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 %     | 1.294 | 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 8  Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of personal income

| Period | High X & ZLB=1 | High X & ZLB=0 | Low X & ZLB=1 | Low X & ZLB=0 |
|--------|---------------|---------------|---------------|---------------|
|        | 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 9  Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of employment

| Period | X = Employment | |
|--------|----------------|----------|----------|----------|----------|
|        | High X & ZLB= 1 | High X & ZLB= 0 | Low X & ZLB= 1 | Low X & ZLB= 0 | |
|        | 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 10  Responses of housing returns to a negative one-standard-deviation mortgage rate shock and the effects of population

| Period | X = Population | High X & ZLB= 1 | High X & ZLB=0 | Low X & ZLB= 1 | Low X & ZLB=0 |
|--------|----------------|-----------------|----------------|----------------|----------------|
|        | Change % deviation | 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
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