Inflation Through the Mortgage Market

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Abstract

We study the impact of the Federal Reserve's pandemic-era Mortgage-Backed Security purchases (QE4) on housing markets and consumer inflation. Using mortgage market segmentation, we generate a cross-sectional interest rate instrument to capture areas more heavily affected by Fed purchases in the conforming mortgage market. We find QE4 substantially decreased mortgage rates, raised house prices, and lowered local unemployment. We interpret these results through a quantitative spatial model, and estimate substantial impacts of mortgage purchases on aggregate house prices and consumer inflation. Our findings suggest that unconventional monetary policy can meaningfully stimulate housing demand and economic activity, but may also amplify inflationary pressures and impact housing affordability.

JEL-Classification: E31, E21, E43, E58, R38

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1 Introduction

Unconventional monetary policy in the form of Quantitative Easing has become a key aspect of central bank operations. In the United States, the Federal Reserve's asset purchases expanded the balance sheet to almost $9 trillion at its peak in April, 2022, including $2.7 trillion in Agency Mortgage-Backed Securities (MBS) (Na et al., 2024). However, despite the scale and prevalence of these purchases, considerable debate ranges on the impact and desirability of such purchases. Some studies find limited effects of earlier QE rounds (Krishnamurthy and Vissing-Jorgensen, 2011), while other studies find larger impacts through channels such as refinancing (Di Maggio et al., 2020). This disagreement is particularly salient in the context of the marked inflation in housing and consumer goods markets that occurred during the pandemic period. Substantial uncertainty persists over the relative contributions of supply (Bernanke and Blanchard, 2025) and demand-side factors, complicating our ability to assess the effects of the Fed's purchases on macroeconomic stability.

This paper estimates substantial pass-through of Federal Reserve mortgage security purchases on mortgage rates faced by borrowers, on house prices for affected consumers, and ultimately on aggregate house prices and consumer goods inflation. To do so, we make use of the segmentation of mortgage markets, and the fact that Federal Reserve purchases affect only mortgages below the national conforming loan threshold, which are eligible for inclusion in To-be-Announced (TBA) mortgage pools exclusively purchased by the Federal Reserve. This market segmentation means that regions are subject to different cross-sectional exposure to QE4 as a product of their local mortgage segment share and time-series variation in relative mortgage spreads. This instrument addresses the fundamental endogeneity of interest rates—that observed mortgage rates move with local economic conditions—and the challenge that aggregate interest rates in integrated capital markets are homogeneous in the time series. Specifically, we exploit the segmentation of mortgage markets and their differential exposure to QE purchases to generate a shift-share style instrument. Using this instrument we establish several key facts on the causal impacts of Fed purchases on local economic activity in housing and labor markets.

First, we find strong evidence for local increases in mortgage origination as a product of exposure to lower rates. This suggests QE4 operated as a substantial positive credit supply shock to affected geographies. Second, we find these effects passed through to housing markets in the form of higher house prices, with more ambiguous impacts on rents. Third, we find evidence for broader channels of aggregate demand in the form of lower unemployment rates in QE-targeted areas. Finally, we find that the spatially targeted nature of QE also has implications for the geography of economic activity, shifting migration flows to areas where credit conditions loosened. This migration response suggests that unconventional monetary policy can have implications for spatial allocation as well as aggregate spending.

To account for the aggregate consequences of QE, including migration, as well as to analyze the impacts on consumer goods prices, we turn next to a dynamic spatial equilibrium life-cycle model. The novelty of our model is to jointly endogenize the dynamic paths of local house prices, rents, non-tradable, and tradable goods. Consistent with our empirical findings, housing markets are segmented within and across two geographic areas. There are two central innovations in the model. The first is to account for the connection between goods and housing markets, which is central to establishing the spillover effects of housing policies. The second is to introduce optimal refinancing decisions by households, in order to capture cash flow extraction channels of monetary policy. The resulting model matches key moments for housing markets, migration flows, as well as cross-sectional and time-series moments relating to the distributions of household income and wealth.

We use the resulting calibrated model to analyze a set of counterfactuals on the role of unconventional monetary policy over this period. We focus on the economy's response to transient declines in interest rates, examining both the role of unconventional policy in isolation (lowering mortgage rates between 70 basis points to 100 basis points for loans at different segments), and a counterfactual experiment which captures conventional monetary policy through a decline in the risk-free rate.

The model successfully matches key features of our quasi-experimental results: house prices increase substantially across geographic areas, while rental dynamics are more nuanced. In the cross-section, the model estimates a 12.5% local increase in house prices in response to a 100 bps decrease in interest rates in the conforming segment, which closely matches our quasi-experimental causal estimate of 11.9%. This tight out-of-sample match lends additional credence to the quantitative spatial model. This fit allows us to go further and calculate the general equilibrium impacts of interest rate reductions, incorporating additional margins of adjustment (i.e. addressing the "missing intercept" problem).

We find that QE led to persistent increases in tradable and non-tradable goods across geographic areas. Our results therefore provide evidence that QE had a considerable impact on inflation in both housing and consumer goods markets. This suggests that some of the substantial increase in price levels in these markets was policy induced.

Three key economic mechanisms for the housing market transmission of monetary policy underlie our results. First, homeowners experience considerable cash windfalls by taking mortgages at lower rates. These windfalls persist whether households access lower rates by refinancing or migrate to areas experiencing credit supply shocks. This leads to higher goods prices. Because interest rates are locked-in by such households, they are reluctant to subsequently move, generating lock-in effects which result in elevated pressure for both house prices and consumer goods.

Second, however, higher house prices ultimately dampen the inflationary impacts of monetary policy

on goods markets via an affordability channel. This generates a crunch in the market to purchase a home, as households must save more to accommodate down payment requirements. Finally, we show that the resulting inflationary pressures on consumer goods markets transmit across regions in several ways. The price of tradable goods is bid up by areas more-affected by the monetary policy shock, which in turn raises consumer prices in less-affected areas. Furthermore, migration spreads shocks across regions. These results therefore highlight the propagation mechanism of QE purchases over the post-pandemic period: initially showing up as large increases in house prices and consumer goods, persisting as higher levels of house prices and consumer goods amid affordability challenges, and transmitting across regions.

We find that the price adjustments from QE are essential to the welfare analysis of the program. Holding house prices fixed, QE leads to an improvement in welfare on average (with small losses only for some homeowners in the high-cost area). However, when prices are allowed to adjust, we estimate that welfare actually *declines* for the eight-year period following QE's introduction. While QE was an initial windfall for owners, who were able to refinance into long-term mortgages, the resulting lock-in effect from these borrowers keeps housing at an elevated price level. At the same time, the households which benefit see windfalls in their wealth position and income savings which push up consumer goods prices. This puts new buyers in an affordability crunch even after interest rates reset: it is harder for them to accumulate down payments for housing purchases given the higher cost of goods, and they face far higher housing prices relative to interest rates. In aggregate, the resulting affordability crunch dominates and results in lower aggregate welfare.

Our results contribute to important ongoing debates about the effectiveness and importance of unconventional tools of monetary policy. Our results suggest that QE policies can have broadly stimulative effects on the economy though housing demand, housing wealth, and cash flow channels. This effect, however, can also contribute to excess inflation when conducted in high-demand periods, and thereby exacerbate concerns about housing affordability and wealth inequality. Our results also point to differing spatial consequences of QE when implemented through targeted purchases of specific mortgage channels. These findings suggest, therefore, important tradeoffs between the objectives of aggregate demand and price stability.

Related literature. Our paper relates to three strands of the literature. The most closely related papers examine the transmission mechanisms of unconventional monetary policy (Krishnamurthy and Vissing-Jorgensen, 2011; Fuster et al., 2024; D'Amico and King, 2013; Abramson et al., 2025; Fang and Xiao, 2025). Several papers examine the most recent QE4 episode (Fuster et al., 2021; Drechsler et al., 2024; Diamond et al., 2022; Nakamura et al., 2025). We differ by focusing on transmission mechanisms between interest rates, house prices, and consumer goods across areas through both quasi-experimental evidence and a structural

spatial model that is closely mapped to the data. Other papers focus on non-policy drivers of house prices and consumer inflation in this period, such as remote work (Mondragon and Wieland, 2022), pandemic shocks (Guerrieri et al., 2022; Stock and Watson, 2025), and supply shocks more broadly (Bernanke and Blanchard, 2025; Shapiro et al., 2022). While we do not estimate the role of supply shocks specifically, we emphasize the role for a well-identified demand shock through policy easing decisions.

We also relate to a literature on household responses to changes in interest rates and house prices, especially in the presence of leverage (Di Maggio et al., 2017; Beraja et al., 2019a; Campbell and Cocco, 2007; Stroebel and Vavra, 2019; Mian et al., 2013; Cloyne et al., 2020; Foulis et al., 2026). We focus on unconventional monetary policy shocks to generate local variation in credit supply shock exposure, using an empirical strategy that builds on the cross-segment price impacts identified by (Adelino et al., 2025). Our work extends the rich literature that studies the effect of inflation on mortgage markets (Campbell and Cocco (2003), Garriga et al. (2017), Guren et al. (2021)) and how they interact with monetary policy transmission (Greenwald (2018), Hedlund et al. (2025)). Our results highlight the reverse link from mortgage credit shocks to inflation, which has not been yet studied, and we analyze the feedback loop between mortgage rates and inflation that is key to understanding and accurately measuring the transmission of monetary policy. We incorporate the endogenous response of goods prices to interest rate shocks in a housing market model, and thus we add to existing work that studies the effect of house prices on consumption and focuses on the valuation channel (Berger et al. (2018), Garriga and Hedlund (2020)). Our equilibrium setting allows us to decompose the various channels through which mortgage rates affect the demand for housing and goods, hence inflation, and to accurately measure their welfare effects on households. We also emphasize moving as an important margin of household response to local credit supply shocks. Fonseca et al. (2025) use a related framework to study the dynamic equilibrium effect of mortgage lock-in on housing markets. We study the effect of unconventional monetary policy and consider segmented mortgage markets, goods markets, and optimal refinancing, which add both substantial complexity to the model solution and richness to the analysis.

Finally, our dynamic spatial equilibrium model of mortgage market spillovers to the cross section of housing and goods markets connects to a broader literature in urban and spatial economics on understanding shocks in spatial equilibrium to prices, labor markets, and mobility (Notowidigdo, 2011; Diamond, 2016; Ganong and Shoag, 2017; Moretti, 2010; Hurst et al., 2016; Guerrieri et al., 2013; Beraja et al., 2019b; Kennan and Walker, 2011a). We contribute by showing how place-based credit supply shocks propagate through house prices and rents, tradable and non-tradable prices, local labor markets, and migration and reallocation across geographies in a spatial equilibrium framework, which is numerically challenging given the size of the resulting state space. Our setting is therefore, to the best of our knowledge, the first to explicitly con-

nect a spatial macro-finance model with the rich empirical literature that has documented the pass-through of mortgage shocks into nominal and real outcomes in the cross section of U.S. regions (e.g., Mian and Sufi (2011), Mian et al. (2013), Mian and Sufi (2014), Di Maggio et al. (2017)).

2 Quantitative Easing and Mortgage Rates

2.1 Background on Quantitative Easing

Large-scale security purchases have been increasingly used by central banks around the world since the global financial crisis of 2008. In comparison to conventional monetary policy, QE interventions typically differ in two key respects. First, they target financial assets with longer duration or credit spreads relative to safe short-term instruments like the Federal Funds rate, which have frequently hit a zero lower bound over this time period. Second, while conventional monetary purchases typically target a desired range of interest rates, committing to asset transactions as necessary to hit that target, QE programs generally entail a prespecified quantity of purchases of different securities.

Figure 1 shows flows (Panel A) of Federal Reserve purchases of MBS from 2013 as well as the stock of purchases (Panel B). QE1 (in 2008) and QE3 (in 2012) entailed large purchases of MBS securities, purchased through open market commitments in the TBA market for Agency MBS. Both rounds were motivated by the objective of further economic stimulus in the context of weakness in the housing market surrounding the global financial crisis, and traditional monetary policy hitting the zero lower bound. As a consequence, roughly 20% of the entire stock of Agency securities were held by the Federal Reserve for the seven year period prior to the pandemic.

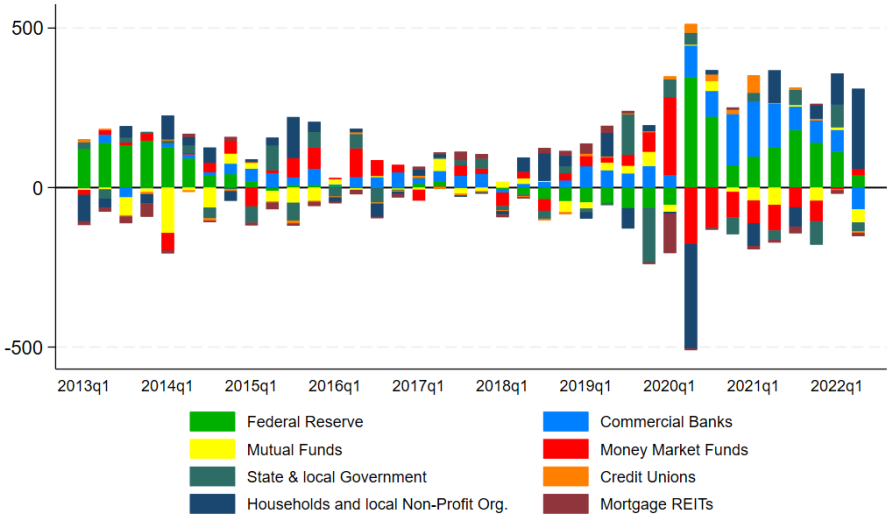
The fourth round of QE, conducted over the pandemic has proved to be substantially larger in scope than prior rounds. The Federal Reserve purchased a meaningful part of the entire stock of new mortgage issuance over this period, ultimately holding almost 40% of the stock of all Agency MBS. Some Ginnie Mae Mortgages were also purchased as a part of QE4

Federal Reserve intervention in this period was motivated by extreme dysfunction in mortgage markets in March 2020, related to the "dash-for-cash" and strong preferences for liquidity. Federal Reserve interventions in MBS markets, as in Treasury markets, therefore had the objective of stabilizing financial conditions in the face of extreme pandemic shocks.

However, these purchases continued well after the introduction of COVID-19 vaccines and broader economic normalization, even as house prices and inflation continued to rise. The national Case-Shiller index grew 12% in 2020, and rose a further 15% in 2021, while the national CPI rose by 7% in 2021 as QE operations

continued, stopping only in March of 2022.

(A) FEDERAL RESERVE'S MONTHLY AGENCY MBS PURCHASE FLOWS (B.)



(B) STOCK OF AGENCY MBS BY MAJOR STAKEHOLDER

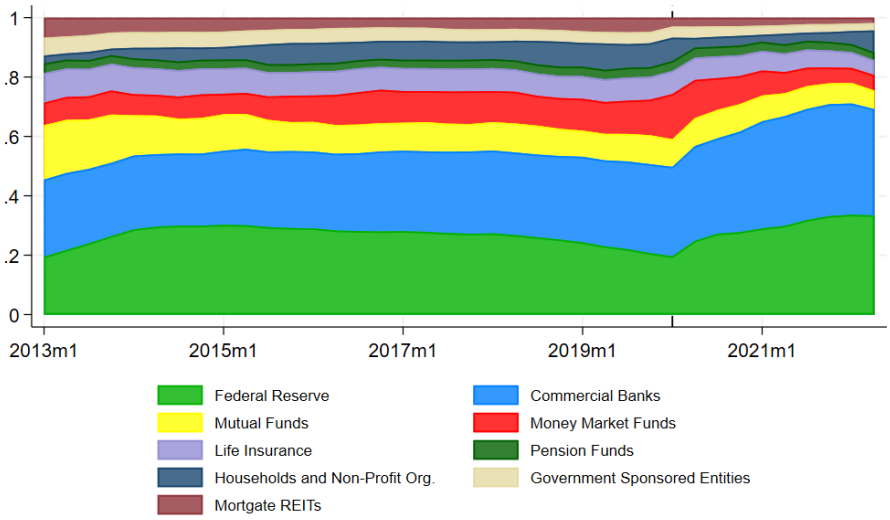


FIGURE 1: EXPANSION OF AGENCY MBS HELD BY FEDERAL RESERVE

These asset purchases also coincided with substantial increases in MBS held by commercial banks (shown in blue in Figure 1). Over this period, consumer deposits grew substantially, driven by "excess savings" resulting from reductions in spending, particularly in services, as well as additional fiscal transfers (stimulus checks, PPP receipts, unemployment insurance, child tax credits), and potentially also monetary policy stimulus as well. Banks appear to have lent a fraction of these deposits in mortgage markets, potentially across both jumbo mortgages (typically held on their balance sheets) as well as the Agency MBS holdings plotted here. The role of other financial intermediaries in contributing to additional mortgage lending may have also contributed to lower mortgage rates in this period across multiple different segments (Fang and Xiao, 2025; Drechsler et al., 2024). For both the Federal Reserve and commercial banks, holdings of these MBS products suffered large valuation shocks in the subsequent period of quantitative tightening, as interest rates rose substantially resulting in large notional losses on the value of MBS holdings (Jiang et al., 2024).

2.2 Impact of Quantitative Easing on Interest Rates

To assess the impact of Federal Reserve purchases, Figure 2 highlights changes in different mortgage interest rates over the QE4 period. Mortgage rates can be decomposed into three underlying components: a risk-free benchmark rate (conventionally the 10-year Treasury, but with a reference duration that can change over time), a secondary spread which expresses the additional risk premium borne by MBS investors, and a primary-secondary spread which captures the markup retained by mortgage originators (to cover both costs of origination as well as profits). The secondary spread, in turn, can be decomposed into an option cost (which encompasses the value of the prepayment option as calculated through Monte Carlo simulations) as well as an option-adjusted spread which reflects the additional risk compensation for holding MBS, and can be seen as compensation for prepayment model risk and other systematic risk components of MBS investments.

Panel A of Figure 2 shows the evolution of the OAS over time. As Federal Reserve interventions took hold in the market, OAS went down, consistent with past periods of QE in which these spreads also declined (Boyarchenko et al., 2019). Because OAS are computed by comparing current MBS prices against projections of future expected cashflow payments under prepayment expectations, Fed purchases which push up bond prices can result in decreases in option-adjusted spreads.

However, these interventions need not translate directly to reductions in mortgage rates faced by borrowers. A key friction in this passthrough is the primary-secondary rate, and Panel A also shows how this spread spiked substantially in the early period of the pandemic close to 200 basis points. This increase may partially reflect unmeasured costs borne by mortgage originators in this unusual time period, but likely also

reflects excess profits retained by mortgage originators in a context in which demand for mortgage product has increased substantially.

Consistent with this interpretation, primary-secondary spreads declined over 2020 as employment in the mortgage industry grew, suggesting that supply-side constraints in mortgage origination act as an important friction in the passthrough of monetary policy to relevant mortgage rates. As mortgage capacity slowly expanded over this sample, the primary-secondary spread started to normalize.

The combination of the low OAS and low primary-secondary spread translates to a lower mortgage rate experienced by borrowers, shown in Panel B as the conforming mortgage. This figure contrasts mortgage rates for loans affected by Fed purchases (conforming mortgage rates) against jumbo mortgages for loans larger than the conforming loan limit, which were not eligible for Fed purchases.

The spread between these two rates is plotted directly in Panel C, as the jumbo-conforming spread, relative to the benchmark policy rate (the Federal Funds Rate). While the historical spread is around 10 basis points (i.e., jumbo rates are typically 10 basis points lower than conforming rates), this period saw an unusual reversal in this trend, with conforming rates reaching as much as 30 basis points lower than jumbo rates in periods of 2020. These spreads reversed in the period of Quantitative Tightening as the federal Reserve began to tighten policy in 2022 as inflation rose.

Conforming-jumbo spreads therefore show enormous variation in this period, with conforming rates falling by 20–40 basis points in the period of QE relative to jumbo rates, before reversing and falling an additional 80 basis points relative to jumbo rates as policy tightened. We exploit this time-series variation and reversals in mortgage spreads across different segments in our quasi-experimental setting.

2.3 Threshold Evidence of QE Impact

We first show motivational evidence that the targeted impact of QE across different segments had meaningful impacts on borrower decisions. To begin with, we show graphical evidence of the impact of QE programs by leveraging discontinuities around conforming loan limits. As mentioned earlier, Federal Reserve purchases in QE target loans under the national conforming loan cutoff, which are therefore eligible for TBA trades. Consequently, loans at or below the conforming cutoff are eligible for conforming loan rates. Loans above the cutoff may still qualify for securitization through Fannie and Freddie loan programs (if they are in certain high-cost counties), or they are subject to jumbo loan pricing with loans typically held on balance sheet by banks.

We therefore examine, in Panel A of Figure 3, the change in house prices for properties purchased by loans around the national conforming loan cutoff in 2020, the year of QE4 program inception. To capture

house prices, we use property-level Deeds data from Infutor and focus on repeat-sale transactions: properties which sell once prior to the year in question, and then sell again at some point in 2020 itself. We adjust for house price appreciation from the origination month using a Zillow ZIP-level house price measure through December 2019, and then plot the resulting change in house price at the time of transaction compared to that benchmark value. We plot a binscatter of the resulting property-level house price changes around the national conforming cutoff. This specification builds on past evidence at loan cutoff boundaries (Adelino et al., 2025; DeFusco et al., 2020; DeFusco and Paciorek, 2017) but focuses on the resulting impact on the house prices of affected properties around conforming cutoff rates during a time when such spreads were high due to QE.

We observe a striking discontinuity in realized house price growth—properties just to the left of the conforming cutoff, which are eligible for a 20–40 basis point reduction in interest rates over this period, see substantially elevated house price growth, over 30%, compared to the properties just to the right of the cutoff, which also see rising house prices but at a rate closer to 25%. The graph suggests a strong discontinuity right around the cutoff, consistent with the idea that access to cheaper mortgage credit increases house prices. In Panel A, Appendix Table A1 we confirm the visual evidence in a regression framework in bands around the threshold controlling for month and zipcode fixed effects, and also show the effects are driven by periods in which QE purchases are high (Panel B).

One important consideration in these results is the possibility of endogenous choices by borrowers. Because the running variable in the discontinuity is loan size, borrowers can potentially take smaller loans to bunch underneath the conforming loan cutoff. This can be achieved by purchasing a cheaper house, holding the loan-to-value ratio the same, or by putting more money down. Therefore, the results should be seen as well-identified evidence that borrowers do indeed respond to lower interest rates and purchase prices—with the aggregate impact depending on the extent to which such purchases represent substitutions away from other foregone purchases.

One way to potentially alleviate this concern is to use a running variable in the discontinuity analysis which is not subject to as much manipulation by borrowers—the house price itself. To substitute for the discontinuity at the conforming loan cutoff, we use instead $1.25\times$ the conforming loan cutoff, which corresponds to the size of property that can be purchased by a borrower who takes a typical 80 percent LTV mortgage at precisely the conforming loan limit. To the extent that borrowers are bunching at the conforming loan cutoff and have relatively static LTV choices, we might expect to see comparable discontinuity evidence at this alternate choice of threshold in the dimension of house prices.

We plot house price growth around this alternate threshold in Panel B of Figure 3, and find again that house price growth appears higher just below this cutoff, compared to properties just above it. This result

is striking because borrowers need not stick to the 80 percent LTV requirement, and to the extent they pick an alternate leverage ratio, we would expect this specification corresponds to a fuzzy discontinuty. Despite some imprecision in this measurement, we still find a substantial difference in house prices for houses which are treated by QE relative to houses which are less likely to be treated. We also examine this relationship in regression form in Appendix Table A2, where we show that the effects are driven by QE purchases.

The key takeaway from this set of analyses is that differences in interest rates around the conforming loan threshold, which we have previously linked to QE policies, appear to relate to housing demand and prices at the individual property level.

3 Aggregate Impacts of QE

Having established that QE4 led to segmented impacts on mortgage markets, and these shifts appear to alter individual behavior at precise thresholds, in this section we turn to a more aggregate analysis of the effects. We directly exploit the segmentation of mortgage markets in order to develop a cross-sectional instrument which uses shift-share style variation in the form of lagged mortgage segment shares combined with time-series variation in interest rates for different segments. We show that this synthetic rate instrument predicts realized mortgage rates, resulting in a local credit supply shock, and through this channel appears to impact housing and labor markets and local levels.

3.1 Synthetic Rate Instrument

To isolate the role of unconventional monetary policy shocks over this period, we construct a local "synthetic mortgage rate" instrument by interacting national mortgage rate shifts by market segment with predetermined local exposure to each segment. Our benchmark measure for locality z is at the ZIP level, but we also consider aggregations at the level of census tract and county. The three mortgage segments we consider are (1) Federal Housing Administration (FHA) mortgages, which can be originated up to a county-specific FHA mortgage limit, which we proxy for using originations into Ginnie Mae pools,[1] (2) jumbo mortgages, and (3) conforming mortgages (which we measure as conforming mortgages not originated through Ginnie Mae). We compute each zipcode's 2018 share of origination through each of these channels k as $s^k_{z,2018}$ from that year's HMDA data. We then connect in annual national rate indices for FHA, jumbo, and conforming segments to form a synthetic ZIP-level rate as a weighted average of these three indices, where the weights are given by the ZIP's 2018 shares:

[1]This measure also captures VA lending, and loans originated into the Office of Public and Indian Housing and the Department of Agriculture's Rural Development.

$$\text{synthetic rate}_{zt} = s^{J}_{z,2018} r^{J}_{t} + s^{C}_{z,2018} r^{C}_{t} + s^{FHA}_{z,2018} r^{FHA}_{t}. \tag{1}$$

Because the exposure shares are fixed in 2018, the variation in this measure comes from local differential exposure to time variation in segment-specific mortgage rates. We use monthly variation in mortgage segment rates to generate the instrument, and take the annual average to connect to other datasets.

3.2 Empirical Specifications

First Stage. We first estimate the passthrough of a ZIP code's synthetic rate against realized mortgage interest rates in that year in a first-stage specification:

$$\text{interest rate}_{zt} = \beta_1 \cdot \text{synthetic rate}_{zt} + \alpha_z + \delta_t + (\gamma_{c(z)t}) + \varepsilon_{zt} \tag{2}$$

with controls for ZIP code and year. Mortgage interest rates are measured in HMDA over the period 2019–2023, after the period in 2018 when the shares defining the synthetic rate instrument are set. Other controls include ZIP and year effects. Some specifications also include county $\times$ year fixed effects. The key coefficient of interest is β_1, which captures the passthrough of local synthetic rates on local mortgages. If this coefficient is one, higher predicted mortgage rates based on segment exposure would raise local mortgage rates 1:1. There are several reasons why we might expect lower passthrough. First, the annual measurement of the variables results in some attenuation bias, to the extent that realized mortgage origination varies across months in the year. Second, realized segment shares will vary over time from their fixed values in 2018. Third, local mortgage spreads (relating to credit spreads, origination fees, etc.) may vary.

Reduced Form. We then use the instrument in a reduced form test directly regressing the synthetic rate against other local outcomes:

$$y_{zt} = \beta_2 \cdot \text{synthetic rate}_{zt} + \alpha_z + \delta_t + (\gamma_{c(z)t}) + u_{zt} \tag{3}$$

in which outcomes y include local mortgage origination, housing market outcomes such as house prices and rents, and labor market outcomes of unemployment. This reduced form directly tests whether local exposure to mortgage segment rate variation translates to changes in local economic outcomes, controlling for time invariant characteristics in local conditions, aggregate time variation, as well as regional time-varying shocks in the form of county-by-year fixed effects in some specifications.

Instrumental Variables. Our primary specification further makes the assumption that the effect of local exposure to synthetic rates comes through local mortgage rates, enabling an instrumental variables specification:

$$y_{zt} = \beta_3 \cdot \widehat{\text{interest rate}}_{zt} + \alpha_z + \delta_t + (\gamma_{c(z)t}) + \nu_{zt} \tag{4}$$

in which interest rates are instrumented for by synthetic rates as in the first-stage specification. Under standard maintained assumptions (including relevance, exclusion, and monotonicity), this specification identifies the causal effect of segment-specific national rate moves on local outcomes.

3.3 First Stage

In Table 1 we show the results of the first stage specification in equation 2 across different levels of aggregation. We find substantial passthroughs in this specification, ranging from 0.33–0.69, depending on the level of aggregation. At the high end of the scale is our estimate for passthrough at the ZIP level when we control for county × year fixed effects. In subsequent specifications, we also report the F-statistic from this first stage.

TABLE 1: FIRST-STAGE: EFFECT OF SYNTHETIC RATE INSTRUMENT ON MORTGAGE RATES

	(1)	(2)	(3)	(4)	(5)	(6)
Synthetic Rate Instrument	0.327***	0.547***	0.339***	0.687***	0.525***	0.417***
	(0.016)	(0.116)	(0.028)	(0.136)	(0.114)	(0.136)
Unit of Observation	Tract	Tract	ZIP	ZIP	County	MSA
N	324,288	322,861	96,414	93,272	15,607	4,522
Year FE	✓		✓		✓	✓
Tract FE	✓	✓				
County × Year FE		✓		✓		
ZIP FE			✓	✓		
County FE					✓	
MSA FE						✓

3.4 Housing Market Outcomes

We next connect the synthetic rate instrument to housing market outcomes. In Table 2 we first show the impact of local exposure to interest rates on mortgage demand of local loan originations (purchase loans only). Columns (1)–(2) show the reduced form specification of equation 3, and columns (3)–(4) show equation 4. Panel A of this table focuses on total loans, and Panel B shows the log of loan originations (i.e., a semi-elasticity).

We find that a 100 bps change in interest rate exposure associates with a 14-46 change in the number of

TABLE 2: MORTGAGE DEMAND

Panel A: Total Loans

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate Instrument	-23.3***	-3.89		
	(1.15)	(3.47)		
Instrumented Interest Rate			-46.3***	-14.2***
			(2.79)	(3.42)
Unit of Observation	Tract	Tract	Tract	Tract
N	356,486	355,296	324,288	322,861
First Stage F-Stat			437	22
Year FE	✓		✓	
Tract FE	✓	✓	✓	✓
County × Year FE		✓		✓

Panel B: Log Loans

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate Instrument	-.364***	-.108*		
	(.0157)	(.0627)		
Instrumented Interest Rate			-1.01***	-.189**
			(.0631)	(.0805)
Unit of Observation	Tract	Tract	Tract	Tract
N	331,574	330,210	324,288	322,861
First Stage F-Stat			437	22
Year FE	✓		✓	
Tract FE	✓	✓	✓	✓
County × Year FE		✓		✓

loans at the Census tract level, or a semi-elasticity of -0.189 in the specification including county-by-year fixed effects. We have a substantial first stage F-statistic of 437 in the census tract specification, and 22 in the version including state-by-year fixed effects.

These results suggest that local mortgage demand is sensitive to financing conditions in this sample period, and thus that QE-related movements in mortgage rates plausibly generated meaningful responses in quantities and loan demand. This result therefore demonstrates the economic relevance of our instrument in that the statistically and quantitatively important first stage translates into materially different mortgage origination outcomes across region. In turn, this helps rule out alternative narratives of increases in mortgage volume in this period (i.e., alternative demand-side narratives relating to amenities or other supply shocks) in showing how a pure credit supply shock instrument generates changes in local mortgage demand.

We next connect our interest rate shock to housing market values—house prices (Panel A) and monthly rents (Panel B) in Table 3. We show the log of prices and rents, so again the results can be interpreted as a semi-elasticity with both reduced-form and instrumental variables specifications. We observe substantial impacts on house prices, from a 14.7%–22% increase in house prices resulting from a 100 bps drop in rates, depending on the inclusion of state-by-year fixed effects. The impact on rents is more sensitive to controls, and ranges from a 6.1% increase in monthly rents to a statistically insignificant drop.

TABLE 3: HOUSING MARKET VALUES

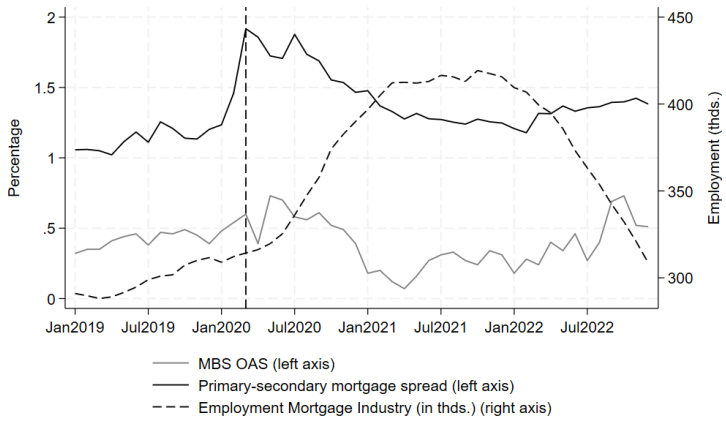
Panel A: House Prices

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate Instrument	-.0727***	-.119***		
	(.0169)	(.0152)		
Instrumented Interest Rate			-.25***	-.159***
			(.0266)	(.0263)
Unit of Observation	ZIP	ZIP	ZIP	ZIP
N	91,683	88,696	89,773	86,693
First Stage F-Stat			144	26
Year FE	✓		✓	
ZIP FE	✓	✓	✓	✓
County × Year FE		✓		✓

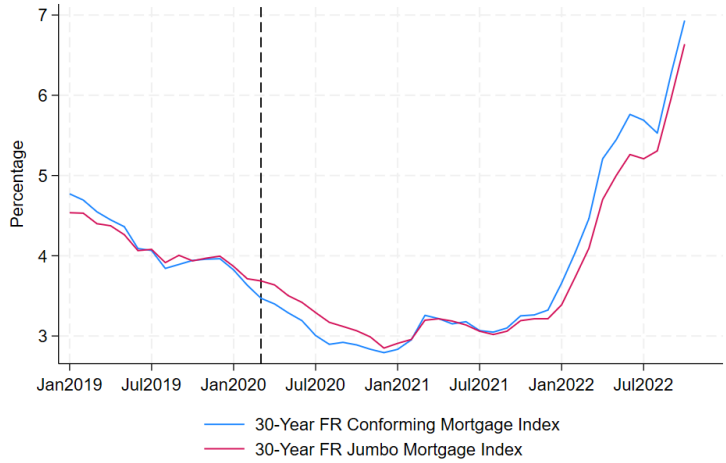
Panel B: Rents

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate Instrument	.0223	-.064***		
	(.0167)	(.0157)		
Instrumented Interest Rate			.0225	-.063***
			(.0151)	(.00852)
Unit of Observation	ZIP	ZIP	ZIP	ZIP
N	11,188	10,623	10,852	10,284
First Stage F-Stat			50	169
Year FE	✓		✓	
Tract FE	✓	✓	✓	✓
County × Year FE		✓		✓

(A) PANEL A: CONFORMING TO JUMBO SPREAD SINCE 2019



(B) PANEL B: MORTGAGE INTEREST RATES SINCE 2019



(C) PANEL C: MORTGAGE SPREADS SINCE 2019

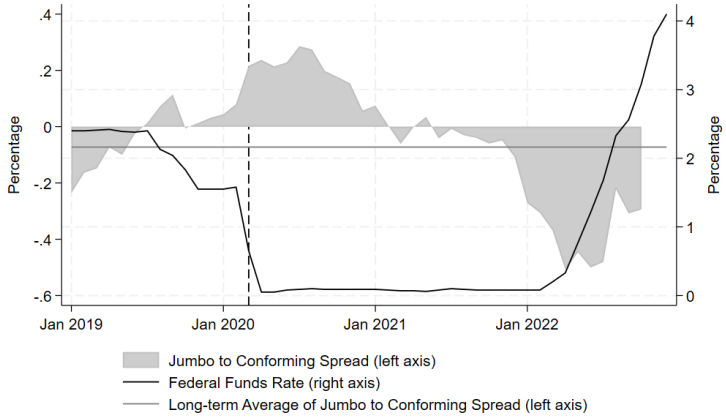
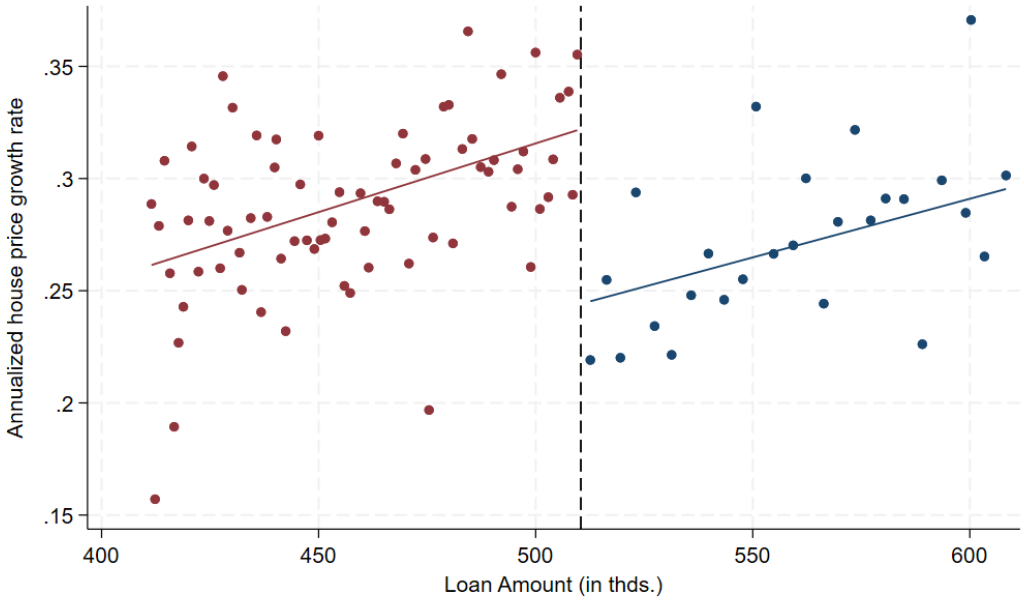


FIGURE 2: MORTGAGE INTEREST RATES OVER TIME

(A) HOUSE PRICE GROWTH AROUND CONFORMING LOAN THRESHOLD (2020)



(B) HOUSE PRICE GROWTH AROUND 1.25× CONFORMING LOAN THRESHOLD (2020)

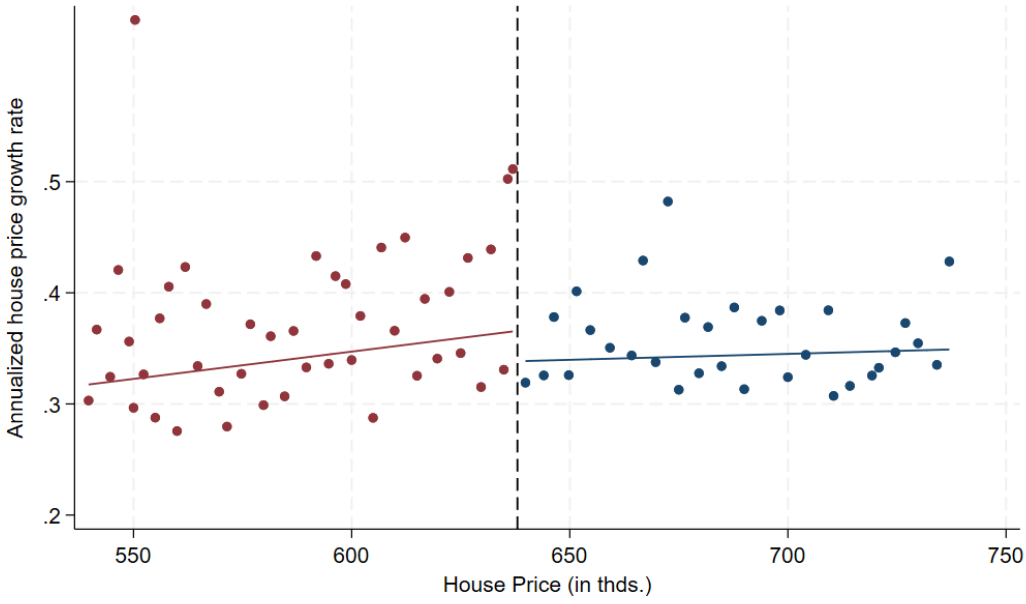


FIGURE 3: HOUSE PRICE GROWTH AROUND CONFORMING THRESHOLDS (2020)

To better benchmark the effects on housing prices, we consider a back-of-the envelope calculation from a standard user cost model. If P is the house price and R is the annual rent, then define the user cost as

$$uc \equiv r + \tau + \delta + m + \mathbf{E}[(P_{t+1} - P_t)/P_t]$$

where r is the interest rate (net of tax interest deductions), τ is the property tax rate, δ is depreciation, m is maintenance, and we account for expected appreciation. The user cost model implies an equilibrium relationship between the per period cost of buying and renting (implicitly assuming full leverage and an interest-only mortgage):

$$R = uc \cdot P \quad \Rightarrow P = \frac{R}{uc}.$$

Holding for the moment R and the non-interest rate components of uc fixed, we have:

$$\frac{\partial \log P}{\partial r} = -\frac{1}{uc}$$

which highlights the convexity in the interest rate-to-price relationship: when the level of interest rates was already low, further declines in rates should have non-linearly higher effects. To quantify the magnitude, consider a baseline in which $r = 4\%$ and the non-rate components of uc sum to 3%. Then a 100 bps decline in rates ($\Delta r = -1\%$) reduces the user cost from 8% to 7%, and implies

$$\frac{\Delta P}{P} \approx \frac{-\Delta uc}{uc} = \frac{1\%}{7\%} = 14.3\%.$$

If instead the non-rate components sum to 5%, we would expect a price increase of 11.1%. Therefore, a roughly 10–15% price increase is expected from an interest rate shift of 100 basis points. Our observed price shifts are broadly in this range. This can be potentially explained by at least two additional factors. First, rents also potentially adjust upwards as a result of higher housing demand, though the magnitude of this effect varies depending on our controls. Second, the cross-sectional nature of this estimate potentially results in offsetting or amplifying migration trends. We explore both channels further in our structural model. Potentially, other aspects of the framework—such as expected housing appreciation, property taxes, and so forth—could also shift.[2]

Taken together, these results imply substantial impacts of QE4 on housing markets in terms of both mortgage demand and the value of residential properties. These effects have the potential to impact local

[2]For instance, lags in the assessment process for residential homes would imply that incremental property value increases might receive more favorable property tax treatment, which would imply a higher valuation increase relative to our benchmark which assumes a proportionate property tax levy.

aggregate demand through a variety of channels—including flow cash flow effects (through lower mortgage rates), upfront cash flow effects (through cash-out-refinancings), and housing wealth effects.

3.5 Labor Market Outcomes

We next explore whether these housing and mortgage market channels impact local aggregate demand. There are several challenges in measuring consumer goods channels, including general equilibrium effects which spill over to the pricing of consumer products across markets. Therefore, we defer a discussion of these broader aggregate price effects to the structural model. Instead, we focus on impacts on local labor markets through employment and migration margins, which result in more geographically segmented effects that we can directly measure.

Table 4 shows a county-level version of our results in which interest rates are regressed on local unemployment rates. We find evidence for a very local Philips Curve, along the lines of Hazell et al. (2022), but at a more granular level. Quantitatively, a 100 bps increase in local mortgage rates increases local unemployment by 1–4 percentage points, when we include state-by-year fixed effects. These results suggest that mortgage market easing has large effects on local aggregate demand and transmits to local labor market slack.

TABLE 4: LABOR MARKET UNEMPLOYMENT

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate Instrument	5.06***	1.21***		
	(.447)	(.332)		
Instrumented Interest Rate			12.8***	4.45**
			(3.42)	(2.21)
Unit of Observation	County	County	County	County
N	15,846	15,841	15,481	15,477
First Stage F-Stat			14	5
Year FE	✓		✓	
County FE	✓	✓	✓	✓
State × Year FE		✓		✓

Table 5 links local credit conditions to migration. The emergence of spatial variation in interest rates in this period has implications for the sorting of households, as migration may enable access to cheaper borrowing rates. We estimate migration using the IRS migration files, over a slightly smaller period (2019–2022) than our main sample. We find that a 100 bps increase in interest rates is associated with about a 2–3 percentage point change in local net migration, which is primarily accounted for by shifts in out-migration rates. The change in local adjusted gross income is slightly higher than this estimate, suggesting that higher-

income earners are more responsive to interest rate opportunities.

TABLE 5: MIGRATION

Panel A: Filers (Households)

	(1) Net Migration (%)	(2) Net Migration	(3) Net AGI	(4) In Migration	(5) Out Migration
Instrumented Interest Rate	-.0234***	-.0201**	-.0573***	-.00763	.0158***
	(.00841)	(.00879)	(.0137)	(.00547)	(.00383)
Unit of Observation	County	County	County	County	County
N	9,057	9,055	8,949	9,057	9,057
First Stage F-Stat	27	43	27	27	27
Year FE	✓		✓	✓	✓
County FE	✓	✓	✓	✓	✓
State × Year FE		✓			

Panel B: Individuals

	(1) Net Migration (%)	(2) Net Migration	(3) Net AGI	(4) In Migration	(5) Out Migration
Instrumented Interest Rate	-.0263***	-.0216***	-.0577***	-.00346	.0229***
	(.00749)	(.00741)	(.0139)	(.0043)	(.00463)
Unit of Observation	County	County	County	County	County
N	9,057	9,055	8,949	9,057	9,057
First Stage F-Stat	27	43	28	27	27
Year FE	✓		✓	✓	✓
County FE	✓	✓	✓	✓	✓
State × Year FE		✓			

Taken together, these quasi-experimental results suggest that QE-induced movements in mortgage financing conditions impact local experienced borrower rates, and propagate into local economic activity. They do so in mortgage markets by impacting local mortgage quantities and the prices of houses, as well as in labor markets by shifting local employment and migration patterns. These reduced-form patterns motivate the general equilibrium analysis that follows. Because house prices, rents, migration, and demand for consumer goods are all jointly determined, the ultimate impact of QE on inflation and welfare depends on carefully modeling the impact of both household demand and local supply in determining equilibrium outcomes.

4 Dynamic Spatial Equilibrium Model

To evaluate the general and spatial equilibrium effects of QE on housing and goods prices, this section describes a dynamic spatial equilibrium life-cycle model with incomplete markets and optimal refinancing.

House prices, rents, non-tradable and tradable goods prices are endogenous. The economy consists of a cross-section of housing markets populated by overlapping generations of heterogeneous households. There are two types of geographic area, corresponding to low- and high-cost, or opportunity, locations. Within each area, households can either rent or choose one from two owner-occupied housing sizes, either small (starter) or large (trade-up) homes.

There are two types of markets. First, owner-occupied and rental housing markets are segmented by geographic area. House prices and rents in each area endogenously adjust for the local housing demand to equate the local housing supply. Non-tradable goods markets are also segmented by area. Non-tradable goods prices in each area endogenously adjust for the local demand to equate the local supply. Second, in contrast with the former, the market for tradable goods is integrated nationwide. There is a single price for tradable goods, which endogenously adjusts for the total demand across areas to equate the total supply. Overall, this results in a total of seven prices. In spatial equilibrium, the entire vector of housing and goods prices and the spatial allocation of households across areas are jointly determined.

On the mortgage market, home buyers can borrow via realistic long-term amortizable fixed-rate loans. The mortgage rate that borrowers lock in at origination depends on the size of their loans: when their loan size is lower than a fixed threshold, they face the current conforming mortgage rate, and otherwise the current jumbo rate. Borrowers can keep their initial fixed mortgage rate as long as they stay in the same house and do not refinance. If they move, they must repay their mortgage and face a new mortgage rate if they borrow to buy another house, which depends on the new size of their loan and the new conforming and jumbo rates at that date. If they stay in the same house and refinance their mortgage, they also face a new mortgage rate, which is determined similarly. In addition, all households can save at the risk-free rate.

As a result, individual mortgage rates, aggregate conforming and jumbo rates and the risk-free rate are state variables of the model–a challenging numerical problem. In equilibrium, households choose their location and housing size over the life cycle depending on their current mortgage rate, housing type, location, age, income, and wealth. Locations have different local characteristics such as amenities and housing and goods supply. The model generates a rich time-varying cross-sectional distribution of households over state variables, which we use to credibly evaluate counterfactual experiments.

4.1 Environment

The economy is populated by overlapping generations of heterogeneous risk-averse households. Markets are incomplete, and house prices, rents, non-tradable and tradable goods prices are endogenous. Population size is stationary, and there is a continuum of measure 1 of households with rational expectations. Time is

discrete.

Life cycle. Households live for twenty periods, each corresponding to four years. They work for the first eleven periods and then retire. Workers earn labor income and retirees earn pension income, which is lower on average. Shares π^j of households are born into geographic areas $j = L, H$ (low- or high-cost). In each of these areas, shares π^{jS}, π^{jT}, and $\pi^{jR} = 1 - \pi^{jS} - \pi^{jT}$ of households are born respectively as owners of starter (S) and trade-up homes (T) and as renters (R).

Preferences. Households have preferences with constant relative risk aversion (CRRA) over a constant elasticity of substitution (CES) aggregator of total consumption c_{it} and housing services h_{it}, with elasticity of substitution $1/(1-\epsilon)$. Total consumption itself is given by a nested CES aggregator of non-tradable goods $c_{NT,it}$ and tradable goods $c_{T,it}$, with elasticity of substitution $1/(1-\eta)$:

$$c_{it} = \left[\theta c_{NT,it}^{\eta} + (1-\theta) c_{T,it}^{\eta}\right]^{\frac{1}{\eta}}. \tag{5}$$

In each area j, homeowners can either own a starter or a trade-up home with one of two (discrete) quality-adjusted sizes that delivers a fixed flow of services h^{jS} or h^{jT}, such that $h^{jS} < h^{jT}$. Renters consume continuous quantities of housing services $h_{it} \in \left(0, h^{jS}\right]$. Homeownership status, location, and housing sizes are determined by households' optimal discrete choices and two i.i.d. idiosyncratic shocks, whose realizations differ across households, which capture residual exogenous motives for owning and moving.[3] At date t, the instantaneous utility function of household i is given by:

$$u\left(c_{it}, h_{it}\right) = \frac{\left[\left((1-\alpha) c_{it}^{\epsilon} + \alpha h_{it}^{\epsilon}\right)^{\frac{1}{\epsilon}}\right]^{1-\gamma}}{1-\gamma} + \Xi_{it} - m_{it} - c_{it}^{r}. \tag{6}$$

Idiosyncratic shocks. The homeownership shock Ξ_{it} captures residual unmodeled benefits (when positive) and costs (when negative) of homeownership. The moving cost shock m_{it} affects households' propensity to move between areas, in addition to local fundamentals. The refinancing cost shock c_{it}^{r} affects households' propensity to refinance when aggregate mortgage rates vary. The three shocks follow type I Extreme Value distributions and cancel out in the aggregate. The means of the homeownership shocks differ between areas if households own (and are zero otherwise), and are summarized by the vector $\boldsymbol{\Xi} = \left(\Xi^{L}, \Xi^{H}\right)'$. The means of the moving cost shocks depend on the movers' origin and destination segment. Because there are

[3] Idiosyncratic shocks are a standard feature of models with housing (e.g., Greenwald et al., 2021) and migration (e.g., Kennan and Walker, 2011b). These shocks help us match ownership levels and moving rates between areas, and thus improve the quantitative level fit but are not required for the main mechanisms. The means of the shocks are calibrated to match residual home ownership and moving motives that are not accounted for by households' choices given local fundamentals, which are described below.

two area types, the matrix $\mathbf{m}$ of moving cost means by origin and destination is of dimension 2×2:

$$\mathbf{m} = \begin{pmatrix} m_{L,L} & m_{L,H} \\ m_{H,L} & m_{H,H} \end{pmatrix}. \tag{7}$$

The entries reflect moves between a low-cost area (L) and a high-cost area (H). In the calibration, the diagonal entries that refer to moving within each of these segments are set to zero. The scale parameters are fixed to 1 for both shocks.

The mean $\mathbf{c^r}$ of the refinancing cost shocks is assumed to be the same across households.

Endowments and risk. Households face idiosyncratic income risk and mortality risk. Their survival probabilities $\{p_a\}$ vary over the life-cycle.

For workers in area j, the logarithm of income for a household i of age a is given by:

$$\begin{aligned} &\log\left(y_{i,a,j,t}\right) = g_a + e_{i,t} + \mu^j, \\ &e_{i,t} = \rho_{e,j} e_{i,t-1} + \varepsilon_{i,t}, \\ &\varepsilon \overset{iid}{\sim} \mathcal{N}\left(0, \sigma^2_{\varepsilon,j}\right). \end{aligned} \tag{8}$$

Households receive income depending on their age, idiosyncratic productivity, and area. g_a is the log of the deterministic life-cycle income profile. $e_{i,t}$ is the log of the persistent idiosyncratic component of income. $\varepsilon_{i,t}$ is the log of the i.i.d. idiosyncratic component of income, which is drawn from a Normal distribution whose volatility $\sigma^2_{\varepsilon,j}$ can differ between geographic areas. μ^j is a spatial income shifter that we allow to differ between low- and high-cost areas. Different areas, as a consequence, can causally shift incomes (e.g., Bilal and Rossi-Hansberg, 2021) by different amounts. In addition, incomes across areas also differ due to selection in the form of endogenous skill sorting (e.g., Couture et al., 2024): more productive households are more likely to locate in the higher-cost area, as their high income makes them more willing to pay for more expensive housing.[4] For retirees, income is modeled to replicate the main features of the U.S. pension system as in Guvenen and Smith (2014).

Risk-free savings and mortgages. Households can invest in a financial asset with a time-varying risk-free rate of return $r_t > 0$ and in housing. Investments in the risk-free asset face a no-borrowing constraint. Renters who buy can use long-term amortizing fixed-rate mortgages to borrow, subject to loan-to-value (LTV) and payment-to-income (PTI) constraints which only apply at origination and are identical across geographic areas.

[4] In our baseline calibration, endogenous skill sorting is sufficient to match observed income differences across areas: $\mu^L = \mu^H = 0$ and $\sigma_{\varepsilon,L} = \sigma_{\varepsilon,H} = \sigma_\varepsilon$.

Loan sizes (negative positions $b_{t+1} < 0$) that are below a fixed threshold $\bar{b}$ are subject to the lower conforming mortgage rate $r^b_{low,t}$, while loans above that threshold are subject to the higher jumbo rate $r^b_{high,t}$:

$$r^b_t(b_{t+1}) = \begin{cases} r^b_{low,t} & \text{if } |b_{t+1}| \leq \bar{b}. \\ r^b_{high,t} > r^b_{low,t} & \text{otherwise.} \end{cases} \tag{9}$$

We assume that $r^b_t > r_t$, which implies that borrowers pay back their debt before holding risk-free assets.[5] The amortization schedule of mortgages is exogenous and balances must be fully repaid when old households die.

Borrowers make endogenous moving and refinancing choices. They keep their initial fixed mortgage rate $r^b_0 = r^b_t$ as long as they do not move or refinance. If borrowers move at a later date $t + s$, they must repay their existing mortgage and give up their initial mortgage rate, and potentially borrow at the new mortgage rate, which is determined by their new loan size $r^b_t(b_{t+1+s})$. If they stay in the same house and refinance, they incur a utility cost with mean c^r and a financial cost C^r that is proportional to the loan size, and they also borrow at the new mortgage rate, which is determined as previously.

Default is endogenous and mortgages are non-recourse. If borrowers default, they face a utility cost d and subsequently become renters in the same area.

Homeownership. Homeownership comes with three main benefits. First, owning allows buyers to access larger homes producing more valuable housing services, as the owner-occupied and the rental markets are segmented (e.g., Greenwald and Guren, 2025). Second, owning can improve consumption smoothing, since buying with a mortgage allows owners to pay only a fraction of the purchase price in the current period while renters have to pay the full rent.[6] Third, owning gives households idiosyncratic utility benefits captured by Ξ. These motives are consistent with the empirical literature on the benefits of homeownership (e.g., Goodman and Mayer, 2018; Sodini et al., 2023).

Cross-section of housing markets. Housing markets are segmented between owner-occupied (O) and rental units (R), and between geographic areas (j). Market segments differ in the level $\{I^{jR}, I^{jO}\}$ and in the price-elasticity $\{\rho^{jR}, \rho^{jO}\}$ of housing supply. They also differ in the means of the idiosyncratic shocks to the value of owning $\boldsymbol{\Xi}$ and to the cost of moving $\mathbf{m}$, which are described above. Equilibrium differences

[5] The assumption that mortgage borrowers cannot save accounts for the large fraction of "wealthy hand-to-mouth" households with few liquid assets in the data (Kaplan and Violante, 2014).

[6] With segmented markets and long-term mortgages, buying may be cheaper and thus more attractive than renting, since it allows buyers to pay for their homes over time. In contrast, when the owner-occupied and rental markets are integrated, the price is a multiple of the rent given by the user cost equation, such that households are indifferent between renting and owning. The fact that owners can better smooth their housing expenditures captures the fact that owner-occupied housing is a hedge against rent risk (Sinai and Souleles, 2005).

in house prices P_t^j and rents R_t^j between areas arise endogenously as a result of differences in local housing supply and demand.

The total supply of homes in each area, measured in square feet, is endogenous and consists of existing units put on the market by households who move out and new construction. Over time, the supply of housing is subject to physical depreciation at rate δ. First, the supply of existing housing depends on owners' decisions to move out of their existing units and into other units, and on owners being forced to move out after they have defaulted on their mortgages and their houses have been foreclosed on. These decisions are described in the dynamic programming problem of the household below (Section 4.2). Second, the construction of new units depends on housing prices through reduced-form functions that capture developers' incentives to build:

$$Construct_t^{jO} = I^{jO} \times \left(P_t^j\right)^{\rho^{jO}} \text{ and } Construct_t^{jR} = I^{jR} \times \left(\frac{R_t^j}{P_t^j}\right)^{\rho^{jR}}. \tag{10}$$

The construction of owner-occupied units depends on house prices P_t for a given area. The construction of rentals depends on rental yields R_t/P_t for a given area.[7] The levels I and the price elasticities ρ of the construction curves differ between areas. The higher I, the lower the price level required to produce a given level of housing supply. The higher ρ, the lower the price change required to induce a given change in housing supply. We assume that there is no conversion between housing types and no vacant homes in the model.

Cross-section of goods markets. The markets for non-tradable goods (NT) are segmented between geographic areas (j). The market for tradable foods (T) is integrated nationwide. Equilibrium differences in non-tradable goods prices $P_{NT,t}^j$ between areas arise endogenously as a result of differences in local goods supply and demand. In contrast, there is a single price $P_{T,t}$ for tradable goods, which arises endogenously as a result of its supply and the total demand for these goods across areas. We assume that the supply of non-tradable goods $c_{NT,t}^{S,j}$ and tradable goods $c_{T,t}^{S,j}$ are exogenous.

Importantly, the demand for goods depend on the demand for housing, hence on whether households are homeowners or renters. For owners, the demand for housing is equal to one of the two fixed housing sizes h^{jS} and h^{jT} and given by the *inter-temporal* optimization problem of the household since housing is a durable good and an asset. The demands for goods, which are non-durable, arise as a result of the separate *intra-temporal* optimization problem, taking housing demand as given. We solve for it in two steps. First,

[7] Davis and Heathcote (2007), Appendix D.2 in Kaplan et al. (2020), and Greenwald and Guren (2025) describe potential microfoundations for the construction curves, which are based on the profit maximization problems of real estate developers producing owner-occupied and rental housing units.

omitting the area subscript j for brevity, we denote the CES denominator in a given area and at date t as

$$\tilde{P}_t^O = \theta^{\frac{1}{1-\eta}} P_{NT,t}^{-\frac{\eta}{1-\eta}} + (1-\theta)^{\frac{1}{1-\eta}} P_{T,t}^{-\frac{\eta}{1-\eta}} \tag{11}$$

Second, the demands for non-tradable and tradable goods are respectively equal to:

$$\begin{aligned} c_{NT,t} &= \frac{w_t \theta^{\frac{1}{1-\eta}} P_{NT,t}^{-\frac{1}{1-\eta}}}{\tilde{P}_t^O} \\ c_{T,t} &= \frac{w_t (1-\theta)^{\frac{1}{1-\eta}} P_{T,t}^{-\frac{1}{1-\eta}}}{\tilde{P}_t^O}, \end{aligned} \tag{12}$$

where w_t are the household resources that are left at date t after solving their inter-temporal optimization problem, in particular choosing their location, housing size and mortgage, and incurring all the related costs.

For renters, the demands for goods and housing are chosen jointly as part of the household *intra-temporal* optimization problem, since rental units are chosen every period. Omitting the area subscript j, we denote the CES price index for non-tradable and tradable goods and the CES denominator in a given area and at date t respectively as

$$P_{c,t} = \left[\theta^{\frac{1}{1-\eta}} P_{NT,t}^{-\frac{\eta}{1-\eta}} + (1-\theta)^{\frac{1}{1-\eta}} P_{T,t}^{-\frac{\eta}{1-\eta}} \right]^{-\frac{1-\eta}{\eta}} \quad \text{and} \quad \tilde{P}_t^R = (1-\alpha)^{\frac{1}{1-\epsilon}} P_{c,t}^{-\frac{\epsilon}{1-\epsilon}} + \alpha^{\frac{1}{1-\epsilon}} R_t^{-\frac{\epsilon}{1-\epsilon}}. \tag{13}$$

Then, the household demands for rental housing, non-tradable and tradable goods are respectively equal to:

$$\begin{aligned} h_t &= \frac{w_t \alpha^{\frac{1}{1-\epsilon}} R_t^{-\frac{1}{1-\epsilon}}}{\tilde{P}_t^R} \\ c_{NT,t} &= \frac{w_t (1-\alpha)^{\frac{1}{1-\epsilon}} \theta^{\frac{1}{1-\eta}} P_{c,t}^{\frac{1}{1-\eta}-\frac{1}{1-\epsilon}} P_{NT,t}^{-\frac{1}{1-\eta}}}{\tilde{P}_t^R} \\ c_{T,t} &= \frac{w_t (1-\alpha)^{\frac{1}{1-\epsilon}} (1-\theta)^{\frac{1}{1-\eta}} P_{c,t}^{\frac{1}{1-\eta}-\frac{1}{1-\epsilon}} P_{T,t}^{-\frac{1}{1-\eta}}}{\tilde{P}_t^R}. \end{aligned} \tag{14}$$

Household choices. Every period, households make discrete choices on whether to move between areas and housing sizes, to buy or rent, and to refinance or default on their mortgage if they have one. They choose their housing size h_t, nondurable consumption c_t (which consists of non-tradable and tradable goods $c_{NT,t}$ and $c_{T,t}$), and save in a risk-free liquid asset $b_t > 0$ or borrow with a long-term mortgage $b_t < 0$.

Timing. A household in a given area and housing size chooses their next area, housing size, and home-ownership status, earns labor and financial income in their area of origin, and then chooses non-tradable and tradable consumption, and debt or savings.

4.2 Household Problem

This subsection describes the household problem in recursive form. The individual state variables are the current mortgage rate r_0^b, area type $j = L, H$ (low- or high-cost), housing size $h = R, S, T$ (rental, starter or trade-up home), age a, net savings b, and income y. The aggregate state variables are the conforming and jumbo mortgage rates, which are described by the rate schedule as a function of the loan size, $r_t^b(b_{t+1})$, and the risk-free rate r_t^f. We describe the problem for low-cost areas L, first for renters R and then for starter homeowners S. The problem is analogous for high-cost areas H and trade-up homeowners T.

4.2.1 Renter

A renter has six options: they can stay put in their current area and rent, or they can move to any one of the other five housing types, thus moving within or across areas, within or across housing sizes. Denote the value function of a renter of age a, with savings b_t and income y_t, who starts the period in area L at date t, when the current mortgage rate schedule is r_t^b and the current risk-free rate is r_t^f, as $V^{LR}(a, b_t, y_t; r_t^b, r_t^f)$. Renters pay the current mortgage rate, depending on their loan size, when they decide to borrow. The envelope value of the six value functions, corresponding to the housing market segment options is:

$$V^{LR}(a, b_t, y_t; r_t^b, r_t^f) = \max \left\{ V^{LR,LR}, V^{LR,LS}, V^{LR,LT}, V^{LR,HR}, V^{LR,HS}, V^{LR,HT} \right\}. \tag{15}$$

Denote $d^{LR} \in \{LR, LS, LT, HR, HS, HT\}$ the resulting policy function for the discrete choice problem. Then, renters choose consumption, housing size, and savings or mortgage debt if they borrow to purchase a house.

1. Renter staying in the same area. The value of staying a renter in area L is given by the Bellman equation:

$$V^{LR,LR}(a, b_t, y_t; r_t^b, r_t^f) = \max_{c_t, h_t, b_{t+1}} u(c_t, h_t) + \beta p_a \mathbb{E}_t \left[V^{LR}(a+1, b_{t+1}, y_{t+1}; r_{t+1}^b, r_{t+1}^f) \right], \tag{16}$$

subject to the constraint that expenses on non-tradable and tradable goods, rental housing, and savings, must be no lower, and at the optimum equal to, resources from labor income and financial income from risk-free assets

$$P_{NT,t}^L c_{NT,t} + P_{T,t} c_{T,t} + R_t^L h_t + b_{t+1} = y_t + (1 + r_t^f) b_t, \tag{17}$$

and subject to a no-borrowing constraint, as well as a constraint on the size of rental housing

$$b_{t+1} \geq 0, \quad h_t \in \left(0, h^{LS}\right]. \tag{18}$$

The current mortgage rate schedule r_t^b does not affect the problem of households who remain renters because they do not borrow. Expectations are taken with respect to the conditional distribution of idiosyncratic income, homeownership, and moving shocks at date t.

2. Renter becoming a starter-home buyer in the same area. When buying a house of type S in the same area L, the renter becomes a starter homeowner at the end of the period, with the corresponding expected continuation envelope value, such that the value function is

$$V^{LR,LS}(a, b_t, y_t; r_t^b, r_t^f) = \max_{c_t, h_t, b_{t+1}} u(c_t, h_t) + \beta p_a \mathbb{E}_t \left[V^{LS}(a+1, r_{0,t+1}^b, b_{t+1}, y_{t+1}; r_{t+1}^b, r_{t+1}^f) \right]. \tag{19}$$

In addition to rental housing purchased at rent R_t^L, the household buys a house at price P_t^L with the budget constraint:

$$P_{NT,t}^L c_{NT,t} + P_{T,t} c_{T,t} + R_t^L h_t + F_m + P_t^L h^{LS}(1 + f_m) + b_{t+1} = y_t + (1 + r_t^f) b_t, \quad h_t \in \left(0, h^{LS}\right], \tag{20}$$

that is, using a mix of savings accumulated over the life cycle, obtaining long-term mortgage debt b_{t+1} at the rate $r_{0,t+1}^b = r_t^b(b_{t+1})$, which they keep as long as they do not move or fully repay their loan, and paying mortgage origination fees with a fixed component (F_m) and a component proportional to the value of the house (f_m). LTV and PTI limits for starter homes in low-cost areas have to hold:

$$\begin{aligned} b_{t+1} &\geq -\theta_{LTV} P_t^L h^{LS}, \\ b_{t+1} &\geq -\frac{\theta_{PTI}}{\left(1 + r_{0,t+1}^b - \theta_{am}\right)} y_t \\ r_{0,t+1}^b &= r_t^b. \end{aligned} \tag{21}$$

θ_{LTV} is the maximum fraction of the house price for starter homes in areas L that the household can borrow, thus $1 - \theta_{LTV}$ is the downpayment requirement. θ_{PTI} is the maximum fraction of their income that borrowers can use to repay the mortgage. As in the data, the constraints only apply at origination and may be violated in subsequent periods if the mortgage rate, income, and/or house prices change.

Every period, existing homeowners with a mortgage pay interest based on their initial fixed interest rate $r_{0,t}^b$, and roll over their current debt subject to the requirement of repaying at least a fraction $1 - \theta_{am}$ of the principal,

$$b_{t+1} \geq \min\left[\theta_{am} b_t, 0\right]. \tag{22}$$

The lowest payment that existing owners can make on their debt in a period therefore equals $\left(1 + r_{0,t}^b - \theta_{am}\right) b_t$.

3. Renter becoming a trade-up-home buyer in the same area. The problem of a renter buying a house of type T in the same area L is analogous. The associated value function is denoted $V^{LR,LT}(a, b_t, y_t; r_t^b, r_t^f)$.

4. Renter moving across areas. When moving to area H while remaining a renter, a renter in L incurs an idiosyncratic moving cost shock with mean $m_{L,H}$ included in utility u and faces the expected continuation envelope value in area H:

$$\begin{aligned} &V^{LR,HR}(a, b_t, y_t; r_t^b, r_t^f) = \max_{c_t, h_t, b_{t+1}} u(c_t, h_t) + \beta p_a \mathbb{E}_t \left[V^{HR}(a+1, b_{t+1}, y_{t+1}; r_{t+1}^b, r_{t+1}^f) \right], \\ &\text{s.t. } P_{NT,t}^L c_{NT,t} + P_{T,t} c_{T,t} + R_t^L h_t + b_{t+1} = y_t + (1 + r_t^f) b_t, \\ &b_{t+1} \geq 0, \quad h_t \in \left(0, h^{HS}\right]. \end{aligned} \tag{23}$$

5. Renter becoming a starter-home buyer in another area. The value of moving to an area H and buying a starter home S is similar to the value of buying in the same area, with the addition of an idiosyncratic moving cost shock with mean $m_{L,H}$ included in u and the corresponding continuation value:

$$V^{LR,HS}(a, b_t, y_t; r_t^b, r_t^f) = \max_{c_t, h_t, b_{t+1}} u(c_t, h_t) + \beta p_a \mathbb{E}_t \left[V^{HS}(a+1, r_{0,t+1}^b, b_{t+1}, y_{t+1}; r_{t+1}^b, r_{t+1}^f) \right], \tag{24}$$

subject to the budget constraint, and the LTV and PTI limits for starter homes in high-cost areas:

$$\begin{aligned} &P_{NT,t}^L c_{NT,t} + P_{T,t} c_{T,t} + R_t^L h_t + F_m + P_t^H h^{HS}(1 + f_m) + b_{t+1} = y_t + (1 + r_t^f) b_t, \quad h_t \in \left(0, h^{LS}\right], \\ &b_{t+1} \geq -\theta_{LTV} P_t^H h^{HS}, \\ &b_{t+1} \geq -\frac{\theta_{PTI}}{\left(1 + r_{0,t+1}^b - \theta_{am}\right)} y_t \\ &r_{0,t+1}^b = r_t^b. \end{aligned} \tag{25}$$

6. Renter becoming a trade-up home buyer in another area. The problem of a renter buying a trade-up home T in another area H is analogous. The associated value function is denoted $V^{LR,HT}(a, b_t, y_t; r_t^b, r_t^f)$.

4.2.2 Homeowner

The problem for existing homeowners follows a similar structure as that of renters, with the addition of their initial mortgage rate as an individual state variable. In contrast to renters, they face eight options: as before, they can stay put in their current area and owner-occupied home, or they can move to any one of the other five housing market types. In addition, their seventh option is to refinance their existing mortgage, and their eighth option is to default on it. The value function for an owner starting the period in a starter

home in area L with an initial fixed mortgage rate $r^b_{0,t}$ is $V^{LS}(a, r^b_{0,t}, b_t, y_t; r^b_t)$. The envelope value of the eight value functions, corresponding to the six housing market segment options plus the option to refinance (r) and default (D) in their current home is:

$$V^{LS}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max\left\{V^{LS,RL}, V^{LS,LS}, V^{LS,LT}, V^{LS,HR}, V^{LS,HS}, V^{LS,HT}, V^{LS,r}, V^{LS,D}\right\}. \tag{26}$$

Denote the resulting policy function for the discrete choice problem as $d^{LS} \in \{LR, LS, LT, HR, HS, HT, r, D\}$.

1. Owner moving into renting in the same area. Owners who sell their house forego their initial mortgage rate $r^b_{0,t}$ and will face the new mortgage rate schedule $r^b_{t+s}(b_{t+1+s})$ when borrowing at a later date $t+s$. When selling and becoming a renter in the same area, they incur a sales transaction cost f_s that is proportional to the value of the house, and an idiosyncratic homeownership shock with mean Ξ^L included in u:

$$V^{LS,LR}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max_{c_t, b_{t+1}} u\left(c_t, h^{LS}\right) + \beta p_a \mathbb{E}_t\left[V^{LR}(a+1, b_{t+1}, y_{t+1}; r^b_{t+1}, r^f_{t+1})\right], \tag{27}$$

subject to the budget and no-borrowing constraints

$$P^L_{NT,t} c_{NT,t} + P_{T,t} c_{T,t} + b_{t+1} = y_t + (1+\tilde{r}) b_t + (1 - f_s - \delta) P^L_t h^{LS}, \tag{28}$$

$$b_{t+1} \geq 0, \tag{29}$$

$$\tilde{r} = \begin{cases} r^b_{0,t} & \text{if } b_t < 0. \\ r^f_t & \text{otherwise.} \end{cases} \tag{30}$$

2. Owner staying in the same home. Owners who stay in their house keep the initial mortgage rate $r^b_{0,t}$. The value of staying a homeowner of a starter home in area L is given by the Bellman equation with fixed housing services h^{LS} and an idiosyncratic homeownership shock with mean Ξ^L included in u:

$$\begin{aligned} &V^{LS,LS}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max_{c_t, b_{t+1}} u\left(c_t, h^{LS}\right) + \beta p_a \mathbb{E}_t\left[V^{LS}(a+1, r^b_{0,t+1}, b_{t+1}, y_{t+1}; r^b_{t+1}, r^f_{t+1})\right], \\ &r^b_{0,t+1} = r^b_{0,t} \end{aligned} \tag{31}$$

subject to the budget constraint, in which owners pay a financial maintenance cost that corresponds to

physical depreciation δ:

$$P^L_{NT,t}c_{NT,t} + P_{T,t}c_{T,t} + b_{t+1} + \delta P^L_t h^{LS} = y_t + (1+\tilde{r})b_t, \tag{32}$$

$$\tilde{r} = \begin{cases} r^b_{0,t} & \text{if } b_t < 0. \\ r^f_t & \text{otherwise.} \end{cases} \tag{33}$$

and the mortgage amortization constraint

$$b_{t+1} \geq \min\left[\theta_{am} b_t, 0\right]. \tag{34}$$

3. Upsizer in the same area. When selling their starter home and purchasing a trade-up home in the same area H, an owner must fully repay their existing mortgage at the initial rate $r^b_{0,t}$ and face the new mortgage rate schedule $r^b_t(b_{t+1})$ when borrowing. In addition, they incur an idiosyncratic homeownership shock with mean Ξ^L included in u:

$$\begin{aligned} &V^{LS,LT}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max_{c_t, b_{t+1}} u\left(c_t, h^{LS}\right) + \beta p_a \mathbb{E}_t\left[V^{LT}(a+1, r^b_{0,t+1}, b_{t+1}, y_{t+1}; r^b_{t+1}, r^f_{t+1})\right], \\ &r^b_{0,t+1} = r^b_t(b_{t+1}) \end{aligned} \tag{35}$$

The new house is purchased with a mix of housing equity, savings in liquid assets (if they have no debt), and a new mortgage b_{t+1}, with current mortgage rate $r^b_t(b_{t+1})$, mortgage origination fees F_m and f_m, and subject to LTV and PTI limits. In addition, they face sales transaction costs f_s on the house sold.

$$P^L_{NT,t}c_{NT,t} + P_{T,t}c_{T,t} + F_m + P^L_t h^{LT}(1+f_m) + b_{t+1} = y_t + (1+\tilde{r})b_t + (1-f_s-\delta)P^L_t h^{LS}, \tag{36}$$

$$\tilde{r} = \begin{cases} r^b_{0,t} & \text{if } b_t < 0. \\ r^f_t & \text{otherwise.} \end{cases} \tag{37}$$

$$b_{t+1} \geq -\theta_{LTV} P^L_t h^{LT}, \tag{38}$$

$$b_{t+1} \geq -\frac{\theta_{PTI}}{\left(1 + r^b_{0,t+1} - \theta_{am}\right)} y_t. \tag{39}$$

4. Owner moving into renting across areas. The problem of a starter homeowner in area L who sells and becomes a renter in another area H is analogous to the value of becoming a renter in the same area, with idiosyncratic moving cost and homeownership shocks with respective means $m_{L,H}$ and Ξ^L included in utility u, and the corresponding rent and continuation envelope value. The associated value function is denoted

$V^{LS,HR}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t)$.

5. Starter-home buyer in another area. When selling their starter home in area L and purchasing a starter home in another area H, an owner must also fully repay their existing mortgage at the initial rate $r^b_{0,t}$ and face the new mortgage rate schedule $r^b_t(b_{t+1})$ when borrowing. They also incur idiosyncratic moving cost and homeownership shocks with respective means $m_{L,H}$ and Ξ^L included in u. The value function is similar to that of the upsizer within the same area and is denoted as

$$\begin{aligned} &V^{LS,HS}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max_{c_t, b_{t+1}} u\left(c_t, h^{LS}\right) + \beta p_a \mathbb{E}_t \left[V^{HS}(a+1, r^b_{0,t+1}, b_{t+1}, y_{t+1}; r^b_{t+1}, r^f_{t+1})\right], \\ &r^b_{0,t+1} = r^b_t(b_{t+1}). \end{aligned} \tag{40}$$

6. Upsizer in another area. When selling their house and purchasing a trade-up home in another area H, a starter-home owner must also fully repay their existing mortgage at the initial rate $r^b_{0,t}$ and face the new mortgage rate schedule $r^b_t(b_{t+1})$ when borrowing. They also incur idiosyncratic moving cost and homeownership shocks with respective means $m_{L,H}$ and Ξ^L included in u. The value function is similar to that of the upsizer within the same area and is denoted as

$$\begin{aligned} &V^{LS,HT}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max_{c_t, b_{t+1}} u\left(c_t, h^{LS}\right) + \beta p_a \mathbb{E}_t \left[V^{HT}(a+1, r^b_{0,t+1}, b_{t+1}, y_{t+1}; r^b_{t+1}, r^f_{t+1})\right], \\ &r^b_{0,t+1} = r^b_t(b_{t+1}). \end{aligned} \tag{41}$$

7. Owner refinancing their mortgage. Owners who stay in their house and refinance face the new mortgage rate schedule $r^b_t(b_{t+1})$ when borrowing. In addition, they incur idiosyncratic homeownership and refinancing cost shocks shock with means Ξ^L and c^r included in u:

$$\begin{aligned} &V^{LS,r}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max_{c_t, b_{t+1}} u\left(c_t, h^{LS}\right) + \beta p_a \mathbb{E}_t \left[V^{LS}(a+1, r^b_{0,t+1}, b_{t+1}, y_{t+1}; r^b_{t+1}, r^f_{t+1})\right], \\ &r^b_{0,t+1} = r^b_t(b_{t+1}) \end{aligned} \tag{42}$$

subject to the budget constraint, in which owners pay a financial maintenance cost that corresponds to physical depreciation δ:

$$P^L_{NT,t} c_{NT,t} + P_{T,t} c_{T,t} + (1 + C^r) b_{t+1} + \delta P^L_t h^{LS} = y_t + (1 + \tilde{r}) b_t, \tag{43}$$

$$\tilde{r} = \begin{cases} r^b_{0,t} & \text{if } b_t < 0. \\ r^f_t & \text{otherwise.} \end{cases} \tag{44}$$

and the mortgage amortization constraint

$$b_{t+1} \geq \min\left[\theta_{am} b_t, 0\right]. \tag{45}$$

8. Mortgage defaulter. Finally, owners who default on their mortgage forego their initial mortgage rate $r^b_{0,t}$ and face the new mortgage rate schedule $r^b_{t+s}(b_{t+1+s})$ when borrowing at a later date $t+s$. They receive an idiosyncratic homeownership shock with mean Ξ^L included in u, immediately incur a utility cost of default d, are only left with their current income to consume, and become renters in the same area in the next period:

$$V^{LS,D}(a, r^b_{0,t}, b_t, y_t; r^b_t, r^f_t) = \max_{c_t, b_{t+1}} u\left(c_t, h^{LS}\right) - d + \beta p_a \mathbb{E}_t\left[V^{LR}(a+1, b_{t+1}, y_{t+1}; r^b_{t+1}, r^f_{t+1})\right], \tag{46}$$

subject to the budget and no-borrowing constraints

$$\begin{aligned} c_t + b_{t+1} &= y_t, \\ b_{t+1} &\geq 0. \end{aligned} \tag{47}$$

4.3 Equilibrium

This subsection defines the equilibrium of the dynamic spatial model of housing and goods markets.

Definition. Given an exogenous time path for unanticipated aggregate shocks to the mortgage rate schedule and the risk-free rate $\{r^b_t(b_{t+1}), r^f_t\}$, a *dynamic spatial recursive competitive equilibrium* consists of the following objects, which are defined for the geographic areas $j = L, H$ and housing sizes $h = R, S, T$ within each area:

(i) sequences of house prices and rents $\left\{P^j_t, R^j_t\right\}$

(ii) sequences of non-tradable and tradable goods prices $\left\{P^j_{NT,t}, P_{T,t}\right\}$

(iii) value functions $\left\{V^{jh}\left(.; r^b_t, r^f_t\right)\right\}$

(iv) policy functions $\left\{d^{jh}\left(.; r^b_t, r^f_t\right), c^j_{NT}\left(.; r^b_t, r^f_t\right), c^j_T\left(.; r^b_t, r^f_t\right), h^{jh}\left(.; r^b_t, r^f_t\right), b^{jh}_{t+1}\left(.; r^b_t, r^f_t\right)\right\}$

(v) a law of motion for the cross-sectional distribution of households $\lambda_t = \lambda\left(r^b_0, j, h, a, b, y; r^b_t, r^f_t\right)$ over individual mortgage rates r^b_0, geographic areas j, housing sizes h, age a, net savings b, and income y,

such that households optimize given prices, the distribution of households is consistent with their choices and prices, and markets clear.

Housing markets. There are two types of geographic areas (low- and high-cost), each with a market for owner-occupied and for rental housing, which results in a total of four housing market-clearing conditions.

Market-clearing for owner-occupied homes in areas $j = L, H$ equates the total demand, for starter and trade-up homes, with the supply in that area, in square feet:

$$\int_{OWN_t^{jS}} h^{jS} d\lambda_t + \int_{OWN_t^{jT}} h^{jT} d\lambda_t = H_t^{jO} = (1-\delta) H_{t-1}^{jO} + Construct_t^{jO}, \tag{48}$$

where OWN_t^{jS} and OWN_t^{jT} are respectively the sets of households owning a starter and a trade-up home in area j at date t.

Market-clearing for rentals in areas $j = L, H$ equates the total rental demand with the supply in that area, in square feet:

$$\int_{RENT_t^j} h^{jR} d\lambda_t = H_t^{jR} = (1-\delta) H_{t-1}^{jR} + Construct_t^{jR}, \tag{49}$$

where $RENT_t^j$ is the set of households renting in area j at date t.

Goods markets. There are two types of geographic areas (low- and high-cost), each with a market for non-tradable goods, and an integrated market for tradable goods across areas, which results in a total of three goods market-clearing conditions.

Market-clearing for non-tradable goods equates the total demand with the supply in each area $j = L, H$:

$$\int_{ALL_t^j} c_{NT,t}^j d\lambda_t = c_{NT,t}^{S,j}, \tag{50}$$

where ALL_t^j is the set of households in area j at date t.

Market-clearing for tradable goods equates the total demand across areas with the supply:

$$\sum_j \int_{ALL_t^j} c_{T,t}^j d\lambda_t = c_{T,t}^S. \tag{51}$$

5 Calibration

This section describes our calibration strategy and the model's ability to match key empirical moments. The calibration presents substantial computational challenges due to the model's rich structure. We solve a heterogeneous agent model with incomplete markets in which we must compute the endogenous cross-sectional distribution of individual state variables. The dynamic spatial equilibrium model includes both housing and goods markets, incorporates mortgage rate lock-in as both individual and aggregate state vari-

ables, allows for optimal refinancing decisions, and is solved over the full transition dynamics.

We combine externally calibrated parameters with internally calibrated parameters chosen to match key moments in the data. One model period corresponds to four years, and all reported targets are annualized for comparability with the data.

5.1 Externally Calibrated Parameters

Table 6 presents the full set of model parameters. We externally calibrate several parameters using existing empirical estimates or institutional features of U.S. housing and mortgage markets.

Preferences, Income, and Wealth. We set the coefficient of risk aversion $\gamma = 2$, a standard value in the literature. For housing, the elasticity of substitution between housing and consumption is taken from Piazzesi et al. (2007). For goods, we set the elasticity of substitution between tradable and non-tradable goods to a standard value in the literature (Akinci (2011).

The income process follows Floden and Lindé (2001) in setting the autocorrelation parameter (ρ_ϵ) and the standard deviation σ_ϵ of idiosyncratic income shocks. Initial wealth b_0 is calibrated to match the average wealth of households under 35 years old in the 2019 Survey of Consumer Finances (SCF).

Mortgage Loans. The risk-free rate is set to 2%, which is the average 30-year Treasury rate from the Federal Reserve's H.15 Selected Interest Rates series. We calibrate conforming and jumbo mortgage rates to reflect the variation observed during our sample period (2019–2023): the conforming rate ranges from 3% in the low-interest rate environment to 4% in the high-rate environment, while the jumbo rate ranges from 3.3% to 4%, capturing the conforming-jumbo spread documented in Section 2.3.

Transaction costs are calibrated to institutional features of the U.S. mortgage market. The selling transaction cost F_b is set as a percentage of the purchase price based on Freddie Mac's Primary Mortgage Survey. The proportional buying transaction cost F_s and fixed buying cost f_s reflect mortgage origination fees as documented in Favilukis et al. (2017).

The amortization parameter θ_{am} (one minus the amortization rate) follows Greenwald et al. (2021) to capture amortization requirements on long-term mortgages. The loan-to-value limit θ_{LTV} and payment-to-income limit θ_{PTI} are set to match limits observed in HMDA data, reflecting typical underwriting standards in the conforming mortgage market.

Geographic and Housing Market Parameters. The housing depreciation rate $\delta = 2.45\%$ annually is drawn from average depreciation rates from the Bureau of Economic Analysis. Housing sizes for starter

TABLE 6: PARAMETERS

Parameter	Description	Value	Source/Target
A. Preferences, Income, and Wealth			
γ	Risk aversion	2	See text
ϵ	CES housing and consumption basket	0.20	From Piazzesi et al. (2007)
α	Weight housing vs. consumption	0.20	Rent/income ratio
η	CES tradable and non-tradable consumption basket	0.50	See text
θ	Weight non-tradable vs. tradable consumption	0.50	Non-tradable expenditure share
ρ_e	Autocorrelation income process	0.70	From Floden and Lindé (2001)
σ_ε	Std. dev. income process	0.39	From Floden and Lindé (2001)
b_0	Initial wealth	25,400	Avg wealth under 35 y.o. (2019 SCF)
B. Mortgage Loans			
r	Risk-free rate	2.00%	Avg 30-year Treasury rate (FRB, H.15 Selected Interest Rate)
r^b_{low}	Conforming mortgage rate (low,high)	(3%, 4%)	U.S. mortgage rates 2019-2023
r^b_{high}	Jumbo mortgage rate (low,high)	(3.3%, 4%)	U.S. mortgage rates 2019-2023
F_b	Selling transaction cost	6.00%	Share of purchase price (Freddie Mac PMS)
F_s	Proportional buying transaction cost	0.60%	Share of mortgage size (Favilukis et al., 2017)
f_s	Fixed buying transaction cost	\$1,200	Mortgage origination fee (Favilukis et al., 2017)
θ_{am}	One minus amortization rate	0.93	Minimum amortization (Greenwald et al., 2021)
θ_{LTV}	LTV limit	0.95	LTV limit (HMDA)
θ_{PTI}	PTI limit	0.50	PTI limit (HMDA)
C^r	Proportional financial cost of refinancing	0.05	Refinancing cost of 5% of loan size
c^r_0	Avg utility cost of refinancing	3	Fraction of refinanced mortgages in steady state
c^r	Avg utility cost of refinancing	3	Fraction of refinanced mortgages during QE4
C. Geographic Areas $\times$ Housing Types			
δ	Housing depreciation rate	2.45%	Avg depreciation (BEA)
h^{LS}	Housing size low-cost starter homes	1.000	Avg housing size 1,662 sqft (2021 CoreLogic)
h^{LT}	Housing size low-cost trade-up homes	1.155	Avg housing size 1,919 sqft (2021 CoreLogic)
h^{HS}	Housing size high-cost starter homes	1.046	Avg housing size 1,739 sqft (2021 CoreLogic)
h^{HT}	Housing size high-cost trade-up homes	1.281	Avg housing size 2,129 sqft (2021 CoreLogic)
ρ^{LR}	Supply elasticity low-cost rentals	0.520	Elasticity (Baum-Snow and Han, 2024)
ρ^{LS}	Supply elasticity low-cost homes	0.520	Elasticity (Baum-Snow and Han, 2024)
ρ^{HR}	Supply elasticity high-cost rentals	0.370	Elasticity (Baum-Snow and Han, 2024)
ρ^{HS}	Supply elasticity high-cost homes	0.370	Elasticity (Baum-Snow and Han, 2024)
π^{LS}	Share initially owning in low-cost starter homes	0.25	Homeownership at 25 y.o. (2021 GCCP)
π^{LT}	Share initially owning in low-cost trade-up homes	0.16	Homeownership at 25 y.o. (2021 GCCP)
π^{HS}	Share initially owning in high-cost starter homes	0.20	Homeownership at 25 y.o. (2021 GCCP)
π^{HT}	Share initially owning in high-cost trade-up homes	0.17	Homeownership at 25 y.o. (2021 GCCP)

Notes: One model period corresponds to four years. Targets are annualized.

and trade-up homes in both low-cost and high-cost areas (h^{LS}, h^{LT}, h^{HS} , h^{HT}) are calibrated to average housing sizes from CoreLogic data for 2021, ranging from 1,662 square feet for low-cost starter homes to 2,129 square feet for high-cost trade-up homes.

Supply elasticities for rental and owner-occupied housing (ρ^{LR}, ρ^{LS}, ρ^{HR}, ρ^{HS}) differ between low-cost and high-cost areas. They are based on merging our data with Baum-Snow and Han (2024), who show that housing supply is more elastic in lower-cost, less regulated markets. Initial homeownership shares by location and housing type (π^{LS}, π^{LT}, π^{HS}, π^{HT}) are set to match homeownership rates at age 25 from the 2021 Goodman Center Census Platform.

5.2 Internally Calibrated Parameters

The remaining parameters are internally calibrated by simulated method of moments to match key features of housing markets, migration patterns, and household balance sheets. Table 7 presents the targeted moments and the model's fit.

TABLE 7: TARGETED MOMENTS

Variable	Data	Model
A. Average House Prices and Rents		
Avg house price low-cost starter homes	193,327.996	193,327.996
Avg house price low-cost trade-up homes	223,222.878	223,222.878
Avg rent low-cost	1,181	1,181
Avg house price high-cost starter homes	390,773.63	390,773.63
Avg house price high-cost trade-up homes	478,411.189	478,411.189
Avg rent high-cost	2,070	2,070
B. Average Income, Moving and Homeownership Rates		
Avg income high/low-cost	1.20	1.44
Avg moving rate between areas	0.05	0.05
Homeownership low-cost areas	0.66	0.65
Homeownership high-cost areas	0.64	0.63
C. Wealth, Expenditure Ratios, Default and Refinancing Rate		
Avg wealth/avg income	4.50	4.24
Avg house price/avg income	5.60	5.58
Avg rent/avg income	0.20	0.20
Non-tradable/(non-tradable + tradable) goods share	0.50	0.49
Avg default rate	0.02	0.04
Increase in fraction of refinanced mortgages during QE	+0.25	$[+0.17, +0.54]$

Notes: Moments are annualized.

Housing Prices and Rents. The model is calibrated to match average house prices and rents across both geographic areas and housing segments. For low-cost areas, average starter home prices are $300,000, trade-up homes are $346,390, and monthly rents average $1,181. For high-cost areas, starter homes average $700,000, trade-up homes $856,987, and monthly rents are $2,070. The model exactly matches these price levels. The price differences reflect substantial geographic variation in housing costs, consistent with the spatial segmentation central to our empirical strategy.

Income, Migration, and Homeownership. The model targets an income ratio of 1.20 between high-cost and low-cost areas, capturing both selection effects (higher-income households sorting into expensive areas) and causal effects of location on earnings. The model generates a slightly higher rate of 1.31. The average moving rate between areas is targeted at 5% annually, and the model is close with 4%. We target a home-

ownership rate of 66% in low-cost areas (the model generates 61%) and 64% in high-cost areas (the model is slightly below at 55%).

Wealth and Housing and Goods Expenditures Ratios. The calibration targets three key financial ratios that discipline household saving and borrowing behavior as well as default rates. The average wealth to income ratio target is 4.50 in the data, and 4.85 in the model. The model closely matches the target house price to income ratio of 5.60 at 5.59. The model also matches the average rent to income ratio of 0.20, which we replicate by choosing the utility weight α. We use a similar approach to calibrate the utility derived from non-tradable versus tradable goods. We set the utility weight θ on non-tradable goods to match their shares in total goods expenditures. These moments ensure that the model generates realistic household balance sheets and housing affordability constraints. Finally, the model exactly replicates the average default rate of 2% annually, which disciplines the tail risk of mortgage default.

Refinancing. The financial cost of refinancing is externally calibrated to 5% of the value of the new loan originated, as in the data. The utility of refinancing is chosen to match the increase in refinancing propensity observed during the QE4 episode. In normal times, around 5% of outstanding mortgages are refinanced annually, which implies a normal refinancing rate of 20% for one model period of 4 years. In the two years following QE4, 37% of outstanding mortgages were refinanced. Extrapolating this moment to match the four-year model frequency, this implies that at least 37% and at most 74% of outstanding mortgages were refinanced during one model period. This implies that the increase in the fraction of mortgages refinanced is between $37 - 20 = 17$ and $74 - 20 = 54$ percentage points. Since interest rates are constant in the steady state of the model prior to the QE shock, there is no incentive for borrowers in the model to refinance in steady state (except for the idiosyncratic shocks to the utility cost of refinancing), and therefore we choose the average utility cost of refinancing in the steady state to generate fraction of refinanced mortgages in the steady state equal to zero. Then, we choose the average utility cost of refinancing during the QE4 shock to match the increase in refinancing behavior observed in the data. The resulting shock captures an increase in borrowers' attention to refinancing around QE4. The model generates an increase in the share of refinanced mortgages during QE4 that is equal to +25 pp, a value that lies well between the two model bounds of +17 and +54 pp.

5.3 Non-Targeted Moments

Table 8 presents non-targeted moments to assess the model's out-of-sample performance. The model successfully matches key features of the credit market and household heterogeneity despite not calibrating

these directly.

Loan-to-Value and Payment-to-Income. The model generates realistic distributions of leverage ratios. The average LTV ratio is 0.60, with a median of 0.73 and 90th percentile of 0.80, which are close to the comparable statistics in the data. Similarly, the model average PTI ratio is 0.27, with a median of 0.29 and 90th percentile of 0.40, also close to comparable data targets. These distributions indicate that the model captures both typical borrowing behavior and the presence of highly leveraged households near regulatory constraints.

Income and Default. The model reproduces substantial income heterogeneity across housing market segments. Average income ranges from $63,112 in starter homes in the low-cost area to $98,650 for trade-up homes in the high cost area. These statistics are generally higher than their data counterparts, but match the heterogeneity in incomes across housing segments and geographical locations. Default rates also vary realistically across segments, from 1.1% for low-cost starter homes to 1.7% for high-cost trade-up homes.

Treatment Effect of QE on House Prices. We use the panel structure of the data generated by the model to compute the equivalent of the difference-in-differences estimate reported in Section 3.4. We do so in three steps.

First, we start by computing the synthetic mortgage rates in each geographic area that are implied by (i) the predetermined distributions of conventional vs. jumbo loans in each area and (ii) interest rate differences between conventional vs. jumbo loans. Let $\bar{r}_L$ denote the average mortgage rate in the low-cost area and $\bar{r}_H$ the average mortgage rate in the high-cost area after the QE shock, which are computed using predetermined loan shares in each area before the shock (denoted with a 0 subscript). $\bar{r}_{L,0}$ and $\bar{r}_{H,0}$ denote the same objects prior to the QE shock; they use the same loan shares but interest rates on conventional vs. jumbo loans are higher than after the QE shock. Formally,

$$\bar{r}_{j,t} = \text{Conventional loan share}_{j,0} \times r^b_{low,t} + \text{Jumbo loan share}_{j,0} \times r^b_{high,t}. \tag{52}$$

We find that $\bar{r}_{L,0} = \bar{r}_{H,0} = 4\%$ because $r_{low,0} = r_{high,0} = 4\%$ in the data and in our calibration. Before the shock, the predetermined loan distributions are Conventional loan share$_{L,0} = 0.73$ and Jumbo loan share$_{L,0} = 0.27$ in low-cost areas and Conventional loan share$_{H,0} = 0.33$ and Jumbo loan share$_{H,0} = 0.67$ in high-cost areas. After the QE shock, $r_{low,0} = 3\%$ and $r_{high,0} = 3.3\%$. Hence, the synthetic mortgage rates after the shock are (in decimal terms) $\bar{r}_L = 0.73 \times 0.03 + 0.27 \times 0.033 = 0.03081$ and $\bar{r}_H = 0.33 \times 0.03 + 0.67 \times 0.033 = 0.03201$.

Second, we compute the (log) house price response to a decrease in mortgage rates that matches the data

in Section 3.4: from 4% to 3% for conventional loans and from 4% to 3.3% for jumbo loans. We consider the house price response in the same period as the QE shock to replicate the experiment in the data. Section 6.1 describes the computation of the corresponding transition dynamics and the results in detail. We find that the house price responses are $\Delta \log P_L = \log P_L - \log P_{L,0} = +7.1\%$ in low-cost areas and $\Delta \log P_H = \log P_H - \log P_{H,0} = +5.6\%$ in high-cost areas.

Third, we compute the difference-in-differences estimator in the model as:

$$DID = \frac{\Delta \log P_L - \Delta \log P_H}{\Delta \bar{r}_L - \Delta \bar{r}_H} = -\frac{0.015}{0.0012} = -12.5 \tag{53}$$

Finally, to replicate the same change in interest rates that corresponds to the data (a 100 bp decrease in the conventional mortgage rate) we multiply this estimate by 0.01 since the rate changes in the denominator were in decimal terms. We obtain a DID coefficient equal to -0.125, which closely matches the value of -0.119 found in Section 3.4 in the comparable specification (using the synthetic instrument, which uses the variation from regional exposure to interest rates, with county by year fixed effects). The ability for the model to match an important quasi-experimental treatment effect in the data suggests that the model is able to match an important feature of the data, and provides additional credence in using it further.

6 Empirical Results: Equilibrium Inflationary Effects of QE and Mechanisms

Having calibrated the model to match key features of housing markets and household behavior, we now use it to evaluate the general equilibrium effects of QE4-style unconventional monetary policy interventions. We conduct two main experiments. First, we examine the transition dynamics following a temporary interest rate shock, which corresponds most closely to the short time-period following the QE4 shock. Second, we compare steady states with permanently different interest rate levels to highlight long-run effects. In both experiments, we distinguish between scenarios in which only mortgage rates decline (isolating the specific QE channel) versus scenarios in which both mortgage and risk-free rates decline (capturing broader monetary policy easing over this period).

6.1 Transition Dynamics: Response to Transitory Lower Rates

We begin by analyzing the economy's response to a temporary decrease in interest rates that lasts one model period (four years) before reverting to baseline levels. This experiment replicates the QE4 episode, in which

TABLE 8: NON-TARGETED MOMENTS

Variable	Data	Model
A. Loan-to-Value and Payment-to-Income Ratios		
Avg LTV	0.75	0.86
P50 LTV	0.80	0.95
P90 LTV	0.90	0.95
Avg PTI	0.35	0.37
P50 PTI	0.37	0.38
P90 PTI	0.48	0.50
B. Average Income and Default Rates		
Avg income in low-cost starter homes	47,880	37,972
Avg income in low-cost trade-up homes	54,023	42,561
Avg income in high-cost starter homes	56,892	60,792
Avg income in high-cost trade-up homes	70,607	63,416
Avg default rate in low-cost starter homes	0.014	0.034
Avg default rate in low-cost trade-up homes	0.008	0.014
Avg default rate in high-cost starter homes	0.010	0.018
Avg default rate in high-cost trade-up homes	0.006	0.015
C. Treatment effect of QE on house prices		
DID estimate	-.119	-.125

Notes: Moments are annualized. The empirical moments are from Fonseca et al. (2024).

the Federal Reserve purchased mortgage-backed securities from April 2020 through March 2022, generating temporarily lower mortgage rates in affected segments before they reverted back to higher values. Specifically, we simulate a decline in conforming mortgage rates from 4% to 3% and in jumbo rates from 4% to 3.3%, to exactly capture the treatment intensity across segments documented in Section 2, and a decline in the risk-free rate from 2.50% to 1.50%. Appendix Section A2 reports the same results focusing only on the decline in mortgage rates.

6.2 Housing Market Responses

Figure A1 presents the dynamic response of house prices and rents to the mortgage rate shock. House prices increase substantially on impact in both low-cost and high-cost areas, rising approximately 1.4% and 1.1% respectively. This immediate response reflects the *cash flow channel* of monetary policy: lower

mortgage rates reduce monthly mortgage payments for both new borrowers and existing homeowners who refinance, freeing up resources for housing consumption. Households respond by bidding up house prices, particularly for properties eligible for conforming loans that experience the largest rate reductions in the low-cost region.

House prices continue rising even after mortgage rates revert to their original levels. This persistent effect arises from the *lock-in effect* central to our model. Households who refinanced or purchased homes during the low-rate period retain their favorable mortgage rates through the fixed-rate structure of U.S. mortgages. These locked-in low rates continue to support housing demand, as these households enjoy permanently lower mortgage payments relative to what current rates would imply.

At the same time, the *valuation channel* begins to dominate the cash flow channel in later periods. Higher house prices make homeownership less affordable for first-time buyers and households looking to upsize, even as existing owners with locked-in rates benefit from wealth effects. This affordability constraint dampens the pace of further house price increases, leading to a gradual stabilization at an elevated level.

Rental markets exhibit different dynamics. Rents initially decline in the low-cost area as homeownership becomes more attractive due to relatively lower lower mortgage rates, shifting some marginal renters into owner-occupied housing. This *substitution effect* reduces rental demand, placing downward pressure on rents. However, as house prices dynamically rise in equilibrium and mortgage rates revert to baseline, the relative attractiveness of homeownership diminishes for households without locked-in low rates, leading rents to gradually recover toward their pre-shock levels. However, rents actually increase in the high-cost area, which experiences a smaller interest rate reduction.

6.3 Goods Market Spillovers

Figure A2 shows how the mortgage market shock transmits to consumer goods prices through cash flow and housing wealth effects. The model generates inflationary pressures in both tradable and non-tradable goods markets, the second of which varies by geographical region. Tradable good prices rise by more than 1%, while non-tradeable goods prices rise by between 0.2–0.6%, depending on the region. The cash flow channel again drives the initial increase: homeowners with lower mortgage payments have additional resources available for consumption, increasing the demand for local goods and services.

As with house prices, the lock-in mechanism generates persistence in further consumer inflationary increases even after rates revert. Households that refinanced at low rates continue to enjoy higher disposable income from permanently lower mortgage payments, sustaining elevated consumption demand. Additionally, housing wealth effects amplify consumption among existing homeowners who experienced capital

gains, further supporting goods prices. These effects show up strongly in the low-cost area just after rate have reverted to their previous values.

6.4 Combined Mortgage and Risk-Free Rate Reductions

Figures 4 and 5 present results when both mortgage rates and risk-free rates decline temporarily. This scenario corresponds to a broader monetary easing in which conventional policy tools (affecting the risk-free rate) accompany unconventional tools (affecting mortgage spreads).

The housing market effects are qualitatively similar but quantitatively larger incorporating the further decline in risk-free rates. This aggregate rate decline further amplifies house price increases by further decreasing total mortgage rates. The combined effect generates house price increases of approximately 7% in low-cost areas and 5.9% in high-cost areas.

However, we see different dynamic effects on goods prices. While the initial period sees inflationary consumer goods prices, subsequent periods are more mixed. We see disinflation in some periods (since our model abstracts from frictions against nominal price declines), followed by subsequent pricing reversals. The price level increases in the long run across both tradable and non-tradable goods, but the trajectory is not uniform. This pattern reflects the complicated interaction of the lock-in channel, migration reallocation, and the reversion of rates. Households which locked in early benefit, leading to continued price pressure, while new entrants face affordabilitiy challenges in the form of persistent high house prices, which forces higher savings and reduces demand.

The net impact on goods prices depends on the distribution of households across borrowers and savers and their respective marginal propensities to consume. In our calibrated model, the positive effect for borrowers dominates initially (resulting in higher prices across the board), while the negative wealth effect for savers becomes more important in some later periods, moderating the inflationary impulse from monetary easing.

6.5 Transmission Mechanisms

The transition dynamics experiment highlights three key transmission mechanisms from mortgage markets to goods markets through housing:

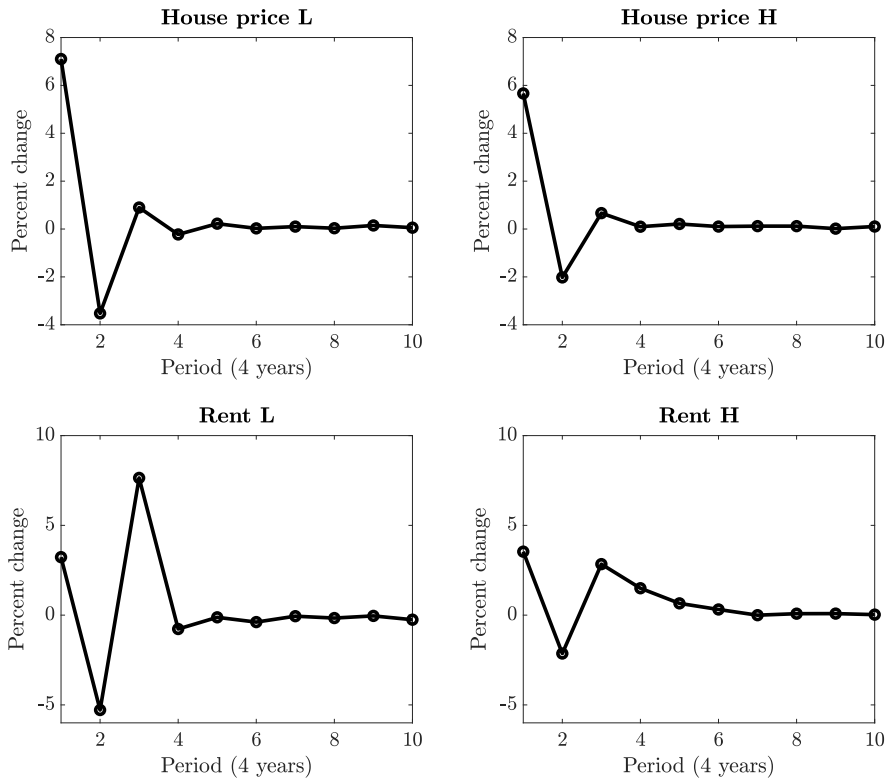
Cash flow channel. Lower mortgage rates reduce monthly mortgage payments for existing homeowners who refinance and for new borrowers, thereby increasing disposable income. This additional cash flow translates into higher consumption demand for both housing (increasing house prices an rents) as well as consumer goods (tradable and non-tradable goods). The channel is most powerful on impact when refi-

nancing and purchasing activity surges, and it is endogenously persistent for households that successfully lock in low rates.

Housing wealth channel. Lower mortgage rates also increase house prices through standard asset pricing effects, redistributing wealth from renters and prospective buyers to existing homeowners. The net effect on aggregate consumption depends on heterogeneous marginal propensities to consume: if constrained renters and first-time buyers have higher MPCs than existing homeowners, the housing wealth channel can dampen consumption even as aggregate wealth increases (*housing affordability channel*). The tension between these effects shapes the non-monotonic dynamics of goods prices.

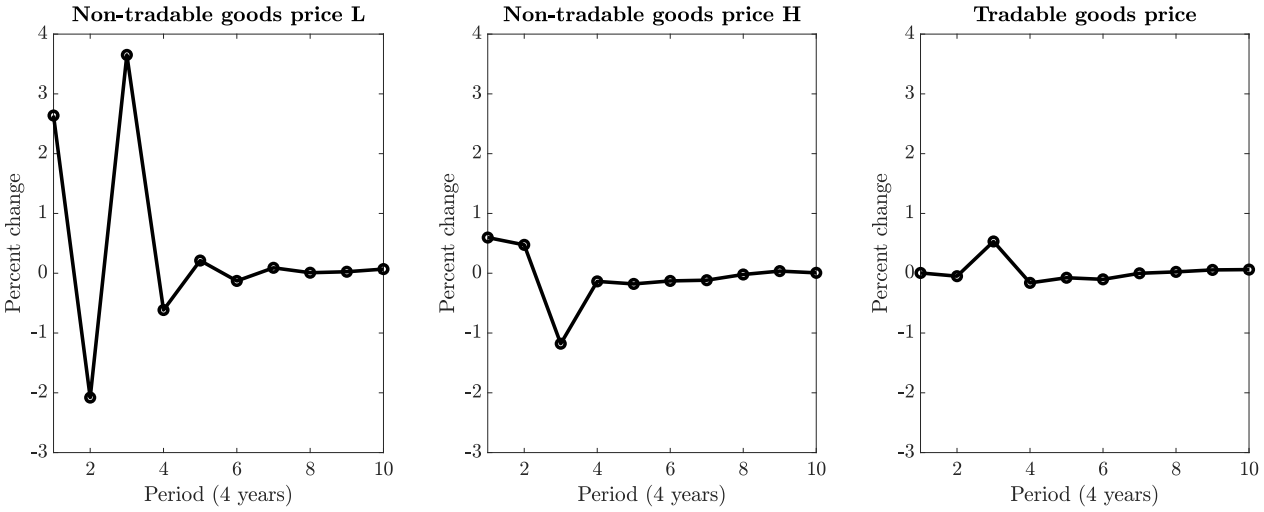
Migration channel. Differential exposure to mortgage rate declines across locations also generates migration flows. This reallocation increases total local demand for both housing and goods in treated areas, amplifying price effects beyond what would occur in a single-region economy and underscoring the importance of endogenous moving choices for equilibrium prices. The ultimate impact on prices depends on the relative supply elasticities between the two regions. The spatial dimension of QE thereby generates redistribution across regions in addition to redistribution across households.

FIGURE 4: DYNAMIC EFFECT OF QE ON HOUSING PRICES: LOWER MORTGAGE AND RISK-FREE RATES



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

FIGURE 5: DYNAMIC EFFECT OF QE ON GOODS PRICES: LOWER MORTGAGE AND RISK-FREE RATES

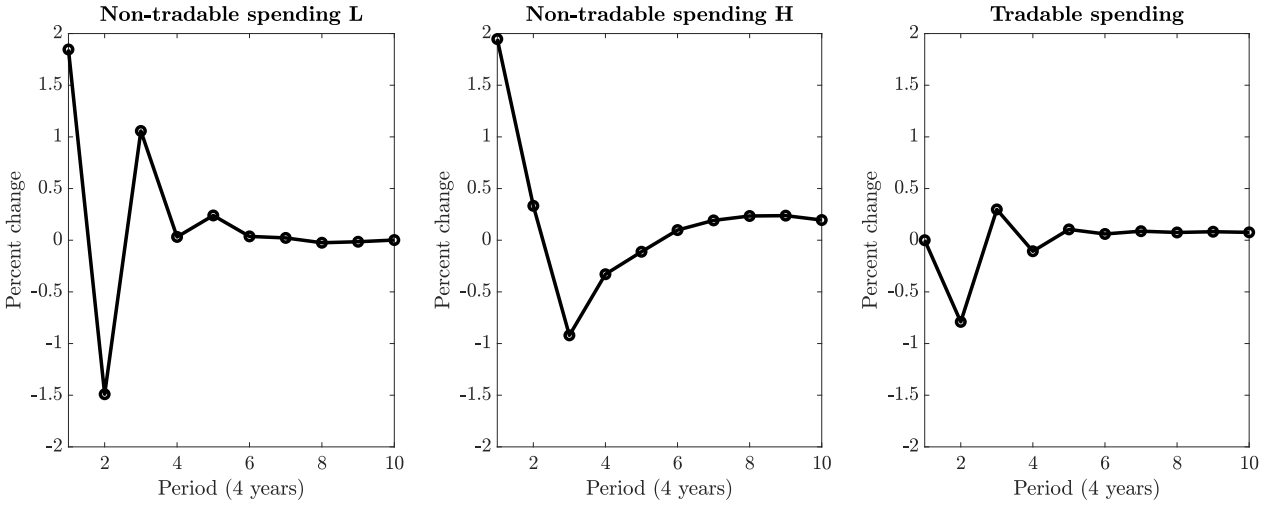


Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

6.6 Partial Equilibrium Spending Response

We next examine how the interest rate shock affects household spending decisions, holding prices fixed at their steady-state values. This partial equilibrium exercise isolates the direct demand-side impulses from QE before equilibrium price adjustment, and thereby helps to clarify the mechanisms underlying the general equilibrium price responses documented above. We examine goods consumption in Figure 6.

FIGURE 6: DYNAMIC EFFECT OF QE ON GOODS CONSUMPTION: LOWER MORTGAGE AND RISK-FREE RATES, NO PRICE ADJUSTMENT



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

We see substantial increases in non-tradable spending across both regions in this experiment. Because we have shut down the housing wealth channel, this suggests that a substantial component of the aggregate demand in this experiment works through the cash flow channel, which reduces obligated monthly spending on the repayment of mortgage interest and principal, thereby freeing up households to spend on other categories of consumption.

After two periods, as rates revert, spending reverts in all categories, and becomes deflationary in non-tradable goods in the low-cost region and tradable goods. This reversal reflects two forces. First, the intertemporal substitution induced by the temporary rate decline reverses: households that front-loaded consumption during the low-rate period now have lower accumulated savings. Second, households that purchased new homes during the low-rate period face ongoing mortgage obligations which crowd out goods spending in subsequent periods, even if these mortgages are at lower rates. By contrast, tradable spending recovers more slowly, reflecting the integrated nature of the tradable goods market which averages across heterogeneous regional demand impulses.

Figure 7 reports the partial equilibrium response of housing consumption, decomposed between owner-occupied and rental segments. Absent the dampening force of house price adjustments, we observe larger increases in the consumption of owner-occupied housing, especially in the low-cost area which experiences a larger reduction in housing. These shifts are the product of substantial substitution away from rental housing, which declines substantially.

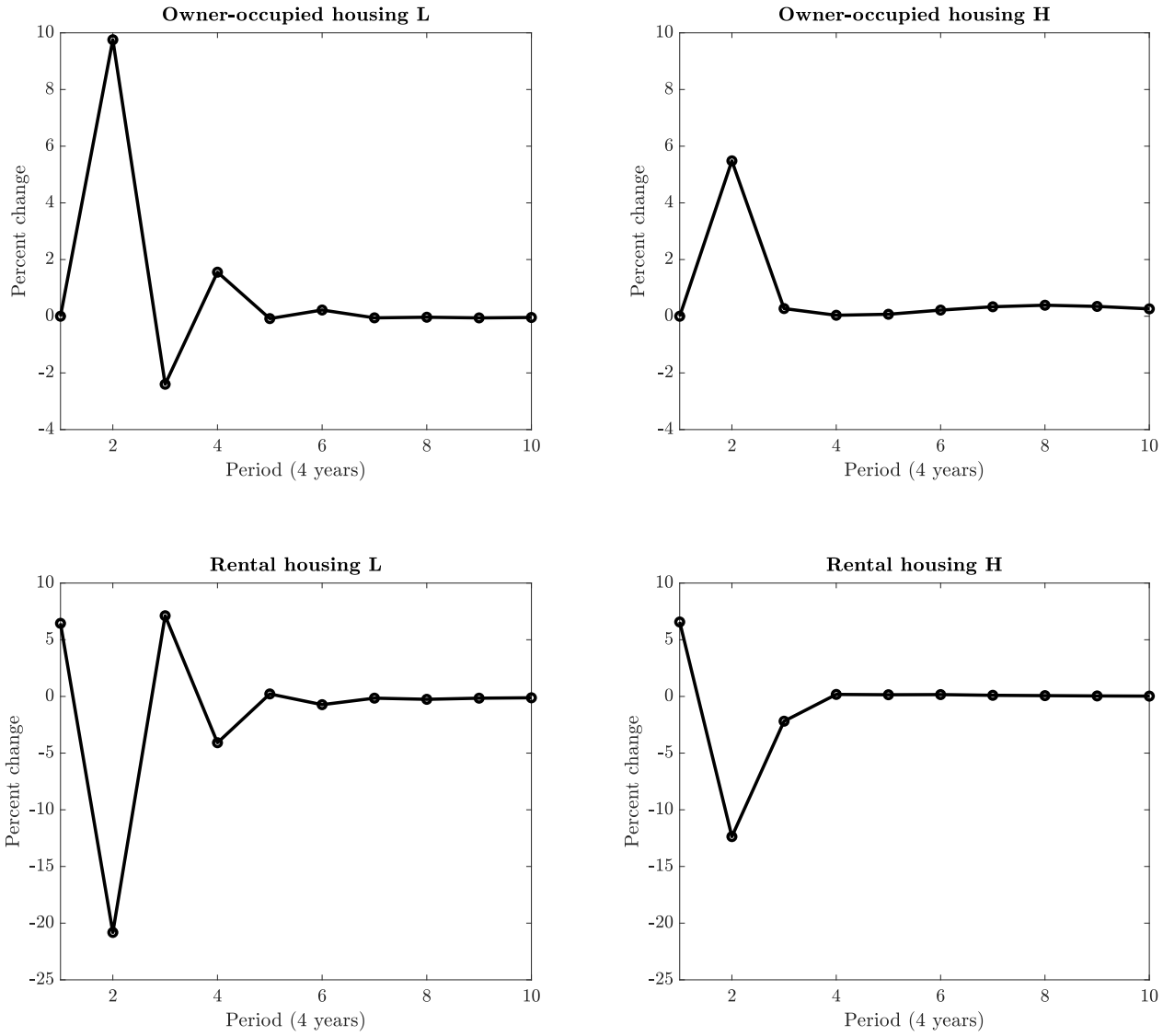
6.7 Decomposition of Mechanisms

To isolate the relative contributions of migration and refinancing to equilibrium housing market dynamics, Figure 8 decomposes the impacts on house prices and rents across areas in two separate counterfactual economies. One in which household migration across areas is shut down, and one in which refinancing is shut down.

This decomposition suggests that refinancing plays a relatively limited role in driving equilibrium price outcomes, as the "No refinancing" counterfactual is virtually on top of the baseline. This is perhaps surprising because of the large observable role we see in refinancing decisions in our counterfactual. However, refinancing itself results in a cash windfall for existing owners, but does little to affect housing demand, especially for new buyers, since refinanced homeowners stay in the same home. The cash windfalls instead largely show up in the consumer goods markets as higher consumption and inflation.

Migration, by contrast, has more nuanced effects. The "No moves" counterfactual actually generate somewhat higher house price effects in the low housing cost area relative to baseline. Without the ability to

FIGURE 7: DYNAMIC EFFECT OF QE ON HOUSING CONSUMPTION: LOWER MORTGAGE AND RISK-FREE RATES, NO PRICE ADJUSTMENT



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

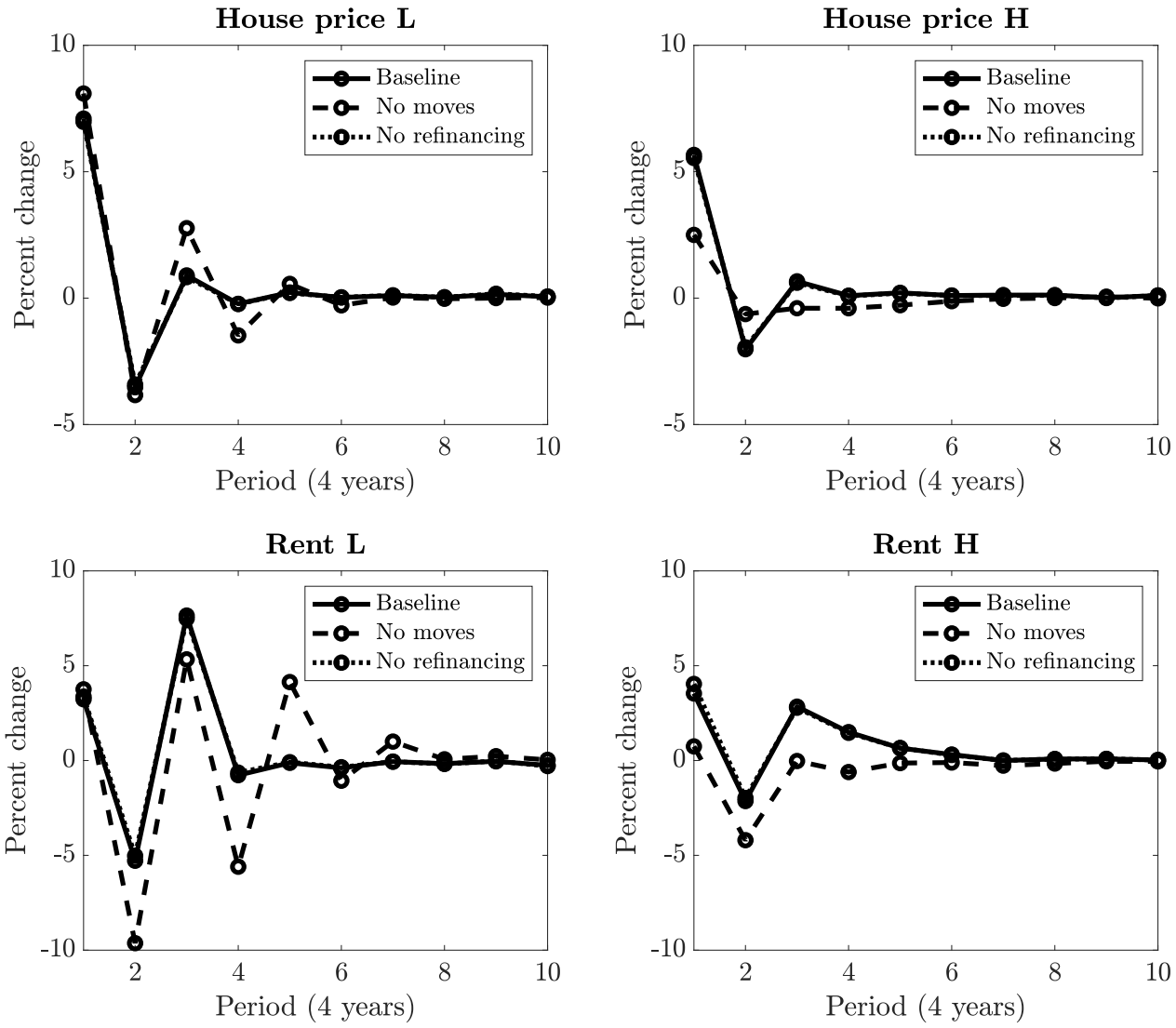
move, all housing demand induced by the conforming rate cut remains concentrated locally, pushing low-cost house prices higher. Conversely, in the high-cost area, shutting down migration slightly reduces the house price response, as the inflow of households attracted by relatively favorable conditions in the high-cost area is eliminated. The differences in house prices between the baseline and "No moves" counterfactual remain modest modest, however, suggesting that migration is not the primary driver of the house price response on impact.

Migration has somewhat more consequential impacts in rental markets, and serves in particular to raise rental demand in the high-cost area while lowering rental demand in the low-cost area. The interpretation is

that, like tradable goods, migration serves as a transmission mechanism to spread spatially uneven shocks across different regions. While the low-cost area experiences a larger interest rate reduction, the resulting pricing adjustments ultimately feed back to the high-cost area as well through tradable goods pricing adjustments and migration responses.

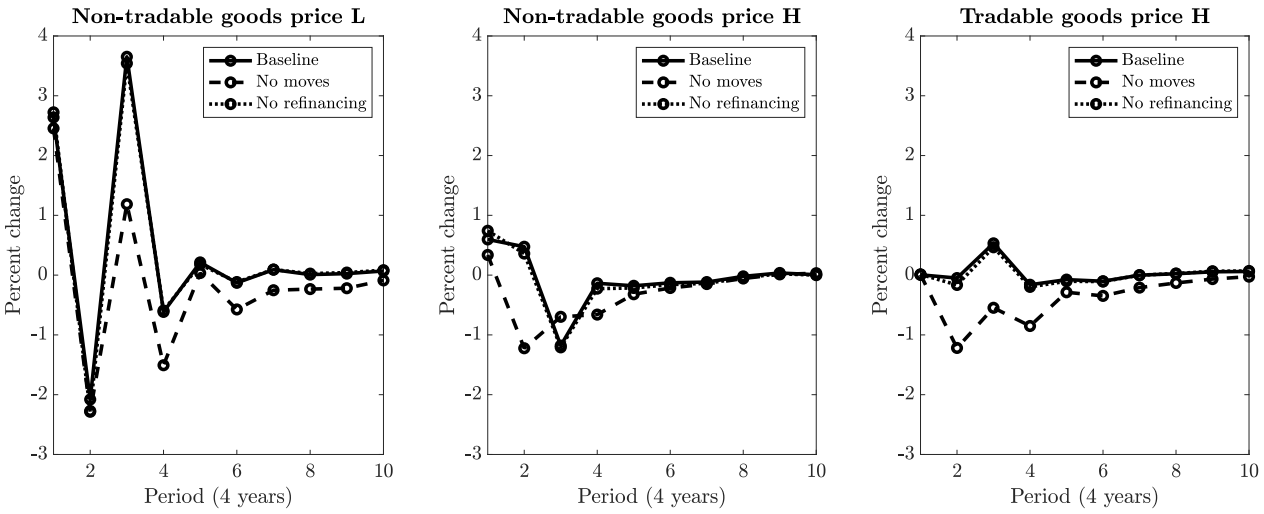
These results highlight that the housing market transmission of QE operates primarily through the direct cash flow and wealth effects, with migration an additional quantitative role, especially in influencing rental markets.

FIGURE 8: DECOMPOSITION OF THE DYNAMIC EFFECT OF QE ON HOUSING PRICES: LOWER MORTGAGE AND RISK-FREE RATES



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

FIGURE 9: DECOMPOSITION OF THE DYNAMIC EFFECT OF QE ON GOODS PRICES: LOWER MORTGAGE AND RISK-FREE RATES



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

7 Dynamic Welfare Impact of QE

7.1 Welfare Computations

Our setting provides a dynamic welfare measure of shocks and policies in an overlapping generations model that is based on *micro level* consumption equivalent variations. This is especially important for shocks and policies like QE that induce significant variations across population groups. Our model of welfare is a one-period consumption equivalent variation.

Definition. Let $V_0\left(s; r_t^b, r_t^f\right)$ be the value function of a household with a vector of individual states $s = \left(a, r_0^b, b, y, j, h\right)$, which consists of their age, individual mortgage rate, net savings, income, geographic area, housing type, and with the aggregate states r_t^b and r_t^f (market mortgage rate and risk-free rate) in the baseline model without shocks (0). Let $V_X\left(s; r_t^b, r_t^f\right)$ be the value function of the same household type in the counterfactual experiment (X) with shocks. The corresponding policy functions for consumption (i.e., the CES aggregator of tradable and non-tradable goods) and housing are similarly index by 0 and X. Computing the dynamic welfare impact of shocks requires keeping track of these policy and value functions over the transition dynamics.

We measure the welfare impact of shocks at date t using the one-period consumption equivalent variation (CEV) $\omega_t(s)$ for this household. We define ω as the one-time change in current consumption in the baseline economy without shocks that would make the household indifferent between living in that econ-

omy and in the economy with shocks. Shocks have a negative impact on welfare when $\omega < 0$, and a positive impact when $\omega > 0$. Mathematically, ω is defined as the change in the household's total consumption basket of both tradable and non-tradable goods and housing services for which the two value functions are equal:

$$V_X\left(s; r_t^b, r_t^f\right) = \frac{\mathrm{u}\left((1+\omega_t(s))c_0\left(s; r_t^b, r_t^f\right), (1+\omega_t(s))h_0\left(s; r_t^b, r_t^f\right)\right)^{1-\gamma}}{1-\gamma} + \Xi(s) - m(s) - c^r(s) + \beta \mathbb{E}_t\left[V_0\left(s'; r_{t+1}^b, r_{t+1}^f\right)\right], \tag{54}$$

Welfare measure. We solve for $\omega_t(s)$ using the homogeneity of degree 1 of both the CES instantaneous utility function $\mathrm{u}(c,h) = ((1-\alpha)c^\epsilon + \alpha h^\epsilon)^{\frac{1}{\epsilon}}$ and the CES aggregator of tradebla and non-tradable goods $c = \left(\theta c_{NT}^\eta + (1-\theta)c_T^\eta\right)^{\frac{1}{\eta}}$, as well as the definition of $V_0\left(s, r_t^b\right)$:

$$\begin{aligned}
V_X\left(s; r_t^b, r_t^f\right) &= \frac{\mathrm{u}\left((1+\omega_t(s))c_0\left(s; r_t^b, r_t^f\right), (1+\omega_t(s))h_0\left(s; r_t^b, r_t^f\right)\right)^{1-\gamma}}{1-\gamma} + \Xi(s) - m(s) - c^r(s) + \beta \mathbb{E}_t\left[V_0\left(s'; r_{t+1}^b, r_{t+1}^f\right)\right] \\
&= (1+\omega(s))^{1-\gamma} \frac{\mathrm{u}\left(c_0\left(s; r_t^b, r_t^f\right), h_0\left(s; r_t^b, r_t^f\right)\right)^{1-\gamma}}{1-\gamma} + \Xi(s) - m(s) - c^r(s) + \beta \mathbb{E}_t\left[V_0\left(s'; r_{t+1}^b, r_{t+1}^f\right)\right] \\
&= \left((1+\omega_t(s))^{1-\gamma} - 1\right) \frac{\mathrm{u}\left(c_0\left(s; r_t^b\right), h_0\left(s; r_t^b\right)\right)^{1-\gamma}}{1-\gamma} + V_0\left(s; r_t^b\right).
\end{aligned}$$

Defining $u_0(s; r_t^b, r_t^f) = \frac{\mathrm{u}\left(c_0\left(s; r_t^b, r_t^f\right), h_0\left(s; r_t^b, r_t^f\right)\right)^{1-\gamma}}{1-\gamma}$, we obtain a closed-form expression for the CEV:

$$\omega_t(s) = \begin{cases} \left(\frac{V_X(s; r_t^b, r_t^f) - V_0(s; r_t^b, r_t^f)}{u_0(s; r_t^b, r_t^f)} + 1\right)^{\frac{1}{1-\gamma}} - 1 \text{ if } \gamma > 1 \\ \exp\left(V_X(s; r_t^b) - V_0(s; r_t^b, r_t^f)\right) - 1 \text{ if } \gamma = 1, \end{cases} \tag{55}$$

7.2 Results

We evaluate the welfare consequences of QE by computing one-period consumption equivalent variations (CEV) for each household segment along the transition path for a policy shift which alters both mortgage and risk-free rates. We compare partial equilibrium welfare effects in Figure 10 which hold all prices fixed at steady-state levels against results in Figure 11 which also incorporates general equilibrium effects in which house prices, rents, and goods prices adjust endogenously.

Figure 10 highlights generally large and positive welfare effects for most housing segments an regions. The average welfare increases by around 5% of the period's consumption at the time of impact of the policy.

This large increase reflects large welfare gains among renters, who experience substantial gains in both regions.

By contrast, existing homeowners in both areas across the segments of starter (S) and trade-up home (T) experience near-zero or slightly negative welfare effects. Owners already hold housing and do not directly benefit from cheaper entry into homeownership. They gain modestly from refinancing at lower rates and lower flow expenses on their mortgage, but this effect is largely offset by the decline in the risk-free rate, which reduces returns on their liquid savings. This exercise holds fixed house prices, and so also abstracts from housing wealth effects.

These partial equilibrium results would suggest that QE operates as a broadly progressive policy, primarily benefiting renters at the margin of homeownership. However, this conclusion changes dramatically once equilibrium price adjustment is taken into account.

Figure 11 highlights negative impacts of QE at the time the policy is introduced, which actually become more more negative in the subsequent period. While renters continue to largely benefit in this calibration, reflecting lower rental rates, general equilibrium adjustments dampen the extent of rental declines and place households in greater affordability crunches due to higher consumer goods inflation and higher cost of future housing access.

The population of owners also experiences substantial welfare losses in the second period. Even though initial homeowners saw windfalls from refinancing and experience ongoing gains in lower flow mortgage expenses, these are balanced by worse outcomes for new buyers who transition into homeownership in subsequent periods, who must purchase housing at higher valuations. Additionally, all homeowners also face higher user costs, since depreciation (which stands in for higher maintenance, physical depreciation, and property taxes) scales with house prices. This channel is empirically realistic, as large increases in house prices in the aftermath of the pandemic have also coincided with increases in insurance costs and property tax assessments. As a result, the capital increases in housing wealth are balanced against higher flow expenses from both housing-related user costs as well as higher real consumption expenses, which in aggregate worsen the average welfare of this population. This pattern reverses in the subsequent period, which sees increases in welfare for owners at the expense of renters, and welfare changes in aggregate close to zero.

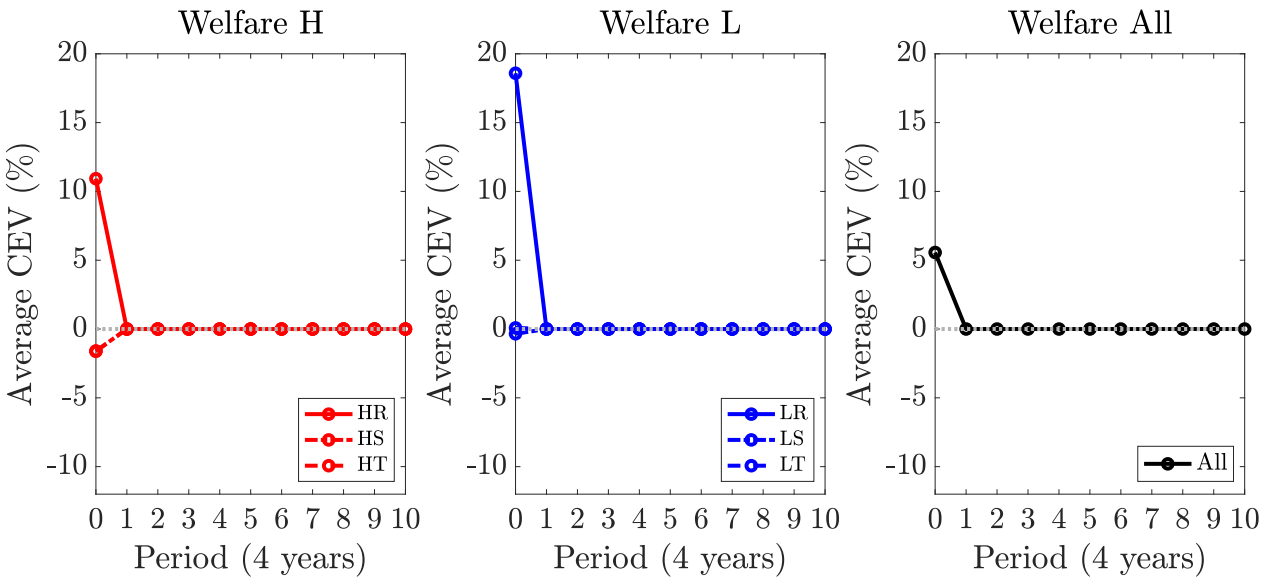
The comparison between the partial and general equilibrium analysis of QE for welfare yields important conclusions about the impact of this policy. It appears that QE is a substantially less desirable policy than a partial equilibrium analysis would suggest. While QE may have had other benefits beyond the ones modeled here (for example, limiting right-tail negative outcomes on housing markets and the broader economy), our results suggest that the scope of broader housing and consumer price adjustments substantially

weakens the welfare impacts of such a policy, and may even make it negative despite the broad success in economic stimulus, due to the importance of inflationary shocks for household welfare.

Additionally, the heterogeneous impact of QE policies on household welfare is important to consider. While renters experience some short-term benefit through a less congested rental market, they also face important long-term affordability challenges as rental markets renormalize, consumer goods markets experience persistent adjustment in price levels, and access to homeownership remains harder due to the persistent house price effects brought about by lock-in effects. Our results therefore can speak to the broader concerns about affordability, which in our model are downstream consequences of demand-side policy interventions themselves. Home owners, also, face important and heterogeneous consequences. While existing home owners receive large windfalls as a product of refinancing and lower flow payments, which persist due to long-term mortgage contracts, they also face higher expenses due to housing user costs and nominal consumer goods prices. New homeowners after the QE intervention face particularly challenging circumstances, since they effectively purchase housing at an interest rate capitalizing the QE reduction, but at normalized rates.

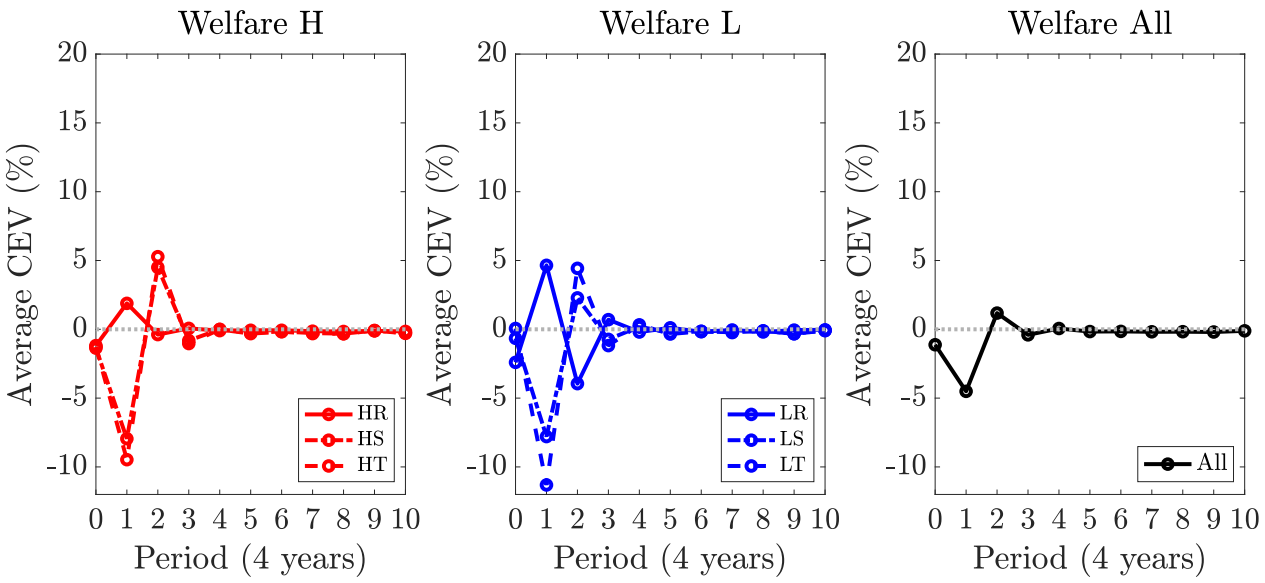
As a result, the biggest beneficiaries of QE in general equilibrium are are instead existing homeowners with locked-in low rates, who tend to be older and wealthier. These distributional consequences persist well beyond the duration of the policy itself, suggesting that the affordability implications of unconventional monetary policy extend over household lifetimes.

FIGURE 10: DYNAMIC WELFARE EFFECT OF QE: LOWER MORTGAGE AND RISK-FREE RATES, NO PRICE ADJUSTMENT



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

FIGURE 11: DYNAMIC WELFARE EFFECT OF QE: LOWER MORTGAGE AND RISK-FREE RATES, WITH PRICE ADJUSTMENT



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

8 Conclusion

The extraordinary and unprecedented interventions by the Federal Reserve over the course of the QE4 episode in 2020 appear to have had substantial impacts on the functioning of mortgage, housing, and broader consumer markets. Unlike prior rounds of QE, the fourth round was considerably larger in scope and continued for a substantial amount of time, even as house prices saw large growth over this time period, the economy had begun recovering from the impact of the coronavirus pandemic, and consumer inflation had started to take off. By exploiting segmented effects around loan thresholds which impact the set of affected mortgage products, we document large changes of QE4 purchases on mortgage rates faced by borrowers, house prices of affected properties at both individual and aggregate levels, as well as labor market outcomes and migration. We then interpret these effects through the lens of a structural dynamic spatial equilibrium life-cycle model.

Our paper makes two key contributions to the understanding of the impacts of Quantitative Easing. First, we find that QE4 substantially amplified pandemic period house price growth. Federal Reserve mortgage purchases reduced conforming mortgage rates by 20-40 basis points relative to jumbo rates, generating 10–15% house price increases in affected segments. This credit supply shock explains a meaningful component of the unprecedented national house price appreciation during 2020–2022, distinct from fundamental demand factors like remote work. This effect was substantial through refinancing, and it was persistent

due to mortgage rate lock-in: households that refinanced at low rates retain those advantages even after monetary policy tightens.

Second, we find that this housing market stimulus substantially contributed to broader labor market dynamics and consumer inflation. Lower mortgage rates transmitted to increases in consumer goods prices through three channels: cash flow effects (lower mortgage payments boost disposable income), wealth effects (house price appreciation stimulates consumption, which reverse over time as affordability pressures bind), and migration (spatial reallocation of consumer demand). The model estimates suggest unconventional monetary policy meaningfully amplified post-pandemic inflationary pressures, with regressive distributional consequences favoring existing homeowners. This is also a non-obvious result due to substantial supply-side pandemic frictions operating in this period. Overall, our results suggest that a substantial component of consumer inflation dynamics can be ultimately attributed to policy decisions by the Federal Reserve.

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Appendix

A Additional Results

A1 Data

TABLE A1: REGRESSION RESULTS FOR LOAN AMOUNTS BY BAND AROUND LIMIT

Panel A estimates a regression of the form: $HP_GR_{i,b} = \mathbb{1}_{2020} + (\mathbb{1}_{2020} \times \mathbb{1}_{\text{below limit},b}) + \mathbb{1}_{\text{below limit},b}$ in which we regress the change in house price in 2020 against an indicator variable for 2020, an indicator for whether properties are associated with mortgages below the conforming loan cutoff, and the key interaction of interest: whether properties have a mortgage below the conforming loan cutoff in 2020. We additionally control for year-month and Zip-code throughout. i indexes houses and b denotes the band around limit: we vary this bandwidth across columns. The base year for comparison is 2019. Panel B renormalizes the treatment shock around the flows of QE purchases: $HP_GR_{i,b} = QE_Flow_{2020,m} + (QE_Flow_{2020,m} \times \mathbb{1}_{\text{below limit},b}) + \mathbb{1}_{\text{below limit},b}$. $QE_Flow_{2020,m}$ is normalized to hundreds of billions of dollars of nominal purchases in 2020 in each month m.

Panel A					
	100k band	50k band	25k band	10k band	5k band
$(\mathbb{1}_{2020} \times \mathbb{1}_{belowlimit,b})$	0.029 ***	0.033***	0.041 ***	0.031 **	0.032
	(0.005)	(0.007)	(0.01)	(0.015)	(0.023)
Observations	350,103	178,786	104,032	59,665	45,323
R^2	0.0011	0.0025	0.0037	0.005	0.0031
$(\mathbb{1}_{2020} \times \mathbb{1}_{belowlimit,b})$	0.013 **	0.020**	0.035 ***	0.032 **	0.047
	(0.006)	(0.008)	(0.011)	(0.012)	(0.03)
Observations	350,103	178,786	104,032	59,665	45,323
R^2	0.153	0.1964	0.2313	0.265	0.2732
Year Month FE	Yes	Yes	Yes	Yes	Yes
Zip-code Treatment FE	Yes	Yes	Yes	Yes	Yes
Panel B					
	100k band	50k band	25k band	10k band	5k band
$(QE_Flow_{2020,m} \times \mathbb{1}_{belowlimit,b})$	0.010 ***	0.012***	0.019 ***	0.015 *	0.012
	(0.003)	(0.004)	(0.006)	(0.008)	(0.012)
Observations	350,103	178,786	104,032	59,665	45,323
R^2	0.0003	0.0018	0.0031	0.0045	0.0026
$(QE_Flow_{2020,m} \times \mathbb{1}_{belowlimit,b})$	0.001	0.003	0.009	0.007	−0.002
	(0.003)	(0.003)	(0.006)	(0.006)	(0.009)
Observations	350,103	178,786	104,032	59,665	45,323
R^2	0.2736	0.2899	0.3056	0.3296	0.3506
Year Month FE	Yes	Yes	Yes	Yes	Yes
Zip-code Treatment FE	Yes	Yes	Yes	Yes	Yes

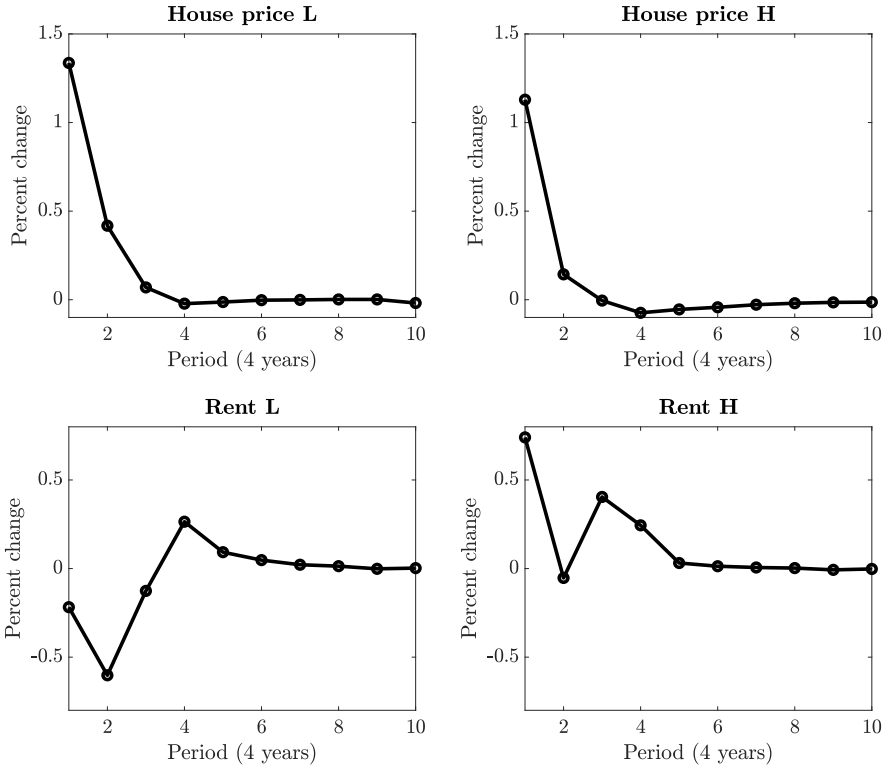
TABLE A2: REGRESSION RESULTS FOR HOUSE PRICES BY BAND AROUND LIMIT * 1.25

This Table alters Appendix Table A1 by adjusting the threshold from the conforming loan cutoff to instead 1.25 $\times$ the conforming loan cutoff, to correspond to the size of a property that can be purchased by a borrower who takes a typical 80 LTV mortgage at precisely the conforming loan limit. Panel A runs the regression $HP_GR_{i,b} = \mathbb{1}_{2020} + (\mathbb{1}_{2020} \times \mathbb{1}_{\text{below 1.25} \times \text{limit},b}) + \mathbb{1}_{\text{below 1.25} \times \text{limit},b}$ and Panel B runs the regression $HP_GR_{i,b} = QE_Flow_{2020,m} + (QE_Flow_{2020,m} \times \mathbb{1}_{\text{below 1.25} \times \text{limit},b}) + \mathbb{1}_{\text{below 1.25} \times \text{limit},b}$. We additionally control for year-month and Zipcode throughout. i indexes houses and b denotes the band around limit: we vary this bandwidth across columns. The base year for comparison is 2019. $QE_Flow_{2020,m}$ is normalized to hundreds of billions of dollars of nominal purchases in 2020 in each month m.

Panel A					
	100k band	50k band	25k band	10k band	5k band
$(\mathbb{1}_{2020} \times \mathbb{1}_{belowlimit,b})$	0.017 ***	0.024***	0.024 **	0.066 ***	0.054**
	(0.006)	(0.008)	(0.011)	(0.018)	(0.025)
Observations	249,300	123,658	64,120	28,089	14,621
R^2	0.0009	0.0014	0.0018	0.0035	0.0064
$(\mathbb{1}_{2020} \times \mathbb{1}_{belowlimit,b})$	0.001	0.018**	0.016	0.055 **	0.092**
	(0.006)	(0.007)	(0.012)	(0.027)	(0.039)
Observations	249,300	123,658	64,120	28,089	14,621
R^2	0.206	0.2685	0.3325	0.4203	0.4643
Year Month FE	Yes	Yes	Yes	Yes	Yes
Zipcode FE	Yes	Yes	Yes	Yes	Yes
Panel B					
	100k band	50k band	25k band	10k band	5k band
$(QE_Flow_{2020,m} \times \mathbb{1}_{belowlimit,b})$	0.008 **	0.014***	0.013 **	0.033 ***	0.024*
	(0.003)	(0.005)	(0.006)	(0.01)	(0.014)
Observations	249,300	123,658	64,120	28,089	14,621
R^2	0.0002	0.0006	0.001	0.0021	0.0052
$(QE_Flow_{2020,m} \times \mathbb{1}_{belowlimit,b})$	0.003	0.009*	0.005	0.016	0.02
	(0.004)	(0.005)	(0.006)	(0.013)	(0.017)
Observations	249,300	123,658	64,120	28,089	14,621
R^2	0.2059	0.2684	0.3325	0.4201	0.4639
Year Month FE	Yes	Yes	Yes	Yes	Yes
Zipcode FE	Yes	Yes	Yes	Yes	Yes

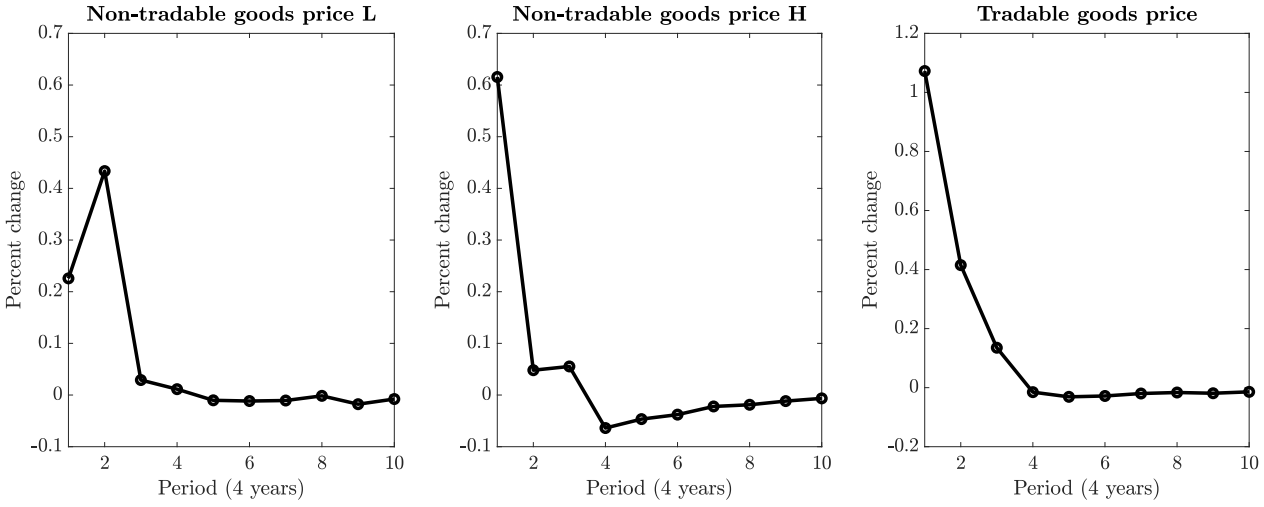
A2 Dynamic Responses to QE

FIGURE A1: DYNAMIC EFFECT OF QE ON HOUSING PRICES: LOWER MORTGAGE RATES



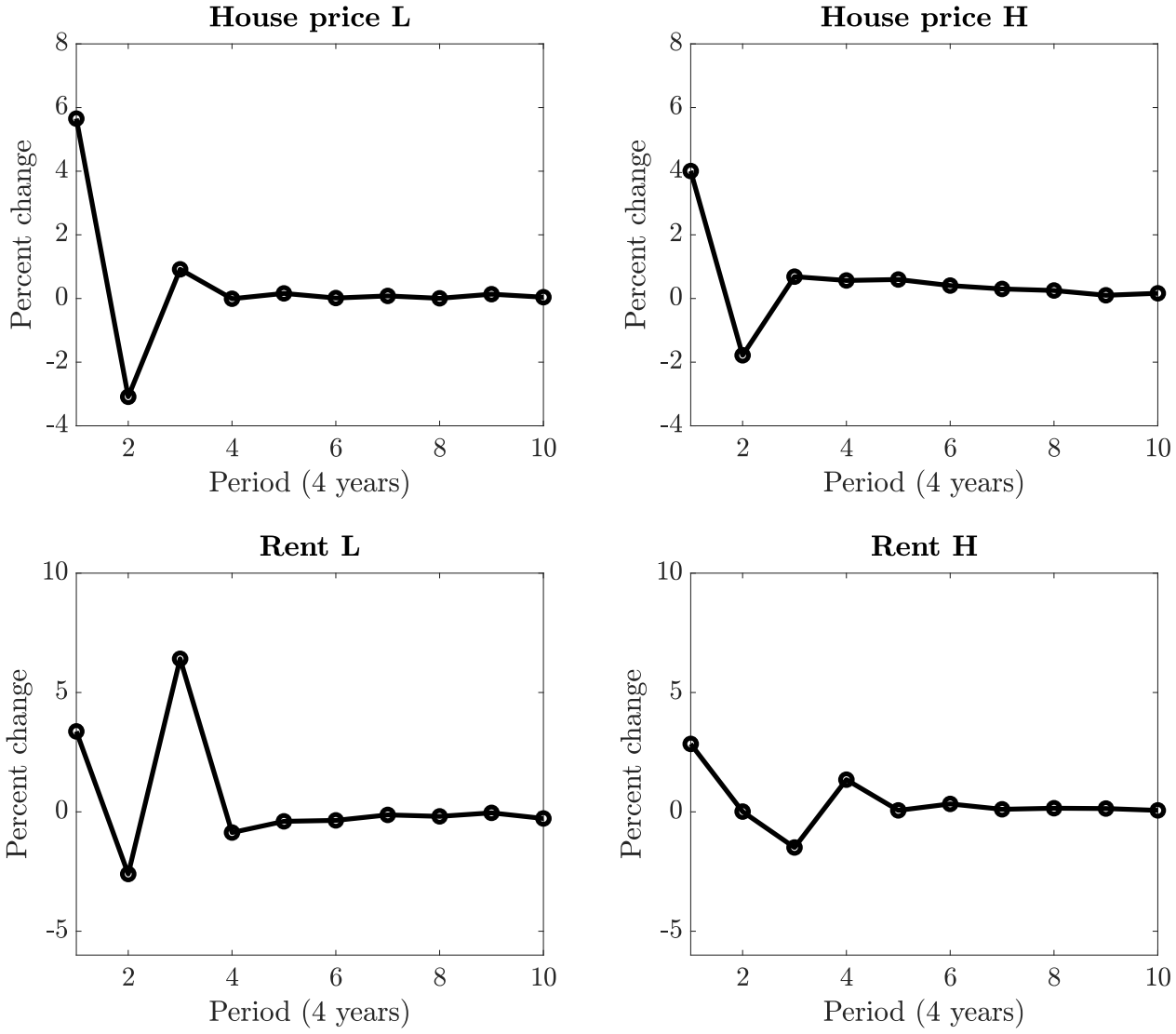
Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage rates, expressed a percentage change from the steady state.

FIGURE A2: DYNAMIC EFFECT OF QE ON GOODS PRICES: LOWER MORTGAGE RATES



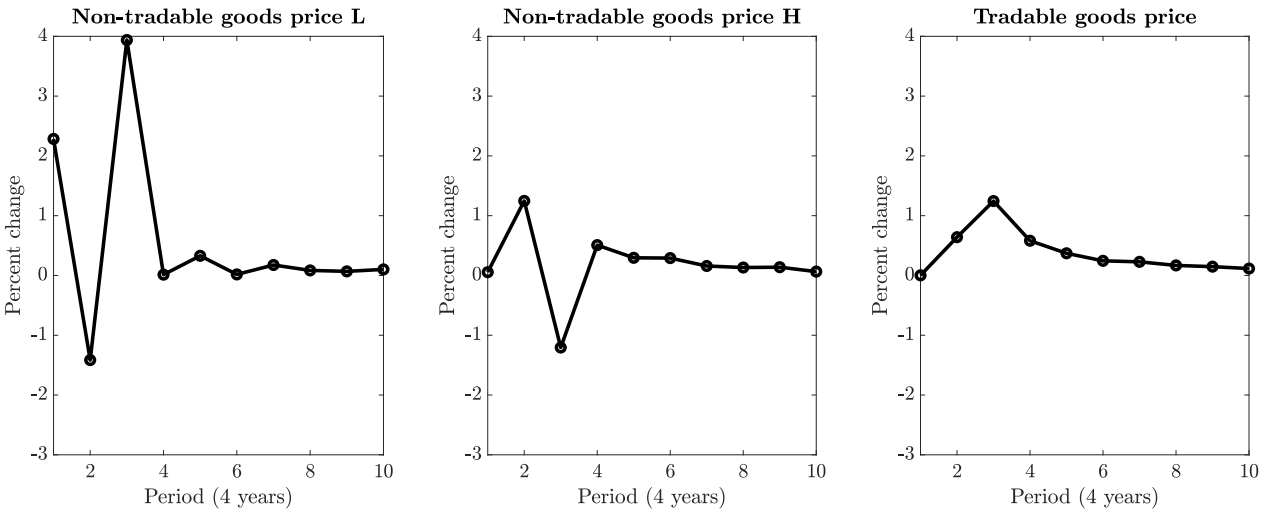
Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage rates, expressed a percentage change from the steady state.

FIGURE A3: DYNAMIC EFFECT OF QE ON HOUSING PRICES: LOWER MORTGAGE RATES



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

FIGURE A4: DYNAMIC EFFECT OF QE ON GOODS PRICES: LOWER MORTGAGE RATES



Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.