Inflation Through the Mortgage Market

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Abstract

This paper studies the affordability consequences of unconventional monetary policy. We build a shift-share design based on mortgage market segmentation and the targeting of Federal Reserve purchases to the conforming market (QE4), and find that house prices and consumer prices rose faster in areas more exposed to rate declines. These estimates validate a dynamic spatial equilibrium model that we use to quantify the aggregate and welfare impacts. The model attributes a substantial share of pandemic-era house price and consumer price increases to fiscal and monetary policy. In general equilibrium, price adjustments imply large and regressive welfare costs through worsened 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. The largest of these programs (QE4) saw the Federal Reserve expand 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). This coincided with a historic deterioration in affordability: house prices rose 32% over 2020–2021, alongside increases in rents and consumer prices, and the ratio of house prices to income reached the highest level in decades. Whether monetary policy contributed to these pressures remains unresolved, reflecting fundamental challenges in estimation. Interest rates are endogenous to economic conditions, and considerable debate persists over the relative contributions of supply (Bernanke and Blanchard, 2025) and demand-side factors over this period. Additionally, even well identified cross-sectional estimates recover only relative effects across areas, and are subject to well-known "missing intercept" problems in aggregation. Finally, assessing the policy implications of any resulting shifts is challenging because house prices, rents, and consumer goods prices adjust jointly in equilibrium. Evaluating the welfare impacts of policy therefore requires accounting for price adjustments across markets.

In this paper, we combine quasi-experimental estimates with structural estimation to show that Quantitative Easing had large positive impacts on the prices of houses and consumer goods, with regressive implications for welfare and affordability. Our results suggest that Federal Reserve mortgage security purchases led to reductions in mortgage rates faced by borrowers, which resulted in an expansion in mortage borrowing and persistent reductions in payments for mortgage borrowers. Our model estimates suggest that a substantial component of the pandemic-era increase in house prices and inflation can be attributed to this credit shock.

Our identification strategy exploits 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 that were the main targets of purchase by the Federal Reserve. We find that QE4 purchases were associated with a decline in conforming mortgage rates relative to unaffected segments, which subsequently reversed in the following period of Quantitative Tightening. We begin by using this segmentation in a motivational discontinuity design and find that house prices differentially increased for properties financed by mortgages targeted by QE4 purchases.

We then turn to our main empirical analysis, in which we use a shift-share strategy to isolate local geographic variation in exposure to different segments of the mortgage market. This allows us to examine how local shifts in mortgage rates impact housing and consumer markets. Our approach combines ex-ante cross-sectional variation in local mortgage market segment shares (conforming, jumbo, and FHA) with

time-series variation in the relative mortgage rates across segments. This approach allows us to condition on fixed effects for both geography and time, as well as granular local controls such as county by year fixed effects when examining outcomes at the ZIP or tract level. This design allows us to isolate local variation in mortgage rates that is plausibly driven by policy intervention but distinct from aggregate economic conditions.

We find strong evidence that the variation in exposure that we isolate translates to the interest rates borrowers face at the local level, and in turn impacts the quantity of mortgage originations. This suggests that our shift-share approach is able to capture an import cross-sectional shock to credit supply. We find these effects passed through to housing markets in the form of higher local house prices, with more ambiguous impacts on rents. We estimate that a 100 basis point reduction in mortgage rates is associated with a local increase in house prices of 11.2%, which is a parameter we later use to help validate our structural model.

We then show that these cross-sectional differences translate to relative inflation in consumer goods and services. We find, for example, that a 100 basis point reduction in the synthetic interest rate we construct in our shift share design leads to a nearly 5 percent reduction in the MSA level regional price parity index, a cross-sectional measure of relative prices, with even larger impacts when focusing specifically on goods markets. Our results therefore suggest important affordability consequences of pandemic area mortage interest rate policy.

We use these findings to help design and calibrate a dynamic spatial equilibrium model, which allows us to better quantify the aggregate policy impacts of unconventional monetary, as distinct from fiscal and conventional monetary policy, as well as assess welfare. The novelty of our model is to jointly endogenize the dynamic paths of local house prices, rents, non-tradable, and tradable goods. The model features housing markets which are segmented within and across two geographic areas. There are two central innovations. 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 fiscal and unconventional monetary policy over this period. We simulate a decline in interest rates which lowers the risk-free and conforming rates more than the jumbo spread, to capture the differential treatment intensity we observe in mortgage rates. We additionally account for fiscal stimulus in this period.

In addition to aggregate moments, the model successfully matches key features of our empirical analysis: house prices and consumer inflation increase substantially across geographic areas, but are amplified

in regions geographically exposed to the quantitative easing due to a local concentration of conforming loans. Importantly, the model closely matches our quasi-experimental estimates of the sensitivity of house prices to interest rates across regions (12.9% in the model). 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 the housing prices, rents, and the prices of tradable and non-tradable goods. 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, which persist for fixed-rate mortgage holders. Second, agents are exposed to higher house prices, which results in more consumption for homeowners with wealth shocks, offset by declines in consumption among renters forced to save more to accommodate down payment requirements (an affordability crunch). Third, our model also features mechanisms for inflationary pressures to transmit across regions through tradable goods and migration. These results therefore highlight the propagation mechanism of QE purchases: 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 incorporating these price adjustments drastically reduces the welfare benefits of QE. Holding house prices fixed, QE leads to an improvement in welfare on average. However, when prices are allowed to adjust, we find that impact on welfare is far lower, and becomes negative on net after policy reverses to a tightening cycle. This reflects affordability costs from higher consumer and housing prices even for households who hold housing choices fixed, as well as large costs for households who transition into homeownership. The only households who gain are those who sell at higher house prices in this period.

One key caveat is that our welfare analysis omits important benefits of QE, including stabilization of financial markets (especially in March of 2020) as well as averting left-tail outcomes in employment and housing markets. We explore employment in our empirical design and find local employment benefits from monetary policy, suggesting an important tradeoff between affordability and stabilization that is not captured by our model. Our welfare estimates are therefore intended as a quantification of the affordability and inflation costs of policy intervention, to be weighed against other benefits.

Our results are also subject to several additional caveats, which we try to address through different robustness exercises. The policy instruments we consider likely interact in important ways. We therefore also decompose the relative roles for fiscal policy stimulus, conventional monetary policy, as well as unconventional monetary policy which specifically targets mortgage spreads. Additionally, policy interventions also likely have impacts on the aggregate price level. We account for this possibility by adjusting the price level to

observed import prices observed at ports, taking an open economy perspective. The resulting quantification suggests that global price changes can account for a majority of observed inflation in this period (consistent with either supply-side shocks or global shocks to demand), but policy factors dominate in explaining the residual consumer inflation in the United States.

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, and thereby exacerbate concerns about housing affordability and horizontal inequity in housing access across generations. 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 financial stabilization and affordability.

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 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 focusing on housing wealth effects (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. Fonseca et al. (2024) use a related framework to study the dynamic equilibrium effect of mortgage lock-in on housing market. Another set of papers (Aladangady et al., 2024; Fonseca and Liu, 2024; Liebersohn and Rothstein, 2025; Batzer et al., 2024) explore lock-in empirically. 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, 2011). 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 connect 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

Since the global financial crisis of 2008, Quantitative Easing (QE) has increasingly been used by central banks around the world. QE interventions differ from conventional monetary policy in two key respects. First, QE targets longer-duration assets and assets with credit spreads, rather than operating primarily through short-term risk-free rates such as the federal funds rate, which frequently approached the zero lower bound over this 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 interventions generally entail a prespecified quantity of purchases of various securities.

Figure 1, Panel A, shows flows of purchases of Agency MBS by the Federal Reserve and other stakeholders, beginning in 2013. Panel B shows the stock of all holdings. Because of large-scale purchases of MBS in earlier QE waves (notably QE1 in 2008 and QE3 in 2012), roughly 20% of the entire stock of Agency MBS were held by the Federal Reserve in 2013. This fraction remained relatively stable in the lead-up to the COVID-19 pandemic.

The fourth round of quantitative easing, conducted during the pandemic, included substantial purchases of agency MBS. These purchases absorbed a sizable share of new mortgage issuance and increased the Federal Reserve's share of outstanding agency securities. The program also included Ginnie Mae securities, though the dominant focus was securities issued by Fannie Mae and Freddie Mac. The intervention was motivated by extreme dysfunction in mortgage markets in March 2020, related to the "dash-for-cash" and strong preferences for liquidity. Purchases in MBS markets, as in Treasury markets, therefore had the objective of stabilizing financial conditions in the face of extreme pandemic shocks.

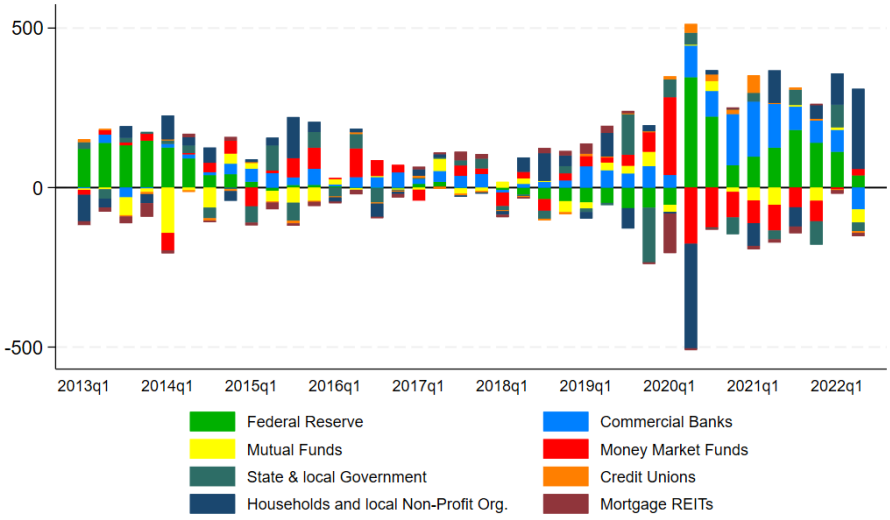
However, these purchases continued well after the introduction of COVID-19 vaccines and broader economic normalization, even as house prices and inflation rose. The national Case-Shiller index grew 11% in 2020, and rose a further 19% in 2021, while the national CPI rose by 7% in 2021 as QE operations continued, tapering in purchases in November of 2021 and stopping only in March of 2022.

This episode also coincided with a substantial increase in the MBS holdings of commercial banks, shown in blue in Figure 1. Over this period, consumer deposits grew substantially, driven by "excess savings" from reduced spending, particularly on services, as well as fiscal transfers through stimulus checks, PPP receipts, unemployment insurance, and child tax credits. Banks appear to have deployed part of these deposits into mortgage markets, both through jumbo mortgages, which are typically held on balance sheet, and through the agency MBS holdings plotted here. The role of financial intermediaries in mortgage lending may have also contributed to lower mortgage rates across market segments (Fang and Xiao, 2025; Drechsler et al., 2024). For both the Federal Reserve and commercial banks, these MBS holdings suffered large valuation shocks during the subsequent period of quantitative tightening, as rising interest rates generated large notional losses (Jiang et al., 2024).

2.2 The Impact of Quantitative Easing on Mortgage Rates

The impact of QE on interest and mortgage rates has been studied in variety of contexts (i.e., Boyarchenko et al. (2019); Fuster et al. (2021); Krishnamurthy and Vissing-Jorgensen (2011)). In this section, we highlight the implications of Federal Reserve purchases on changes in mortgage spreads across different segments during the latest round of QE4, which we use to justify our focus on using this spread variation in our empirical

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



(B) STOCK OF AGENCY MBS BY MAJOR STAKEHOLDER

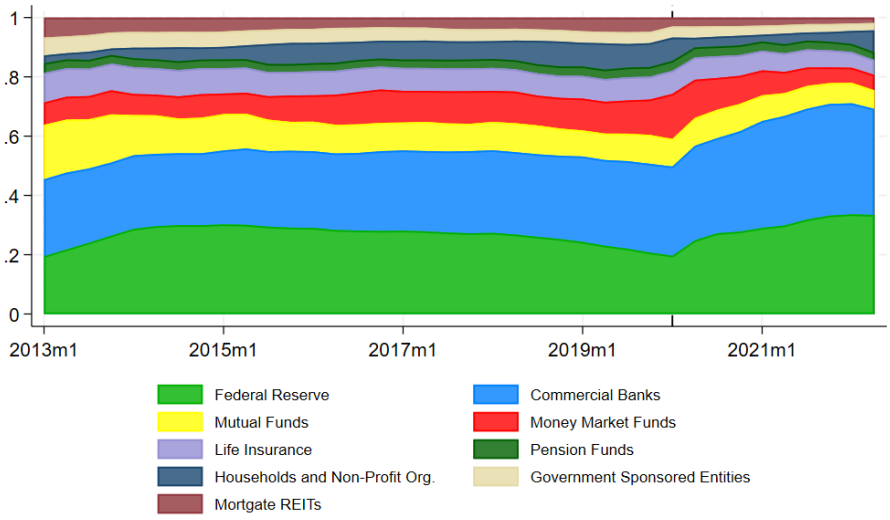


FIGURE 1: EXPANSION OF AGENCY MBS HELD BY FEDERAL RESERVE

design. Figure 2 highlights changes in key mortgage pricing indicators 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, reaching nearly 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 increased substantially.

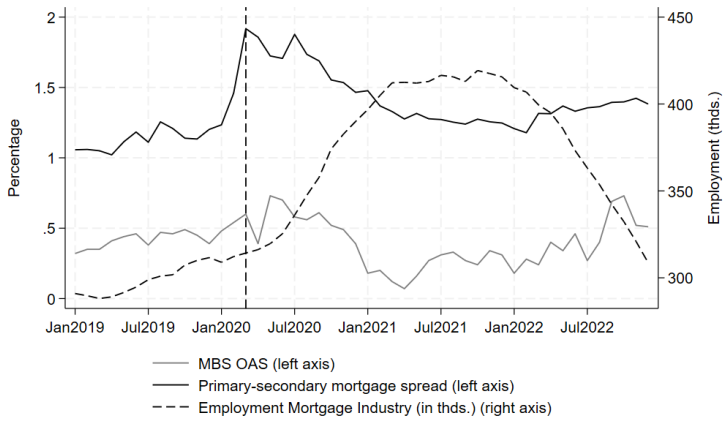
Consistent with this interpretation, primary-secondary spreads declined over 2020 as employment in the mortgage industry grew, suggesting that supply-side constraints in mortgage origination act as an important friction in the passthrough of monetary policy to relevant mortgage rates. As mortgage capacity 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 generally not eligible for Fed purchases.[1]

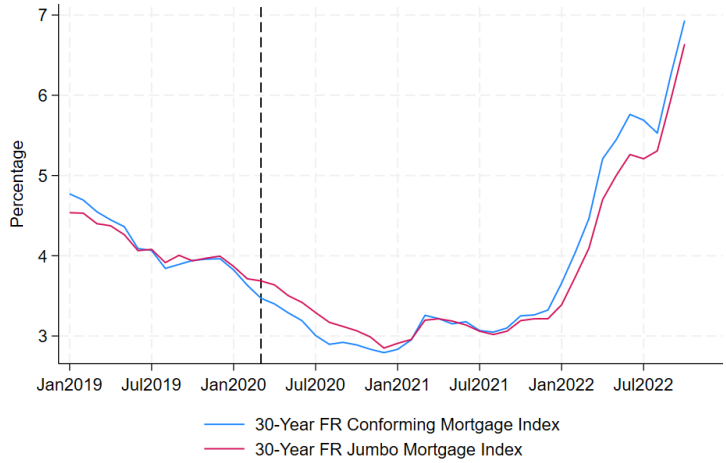
The spread between these two rates is plotted directly in Panel C, as the jumbo-conforming spread, relative to the benchmark policy rate (the Federal Funds Rate). While the spread in the recent period before the pandemic was around 10 basis points, the post-QE period saw a reversal with conforming rates reaching

[1]TBA pools are permitted to contain as much as 10% of balance consisting of super-conforming loans, which are Agency-backed but have a balance between the national conforming limit and local county-specific loan limits.

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



(B) PANEL B: MORTGAGE INTEREST RATES SINCE 2019



(C) PANEL C: MORTGAGE SPREADS SINCE 2019

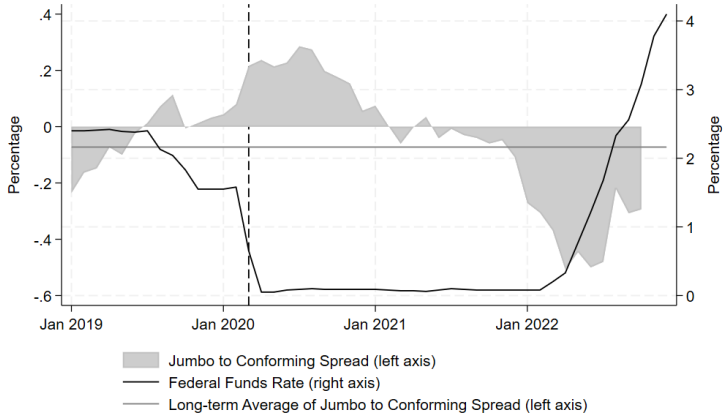


FIGURE 2: MORTGAGE INTEREST RATES OVER TIME

as much as 30 basis points lower than jumbo rates in periods of 2020. These spreads reverted back in the period of Quantitative Tightening as the Federal Reserve began to tighten policy in 2022 as inflation rose.

Conforming-jumbo spreads therefore show meaningful 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 rising relative to jumbo rates as policy tightened. We view the association between mortgage spreads and policy actions as indicative of a substantial role for monetary policy as a driver of relative mortgage spreads in this sample period. This evidence is qualitatively consistent with the findings of Fuster et al. (2021).

2.3 Housing Market Outcomes at the Jumbo-Conforming Threshold

We next examine the implications of the mortgage rate differential across segments for housing and mortgage market outcomes. We begin by showing motivational evidence that the difference in mortgage rates between jumbo and conforming loans led to sharp differences in home prices appreciation at the conforming loan limit, which as discussed above corresponds to the threshhold for inclusion in QE purchases.

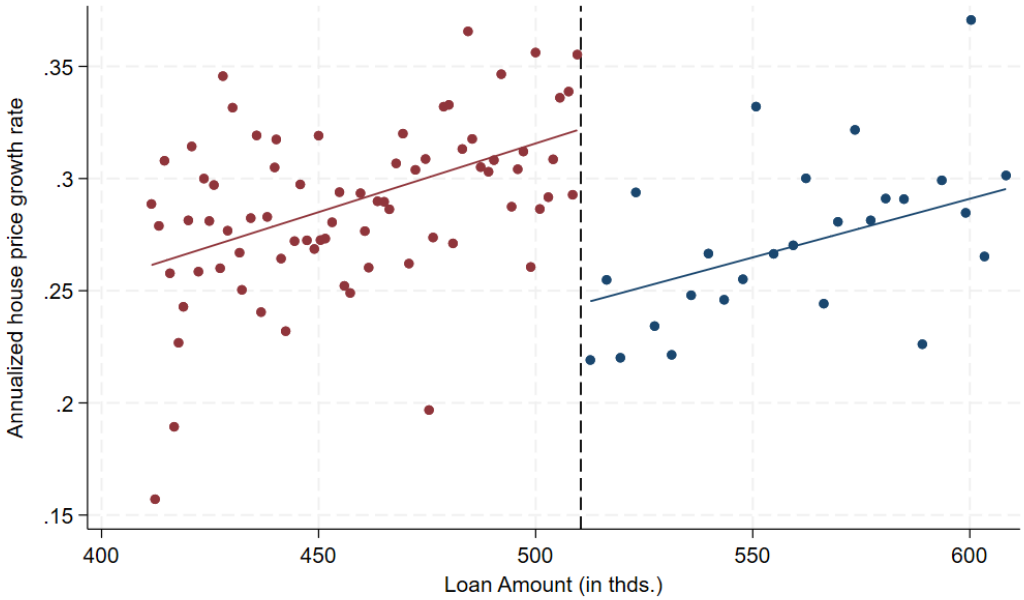
Panel A of Figure 3 shows the annualized house-price growth rate for properties purchased in 2020 with loans just above versus just below the conforming loan limit. To capture house price growth, we use property-level Deeds data and focus on repeat-sale transactions: properties which sell once prior to the year in question, and then sell again at some point in 2020 itself.[2] We adjust for house price appreciation from the origination month to December 2019 using a Zillow ZIP-level house price index, 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 on the impacts of differential interest rates at the conforming loan limit (Adelino et al., 2025; DeFusco et al., 2020; DeFusco and Paciorek, 2017).

We observe a striking discontinuity, with higher growth for loans under the conforming loan limit. For borrowers just below the cutoff—who faced mortgage rates that were roughly 20-40 basis points lower—prices grew by over 30%. Borrowers just above the cutoff saw house price growth of closer to 25%. This pattern is consistent with the notion that cheaper credit for conforming loans raised house prices. In Panel A, Appendix Table A1 we confirm the results in this plot in a regression framework that compares transactions around the threshold while controlling for month and ZIP code fixed effects. This specification is also able to control for any effects from the conforming threshold in general, showing that the effects are driven specifically by periods in which QE purchases were 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

[2]Our Deeds data source is Infutor/Verisk Marketing Solutions.

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



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

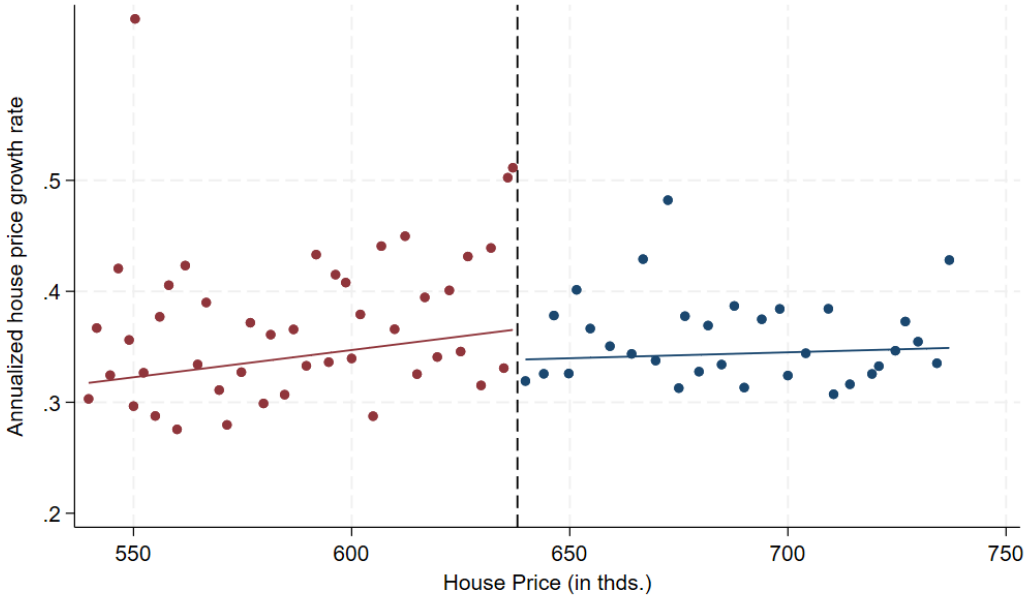


FIGURE 3: HOUSE PRICE GROWTH AROUND CONFORMING THRESHOLDS (2020)

to bunch underneath the conforming loan cutoff. This can be achieved by purchasing a cheaper house (holding the loan-to-value (LTV) 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—with

the aggregate impact on prices depending on the extent to which such purchases represent substitutions away from other foregone purchases.

One step toward alleviating this concern is to use a running variable that is less subject to manipulation by borrowers—the house price itself. In Panel B of Figure 3 we consider the relationship between house price growth and the transaction price, focusing on transactions just above and just below 125% of the conforming loan limit. This 125% threshold represents the purchase price for 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 in house prices at this alternative threshold.

The plot indicates that house price growth is indeed higher for transactions just below this price-based cutoff, compared to transactions 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 that this specification corresponds to a fuzzy discontinuity. Despite some imprecision in measurement, we find a substantial difference in house prices.[3]

The key takeaway from this set of analyses is that differences in interest rates around the conforming loan limit relate to housing demand and prices at the individual property level.

3 The Cross-Sectional Impacts of Exposure to Conforming Rates: A Shift-Share Approach

Given the evidence that differential interest rates across mortgage market segments impacted housing market outcomes during QE4, we next turn to the aggregate impacts across geographies. Specifically, we compare outcomes for areas that were more exposed to conforming loans ex-ante against those which were less exposed. To do so, we develop a shift-share style measure that interacts the 2018 local intensity of different mortgage market segments with time series variation in segment specific interest rates. We show that the resulting variable, which we term the synthetic rate, predicts realized mortgage rates and local expansions of credit supply. These expansions, in turn, appear to impact housing, consumer goods, and other markets.

3.1 Synthetic Rate Measure

We construct a local "synthetic rate" by interacting national mortgage rate shifts by market segment with predetermined local exposure to each segment. For expositional purposes, we describe the construction

[3]We also examine this relationship in regression form in Appendix Table A2, where we show that timing of the effects are concentrated in periods with higher QE purchases.

of this variable at the ZIP level z, but we also consider aggregations at the census tract, county, and MSA in various parts of our analysis. The process for building the variable is analagous at all geographic levels. 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,[4] (2) jumbo mortgages, and (3) conforming mortgages (which we measure as conforming mortgages not originated through Ginnie Mae). We compute each ZIP code'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 ($r^J_t, r^c_t, and r^{FHA}_t$) to form a synthetic ZIP-level rate as a weighted average of these three indices, where the weights are given by the 2018 ZIP shares:

$$\text{synthetic rate}_{zt} = s^J_{z,2018} r^J_t + s^C_{z,2018} r^C_t + s^{FHA}_{z,2018} r^{FHA}_t. \tag{1}$$

Because the exposure shares are fixed in 2018, the variation in this measure comes from differential exposure to the time-series variation in segment-specific mortgage rates. We use monthly variation in mortgage segment rates to generate the instrument, and take calendar year averages when connecting to annual datasets.

3.2 Empirical Specifications

We use the synthetic rate measure in two ways. First, we directly regress this local rate exposure shock on other local markets (the "Reduced Form" specification below). Second, we also consider an instrumental variables specification which makes additional assumptions on how rate exposure matters for local markets only through its impact on realized local mortgage rates (see the "First Stage" and "Instrumental Variables" specifications below).

First Stage. We estimate the passthrough of a ZIP code's synthetic rate to 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. In some specifications we additionally include county $\times$ year fixed effects. The key coefficient of interest is β_1, which captures the passthrough of local synthetic rates to local mortgages. If this coefficient is one, higher pre-

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

dicted 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 also directly regress local outcomes on our synthetic rate in our reduced form specification.

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

in which y includes local mortgage origination, housing market outcomes such as house prices and rents, and consumer inflation measures. 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 (or state-by-year) fixed effects. The key difference between this specification and our IV specification is that the reduced form allows for the impact of rate exposure to matter for local areas through channels other than realized mortgage rates (for instance, through mortgage denial or composition channels).

Instrumental Variables. Our IV specification further makes the assumption that the effect of local exposure to synthetic rates comes only through realized local mortgage rates:

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

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.

There are at least two key concerns with the assumptions underlying the IV approach. First, the exclusion restriction requires that, conditional on fixed effects, predetermined 2018 segment shares affect local outcomes only through their exposure to national segment-rate movements. Segment shares may be correlated with local characteristics such as house price levels, incomes, and demographics. While our fixed effects ensure that the variation we isolate does not reflect time-invariant differences in these characteristics, it is possible that particular areas experienced different evolutions through the pandemic era in ways that correlate with ex-ante shares. Our preferred specifications include county-by-year (or state-by-year)

fixed effects, which absorb time-varying regional shocks and ensure that resulting identification comes from within-county variation in exposure, but the concern still holds. Second, the first stage need not capture a pure shift in mortgage rates holding borrower composition fixed. Changes in the synthetic rate may affect observed average interest rates both by changing the rates faced by comparable borrowers and by changing the composition of borrowers, loan types, or transactions observed in the data. If this is the case, the IV estimates may not reflect the impact of a uniform shift in mortgage rates.

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 passthrough in this specification, ranging from 0.31–0.73, depending on the level of aggregation and fixed effects. At the high end of the scale is our ZIP level estimate that includes controls for county × year fixed effects (0.73). This evidence indicates that local exposure to conforming versus other mortgage market segments is highly predictive of realized interest rates. In subsequent IV specifications, we also report the F-statistic from these first stages.

TABLE 1: THE SYNTHETIC RATE AND REALIZED MORTGAGE RATES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Synthetic Rate	0.333***	0.570***	0.345***	0.731***	0.524***	0.306**	0.543***
	(0.015)	(0.022)	(0.027)	(0.044)	(0.114)	(0.129)	(0.141)
Unit of Observation	Tract	Tract	ZIP	ZIP	County	County	MSA
N	345,549	344,283	99,774	96,809	15,609	15,599	4,571
Tract FE	✓	✓					
ZIP FE			✓	✓			
County FE					✓	✓	
MSA FE							✓
Year FE	✓		✓		✓		✓
County × Year FE		✓		✓			
State × Year FE						✓	

Notes: This table reports regressions of average mortgage interest rates on the synthetic rate. The synthetic rate combines national mortgage-rate indices with baseline 2018 mortgage composition shares at the indicated geographic level. The sample covers 2019–2023. Standard errors are clustered at the unit of observation. All specifications include the fixed effects shown in the table. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3.4 Housing Market Outcomes

We next examine the relationship between the synthetic rate and housing market outcomes. In Table 2 we show the impact of local exposure to interest rates on local loan originations (purchase loans only). Columns (1)–(2) show the reduced form specification of equation 3, and columns (3)–(4) show the IV specification from 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).

TABLE 2: MORTGAGE QUANTITIES

Panel A: Total Loans

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate	-18.1***	-12.2***		
	(.77)	(1.28)		
Instrumented Interest Rate			-51.4***	-20.5***
			(2.99)	(2.35)
Unit of Observation	Tract	Tract	Tract	Tract
N	353,099	351,885	345,549	344,283
First Stage F-Stat			514	653
Tract FE	✓	✓	✓	✓
Year FE	✓		✓	
County × Year FE		✓		✓

Panel B: Log Loans

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate	-.37***	-.127***		
	(.0146)	(.025)		
Instrumented Interest Rate			-1.02***	-.221***
			(.0578)	(.0434)
Unit of Observation	Tract	Tract	Tract	Tract
N	353,099	351,885	345,549	344,283
First Stage F-Stat			514	653
Tract FE	✓	✓	✓	✓
Year FE	✓		✓	
County × Year FE		✓		✓

Notes: This table reports tract-level regressions of mortgage quantities on the synthetic rate. Panel A uses total loan counts as the dependent variable, and Panel B uses log loan counts. The synthetic rate combines national mortgage-rate indices with baseline 2018 mortgage composition shares at the tract level. The sample covers 2019–2023. Standard errors are clustered at the tract level. All specifications include the fixed effects shown in the table. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2 shows that mortgage originations respond strongly to the synthetic rate. In our preferred specification with county-by-year fixed effects, a 100 basis point increase in the synthetic rate is associated with 12 fewer loans per Census tract and an approximately 13 percent decline in loans. The IV estimates imply that a 100 basis point increase in realized mortgage rates reduces originations by 21 loans per tract, or a decline of about 20 percent. The first stage is strong, with an F-statistic of 653 in the preferred specification.

These results suggest that local mortgage demand is sensitive to financing conditions in this sample period, and thus that movements in mortgage rates plausibly associated with QE generated meaningful

responses in credit quantities. This result therefore demonstrates the economic relevance of our shift-share variable as a driver of materially different mortgage origination patterns across region.

We next consider the impact of the sythetic rate on—house prices (Panel A) and monthly rents (Panel B) in Table 3, both measured using ZIP level indicies from Zillow. We show the log of prices and rents, so again the results can be interpreted as a semi-elasticity of interest rates on prices with both reduced-form and instrumental variables specifications. In the specification with county by year fixed effects, we observe a semi-elasticity of -0.112 in response to the reduced form variation, and -0.142% in the IV. This is a critical moment establishing the sensitivity of house prices to interest rates in the cross-section, which we subsequently use to help validate our dynamic spatial equilibrium model. The impact on rents (Panel B) is more sensitive to controls, and ranges from a null effect to a 5.9% increase in monthly rents.

TABLE 3: HOUSING MARKET VALUES

Panel A: Log House Prices

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate	-.0758***	-.112***		
	(.00478)	(.00563)		
Instrumented Interest Rate			-.229***	-.142***
			(.0244)	(.00987)
Unit of Observation	ZIP	ZIP	ZIP	ZIP
N	92,970	90,091	92,970	90,091
First Stage F-Stat			157	369
ZIP FE	✓	✓	✓	✓
Year FE	✓		✓	
County × Year FE		✓		✓

Panel B: Log Rents

	Reduced Form		Instrumental Variable	
	(1)	(2)	(3)	(4)
Synthetic Rate	-.00155	-.052***		
	(.00368)	(.00606)		
Instrumented Interest Rate			-.00517	-.0587***
			(.0123)	(.00765)
Unit of Observation	ZIP	ZIP	ZIP	ZIP
N	16,530	15,778	16,530	15,778
First Stage F-Stat			57	193
ZIP FE	✓	✓	✓	✓
Year FE	✓		✓	
County × Year FE		✓		✓

Notes: This table reports ZIP-level regressions of housing market outcomes on the synthetic rate. Panel A uses log house prices as the dependent variable, and Panel B uses log rents. The synthetic rate combines national mortgage-rate indices with baseline 2018 mortgage composition shares at the ZIP level. The sample covers 2019–2023. Standard errors are clustered at the ZIP level. All specifications include the fixed effects shown in the table. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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 R and the non-interest rate components of uc fixed for the moment, 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 4%. Then a 100 bps decline in rates ($\Delta r = -1\%$) reduces the user cost from 8% to 7%, and implies

$$\frac{P_1 - P_0}{P_0} = \frac{uc_0}{uc_1} - 1 = \frac{8\%}{7\%} - 1 = 14.3\%.$$

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 in the cross-section. This result is in contrast to aggregate time-series estimates of the user cost relationship, which typically show weaker relationships. One possible reason is that the arbitrage necessary to make the user cost equation hold in the time-series requires frictionless transitions between owning and renting, which may be challenging due to financial frictions and other constraints. By contrast, the cross-sectional user cost relationship holds as a result of prospective home purchasers being able to arbitrage across space, which may be less prone to frictions.

Our findings indicate substantial passthrough of interest rates into local house prices, roughly in line with frictionless benchmarks in the cross-section. Under the assumption that the bulk of the rate variation is policy-induced, this suggests a substantial impact of QE4 on housing markets in terms of both mortgage quantities and the value of residential properties. These effects also have the potential to impact local ag-

gregate 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 The Impact on Consumer Inflation

The strength of the housing and mortgage market channels suggests that there may be broader implications of the cross-sectional interest rate shocks we study for consumer spending and aggregate demand. However, measuring inflation at local levels is challenging relative to our estimation of house prices. The Consumer Price Index (CPI) is published for only a small set of metropolitan areas, while comprehensive local price data are otherwise challenging to obtain. To address these issues, we use the Bureau of Economic Analysis Regional Price Parity (RPP) Index, which measure the price level of goods and services in each metropolitan area relative to the national average, and which are available annually for a large set of CBSAs.[5]

TABLE 4: CONSUMER INFLATIONARY IMPACTS

	Reduced Form			Instrumental Variable		
	(1) All	(2) Goods	(3) Services	(4) All	(5) Goods	(6) Services
Synthetic Rate	-4.635***	-11.599***	-5.000***			
	(1.348)	(1.746)	(1.529)			
Instrumented Interest Rate				-9.576**	-24.499***	-10.475**
				(4.143)	(8.996)	(4.614)
Unit of Observation	CBSA	CBSA	CBSA	CBSA	CBSA	CBSA
N	1,835	1,835	1,835	1,800	1,800	1,800
First Stage F-Stat				8	8	8
CBSA FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓

Notes: This table reports CBSA-level regressions of Regional Price Parities on the synthetic rate. Regional Price Parities are BEA measures of local price levels, expressed as a percentage of the overall national price level in a given year. Values above 100 indicate prices above the national average, while values below 100 indicate prices below the national average. Columns 1–3 report reduced-form specifications, and columns 4–6 report instrumental-variable specifications. The outcomes are overall RPP, goods RPP, and non-housing services RPP. The synthetic rate combines national mortgage-rate indices with baseline 2018 mortgage composition shares at the CBSA level. The sample covers 2019–2023. Standard errors are clustered at the CBSA level. All specifications include CBSA and year fixed effects. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Our results, shown in Table 4 4, show that differences in local mortgage rates translate directly into differences in consumer prices. A 100 basis point decline in the local synthetic rate is associated with a 4.64 increase in the CBSA price level. Because the RPP index is normalized at 100, this can be interpreted roughly as a 4.64% increase in the price level relative to the national average. The increase is larger in our IV specification (9.6), and is also higher for goods than services.

[5]The prevalence of uniform pricing across retail establishments (DellaVigna and Gentzkow, 2019) makes it challenging to use retail scanner data for this purpose.

Of course, differences in mortgage rates may also translate to diffeernces in labor maket outcomes, which we explore breifly in our appendix. Appendix Table A3 shows a county-level version of our results in which interest rates are regressed on local unemployment rates. 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. We also find some evidence for migration channels in Appendix Table A4, where we document 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. We discuss the labor market results as highlighting left-tail protections in our analysis on welfare, and consider migration as a household response in our equilibrium spatial model. Together, these results confirm local Philips curve dynamics more broadly (Hazell et al., 2022).

Overall, our findings provide quasi-experimental evidence that movements in mortgage financing conditions—plausibly driven by QE—impact experienced borrower rates and propagate into local economic activity. These reduced form patterns motivate the general equilibrium analysis that follows. While we examine the margins of house prices, rents, migration, and demand for consumer goods individually, these variables are all jointly determined. Additionally, these cross-sectional estimates cannot in isolation recover the aggregate component of the price response due to the missing intercept problem. Therefore understanding the impact of the policy mix on aggregate conditions and welfare requires a structural approach.

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 geographic areas, corresponding to low- and high-cost regions. Within each area, households can either rent or choose one from two owner-occupied housing sizes, either small (starter) or large (trade-up) homes. The regions are intended to map to areas more affected by QE (the low-cost area, with more conforming borrowers) and less affected (the high-cost area).

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. The market for tradable goods is integrated nationwide, with a single price 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 three i.i.d. idiosyncratic shocks, whose realizations differ across households, which capture residual exogenous motives for owning and moving.[6] 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 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.

[6] Idiosyncratic shocks are a standard feature of models with housing (e.g., Greenwald et al., 2021) and migration (e.g., Kennan and Walker, 2011). 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.

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.[7] 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.

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

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

We assume that $r^b_t > r_t$, which implies that borrowers pay back their debt before holding risk-free assets.[8] The amortization schedule of mortgages is exogenous and balances must be fully repaid when old house-

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

[8] 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).

holds die.

Borrowers make endogenous moving and refinancing choices. They keep their initial fixed mortgage rate $r_0^b = r_t^b$ 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 $r_t^b(b_{t+1+s})$. 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.[9] 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 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. 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). The construction of

[9] 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).

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.[10] 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 goods (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 $c_{T,t}^S$ 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, 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:

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

[10] 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.

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:

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

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:

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

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 $r_{0,t}^b$ is $V^{LS}(a, r_{0,t}^b, b_t, y_t; r_t^b)$. 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:

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

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 home-ownership 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 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 $\{r_t^b(b_{t+1}), r_t^f\}$, 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 $\left\{P_t^j, R_t^j\right\}$

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

(iii) value functions $\left\{V^{jh}\left(.; r_t^b, r_t^f\right)\right\}$

(iv) policy functions $\left\{d^{jh}\left(.; r_t^b, r_t^f\right), c_{NT}^j\left(.; r_t^b, r_t^f\right), c_T^j\left(.; r_t^b, r_t^f\right), h^{jh}\left(.; r_t^b, r_t^f\right), b_{t+1}^{jh}\left(.; r_t^b, r_t^f\right)\right\}$

(v) a law of motion for the cross-sectional distribution of households $\lambda_t = \lambda\left(r_0^b, j, h, a, b, y; r_t^b, r_t^f\right)$ over individual mortgage rates r_0^b, 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 variables, 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 5 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) and set to 1.25. It implies that consumption and housing services are moderate substitutes. For non-tradable and tradable goods, we assume that $\eta = -1$. This implies an elasticity of substitution between these goods of 0.5, in the range of available estimates from the literature (see, e.g., for a survey Akinci (2011)), and thus that the two goods are moderate complements.

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 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

TABLE 5: 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	-1	See text
θ	Weight non-tradable vs. tradable consumption	0.60	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	2.50%	See text
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.

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 6 presents the targeted moments and the model's fit.

TABLE 6: 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	1.41
Avg moving rate between areas	0.05	0.05
Homeownership low-cost areas	0.66	0.65
Homeownership high-cost areas	0.64	0.60
C. Wealth, Expenditure Ratios, Default and Refinancing Rate		
Avg wealth/avg income	4.50	4.01
Avg house price/avg income	5.60	5.59
Avg rent/avg income	0.20	0.20
Non-tradable/(non-tradable + tradable) goods share	0.50	0.49
Avg default rate	0.02	0.05
Increase in fraction of refinanced mortgages during QE	+0.17	+0.17

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 $193,328, trade-up homes are $223,223, and monthly rents average $1,181. For high-cost areas, starter homes average $390,774, trade-up homes $478,411, 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 higher rate of 1.41. The average moving rate between areas is targeted at 5% annually, which the model matches exactly. We target a homeownership rate of 66% in low-cost areas (the model generates 65%) and 64% in high-cost areas (the model is slightly below at 60%).

Wealth, 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 4.01 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. To compute this share, we use aggregate spending data from the 2024 U.S. Consumer Expenditure Survey. We assume that non-tradable goods are measured by services and tradable goods by goods spending, and we exclude housing from these calculations. These moments ensure that the model generates realistic household balance sheets and housing affordability constraints.

Mortgage refinancing and default. 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. This implies that the increase in the fraction of mortgages refinanced is about $37 - 20 = +17$ 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 +17 pp. Finally, the model targets an observed default rate of 2% annually, which disciplines the tail risk of mortgage default, which is 5%.

5.3 Non-Targeted Moments

Table 7 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 0.87, with a median of 0.95 and 90th percentile of 0.95, which are close to the comparable statistics in the data. Similarly, the model average PTI ratio is 0.38, with a median of 0.38 and 90th percentile

of 0.50, 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 $37,873 in starter homes in the low-cost area to $63,583 for trade-up homes in the high-cost area. These statistics are generally lower than their data counterparts, but match the heterogeneity in incomes across housing segments and geographical locations. Default rates also vary realistically across segments, from 3.6% for low-cost starter homes to 1.5% for high-cost trade-up homes.

Treatment Effect of QE on House Prices: Cross-Sectional Elasticity of Prices to Interest Rate. 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 $\text{Conventional loan share}_{L,0} = 0.72$ and $\text{Jumbo loan share}_{L,0} = 0.28$ in low-cost areas and $\text{Conventional loan share}_{H,0} = 0.34$ and $\text{Jumbo loan share}_{H,0} = 0.66$ in high-cost areas. After the QE shock, the rates are $r_{low,0} = 3\%$ and $r_{high,0} = 3.3\%$. Hence, the synthetic mortgage rates after the shock are (in decimal terms) $\bar{r}_L = 0.72 \times 0.03 + 0.28 \times 0.033 = 3.08\%$ and $\bar{r}_H = 0.34 \times 0.03 + 0.66 \times 0.033 = 3.20\%$.

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. Because our data only identifies the impact of lower mortgage rates on house prices, we focus on the latter and hold the risk-free rate fixed to compute this elasticity. Section 6.1 describes the computation of the corresponding transition dynamics. We find that the house price responses are $\Delta \log P_L = \log P_L - \log P_{L,0} = +8.85\%$ in

low-cost areas and $\Delta \log P_H = \log P_H - \log P_{H,0} = +7.3\%$ in high-cost areas.

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

$$DID = \frac{\Delta \log P_L - \Delta \log P_H}{\Delta \bar{r}_L - \Delta \bar{r}_H} \times 0.01 = -\frac{0.0885 - 0.0730}{0.0308 - 0.0320} \times 0.01 = -0.129 \tag{53}$$

To replicate the same change in interest rates that corresponds to the data (a 100 bp decrease in the conventional mortgage rate) we multiply the estimate from the second step by 0.01 since the rate changes in the denominator are in decimal terms. We obtain a Difference-in-Differences coefficient equal to -0.129, which is close to the value of -0.112 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).[11] 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 for aggregation.

6 Aggregate 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. Our central counterfactual focuses on the transition dynamics following a temporary interest rate shock, which is meant to reflect the short-term immediately following the QE4 shock. Our baseline approach considers a scenario in which both mortgage and risk-free rates decline (capturing broader monetary policy over this period) together with fiscal stimulus. We also consider experiments in which only mortgage rates decline and fiscal stimulus alone in order to isolate specific policy instruments.

6.1 Transition Dynamics: Response to Transitory Lower Rates and Fiscal Stimulus

We begin by analyzing the economy's response to a temporary unanticipated decrease in interest rates that lasts one model period (four years) before reverting to baseline levels. This experiment is intended to match the QE4 episode, in which 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 at $t = 0$ 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%. In addition, we simulate

[11] We match with our reduced form estimates which correspond to a regional treatment interpretation. However, the model also closely matches our IV estimate, of -0.142.

TABLE 7: NON-TARGETED MOMENTS

Variable	Data	Model
A. Loan-to-Value and Payment-to-Income Ratios		
Avg LTV	0.75	0.87
P50 LTV	0.80	0.95
P90 LTV	0.90	0.95
Avg PTI	0.35	0.38
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	37,873
Avg income in low-cost trade-up homes	54,023	42,549
Avg income in high-cost starter homes	56,892	61,022
Avg income in high-cost trade-up homes	70,607	63,583
Avg default rate in low-cost starter homes	0.014	0.036
Avg default rate in low-cost trade-up homes	0.008	0.015
Avg default rate in high-cost starter homes	0.010	0.019
Avg default rate in high-cost trade-up homes	0.006	0.015
C. Treatment effect of QE on house prices		
Cross-sectional price rate-elasticity (DiD estimate)	-0.112	-0.129

Notes: Moments are annualized. Default rates are computed as a fraction of total default in each area, and thus default rates across segments in the same area sum to the area-wide default rate. The empirical moments are from Fonseca et al. (2024).

income-based fiscal transfers to households that replicate the three main rounds of fiscal stimulus checks in 2020–2021. The first round came with the CARES Act of 2020 and gave $1,200 per adult and $500 per qualifying child; the second round in the December 2020 relief package gave $600 per adult and $600 per qualifying child; and the third round came with the American Rescue Plan and gave $1,400 per adult and per dependent. All tax-filing residents with married household income below $150,000 ($75,000 if single) on average across the three rounds were eligible for the complete amount of transfers. In the model we assume that all households with income below $150,000 receive a one-period (four-year) government transfer of $7,650 (corresponding to the transfer for the average U.S. household size) that is added to their budget constraint. Agents in the model are surprised by the initial shock, then have perfect foresight about future rate changes. We solve for the full nonlinear transition path of prices which clear owner-occupied housing, rental, and goods market at each period during the transition. This is a numerically complex problem for which we combine a shooting algorithm with Anderson acceleration. Section 6.4 reports a parallel exercise

focusing only on the decline in mortgage rates and the fiscal stimulus.

6.2 Main Results

Figures 4 and 5 present the transition dynamics for housing, rents, and goods prices when both mortgage rates and risk-free rates decline temporarily. This scenario corresponds to a broad monetary easing—meant to mimic the real world policy response in 2020—in which conventional policy tools (affecting the risk-free rate and stimulus payments) accompany unconventional tools (affecting mortgage spreads).

House prices increase substantially on impact in both low-cost and high-cost areas, rising approximately 9% and 7% respectively. This suggests an aggregate impact of QE and other policy interventions on overall house prices of around 8%, which is smaller than the amount implied by naively scaling up our cross-sectional empirical estimates. General equilibrium factors therefore play a role in lowering aggregate estimates due to to broader adjustments we incorporate such as migration and price changes. Despite this, our estimates suggest substantial aggregate impacts of policy interventions on house prices (measured in units of our numeraire, wage income).

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.

We observe a reversion in the second period, with house prices falling below the original level, especially in the low-cost region. The reason for this reversal is that many buyer who would have counterfactually have purchased in this time period see their purchases pulled forward into period zero, leaving less demand in period one (when interest rates have reverted). In the second period, house prices bounce back and remain at slightly elevated levels that that slowly converges back to the steady-state. This elevation of house prices, even as mortgage rates have reverted, reflects the role of lock-in effects keeping fixed-rate borrowers in place.

The dampening reflects a *valuation channel* beginning 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 lowers the pace of further house price increases.

Rental dynamics are more complicated and reflect the interplay of three factors. First, lower interest rates push some renters into buying, which pushes down rents. Second, fiscal and monetary stimulus increases aggregate demand, including for rental housing. Third, the valuation channel of higher house price pushes

some potential buyers into the rental market, lowering rents. At impact, rents increase in both regions by 6–7%, suggesting that the aggregate effect dominates. Interestingly, we do not see much of a difference across regions, though the aggregate response is high. This corresponds to our cross-sectional estimates, which are smaller in magnitude and not consistent across specifications, and highlights the importance of using our model for analyzing aggregate impacts (i.e., we would conclude minimal rental impact using the data alone). In subsequent periods, rental rates oscillate, reflecting the complicated interplay of the three forces driving rents.

We also observe strong evidence of inflationary dynamics in goods prices. Initially, we observe strongly elevated non-tradable goods prices in the low-cost area, around 13%. Non-tradable prices increase somewhat in the high-cost area, by 1%, but are concentrated in the region with greater exposure to the stimulus. Consumer prices slowly revert to steady state, but this process takes five periods in the low-cost region (i.e., 20 years).

Tradable goods show inflationary patterns that largely mirror non-tradables in the low-cost area, although they are slightly muted. Despite the reversal of the monetary stimulus, we observe persistent inflation in consumer goods prices reflecting the role of locked-in homeowners being able to continue higher consumption. Importantly, tradable goods serve as an important source of inflation transmission across regions to the high-cost area, which otherwise does not see as much inflation in the cost of local non-tradables.

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.

6.3 Transmission Mechanisms

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

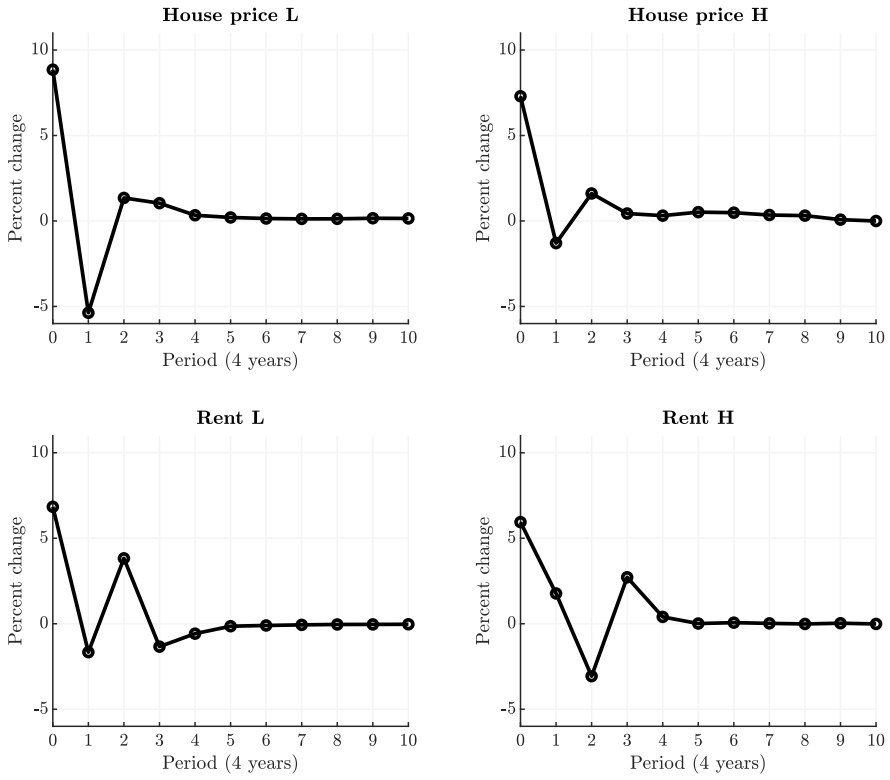
Cash flow channel. Lower mortgage rates reduce monthly mortgage payments for existing homeowners who refinance and for new borrowers, thereby increasing disposable income. This additional cash flow translates into higher consumption demand for both housing (increasing house prices and rents) as well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

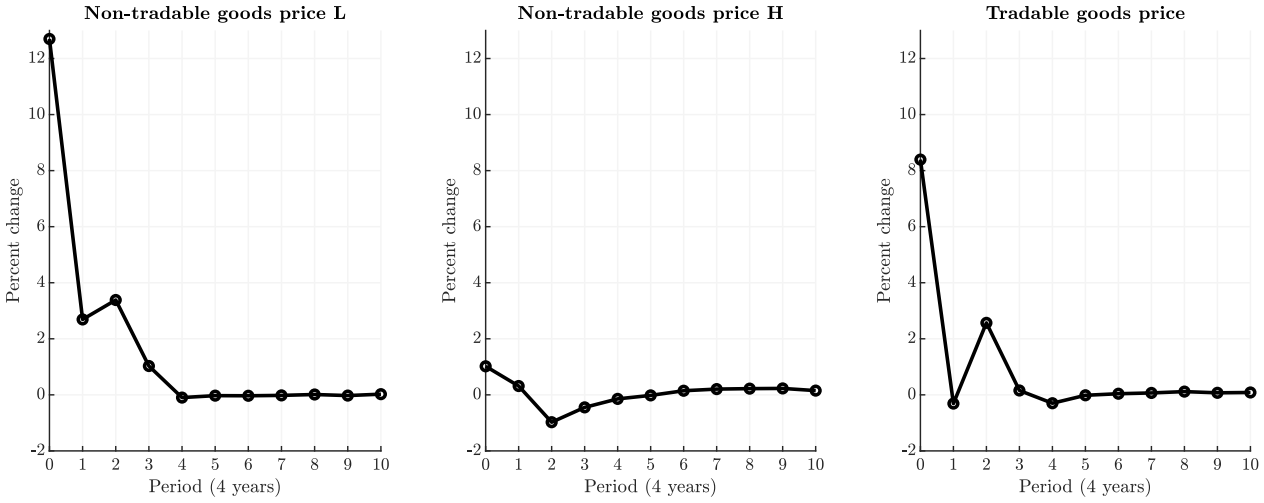
Fiscal Stimulus channel. The stimulus payments represent a more classic transmission mechanism of aggregate demand, to the extent that households have MPCs out of transitory windfalls.

FIGURE 4: DYNAMIC EFFECT OF QE ON LOCAL HOUSE PRICES AND RENTS



Notes: This figure shows the transition path in response to monetary and fiscal policies, expressed a percentage change from the steady state.

FIGURE 5: DYNAMIC EFFECT OF QE ON LOCAL NON-TRADABLE AND TRADABLE GOODS PRICES



Notes: This figure shows the transition path in response to monetary and fiscal policies, expressed a percentage change from the steady state.

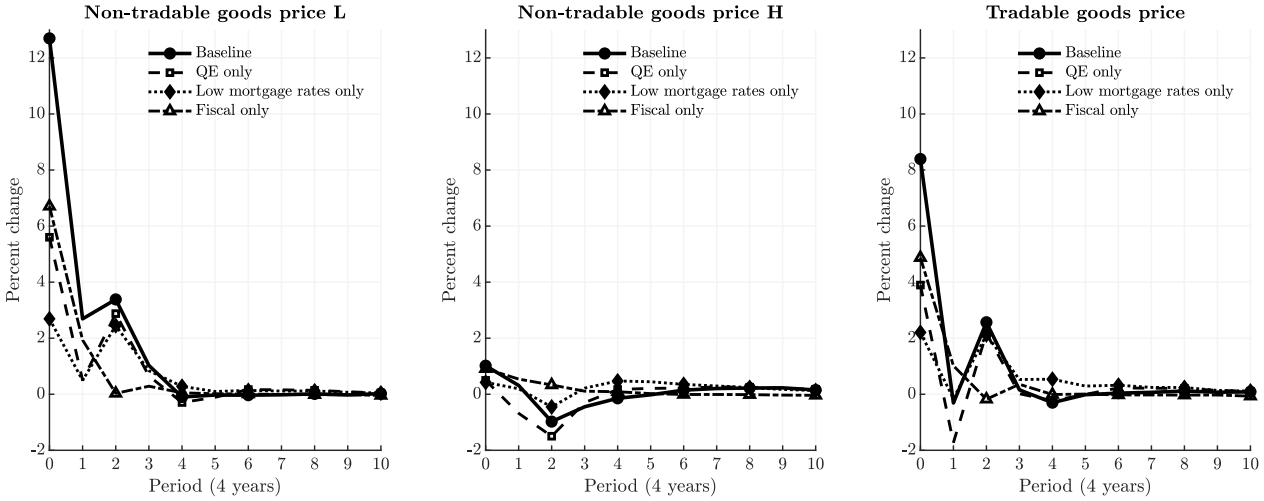
6.4 Decomposition of QE vs. Fiscal Stimulus Effects

In this section, we decompose the effects of monetary and fiscal policies. We compare the price responses to monetary and fiscal policies in the baseline model to the same responses in counterfactual experiments which focus in isolation on the decrease in mortgage and risk-free rates ("QE only"), on the decrease in mortgage rates ("Low mortgage rates only"), and on fiscal stimulus ("Fiscal only").

The results are shown in Figures A4 for housing markets and 6 for goods prices. Monetary policy channels (both conventional and unconventional) play a large role in generating house price effects, while fiscal policy is more important for generating our rental market dynamics. This result is consistent with a house price channel largely reflecting the capitalization of low-interest rate mortgages, while rental markets are more complicated and reliant on lower-income households who disproportionately received stimulus payments.

Fiscal channels also account for roughly half of the overall impact on non-tradable and tradable goods prices at impact, while the remaining half is accounted for by conventional and unconventional monetary policy. Interestingly, the impact of monetary and fiscal policy appears to be roughly additive in the case of consumer goods, but is slightly less than additive in the case of property prices.

FIGURE 6: DECOMPOSITION OF QE VS. FISCAL POLICIES ON LOCAL NON-TRADABLE AND TRADABLE GOODS PRICES



Notes: This figure shows the transition path in response to monetary and fiscal policies, expressed a percentage change from the steady state.

6.5 Decomposition of Mechanisms

In this section, we decompose the contributions of the main model mechanisms to the price responses when the economy is subject to monetary and fiscal policies. We compare the price responses to monetary and fiscal policies on impact in the baseline model to the same responses in counterfactual experiments which turn off various model channels in isolation one at a time. We focus on channels that arise in the dynamic spatial equilibrium of the model: migration effects ("No migration") and the endogenous house price or valuation effects ("No valuation").

Figures 7 reports the effect of the policies on impact. The full transition paths for prices are shown in Appendix Figures A1 and A2. On each panel, the first bar shows the response to the policies in the baseline model. The remaining bars show the response to the same policies in counterfactual experiments that turn off the model channels one at a time.

Mechanically, shutting off the valuation channel results in no house price change. The absence of house price effects lowers the impact on non-tradable goods prices in the low-cost region by about a third, and lowers the impact on tradable goods by about 20%. In contrast, non-tradable goods prices are actually slightly higher in the high-cost region if house prices are held fixed.

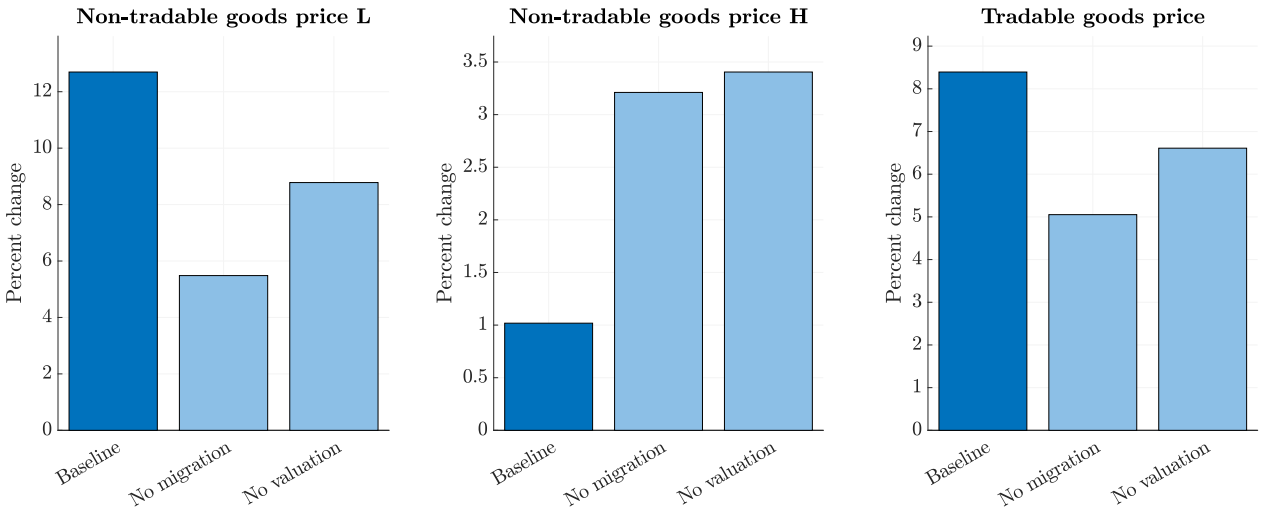
This result has two key implications for understanding our findings. First, it highlights that cash flow channels likely play a key role over wealth or valuation effects in driving inflation. In other words, the cash flow impacts of lower mortgage rates play a key role in facilitating spending, even without a housing wealth effect. Part of the reason why is accounted for in a second key implication, which is that affordability concerns from valuation effects cut both ways for inflationary impacts. Consumer inflation is actually dampened in high-cost areas because local renters have to save more to afford housing, which puts downward pressure on spending and inflation.

Migration also plays a key role. A no migration benchmark features more inflation in the high-cost area, and less inflation in the low-cost area. This suggests that migration towards cheaper area, partially facilitated by the availability of local low-interest rate mortgages, may have further amplified inflationary impacts spatially, while dampening them in existing high-cost markets.

6.6 Robustness: Alternative Numeraire

Our baseline results take as given the wage series, and compute price impacts relative to wages as the numeraire. We use this framework because a key objective of our analysis is to understand affordability, which is well captured by shifts in prices relative to income. However, it is likely in practice that monetary policy also shifts wages across regions and consumers.

FIGURE 7: DYNAMIC SPATIAL EQUILIBRIUM EFFECTS OF QE ON GOODS PRICES



Notes: This figure shows the response on impact to monetary and fiscal policies, expressed a percentage change from the steady state.

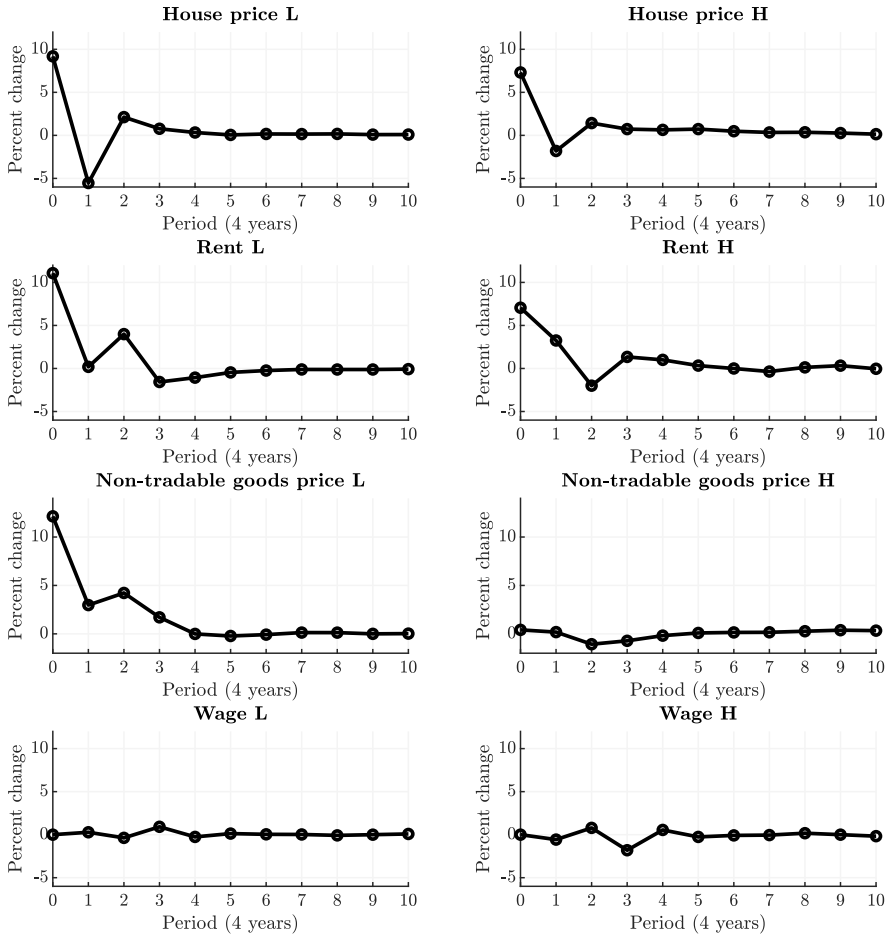
We account for that possibility in this section by adopting the framework of small open economy models and allow the price of tradable goods to serve as the exogenous numeraire. In this model, wages are endogenous in both areas. The price of tradable goods and the resulting inflation path are exogenously taken from at the dock import prices for all commodities by the Bureau of Labor Statistics, similar to the approach of the trade literature (e.g., Cravino and Levchenko (2017)).

We assume that wages are set by competitive firms that have the same fixed capital across areas and make zero profits, and that local labor markets are segmented due to moving frictions and unmodeled geographic differences in industry composition. In each area j, wages are equal to the local marginal productivity of labor: $w_j = \xi A K L_j^{\xi-1}$, where $\xi = 0.66$ is a decreasing returns to scale parameter and $L_j = \int_j y d\lambda_j$ is the aggregate supply of efficiency units of labor in area j (we abstract from the i, a, j, t subscripts on y for brevity). Hence, local wages depend on the local cross-sectional distribution of households through the number of local workers, their age, and their productivity distribution. The difference for the household problem is that y is now multiplied by the wage w; in the rest of the paper, wages are the numeraire and normalized to 1, so they do not appear in the household problem.

We find that the results (Figure 8) are similar under this alternative price normalization. The main difference is that rents increase slightly more than in the baseline, while there is slightly less inflation in non-tradable goods prices. Wages do not vary significantly in response to QE and the fiscal stimulus because the composition of local areas does not vary substantially.

This framework allows us to quantify the respective contributions of global prices and domestic policy to aggregate consumer inflation. Cumulative CPI inflation over the four-year window corresponding to

FIGURE 8: ALTERNATIVE NUMERAIRE: DYNAMIC EFFECT OF QE ON LOCAL HOUSE PRICES AND RENTS



Notes: This figure shows the transition path in response to monetary and fiscal policies, expressed a percentage change from the steady state. The price of tradable goods is the numeraire and it exogenously increases by +13% in $t = 0$ as in the data before going back to 1.

the shock period (2020–2023) was approximately 19 percent. 13 percentage points of this increase in this exercise can be ascribed to the import price increase of global tradable goods, which therefore accounts for two-thirds of consumer inflation. These global goods prices may reflect supply-side shocks, or potentially other demand-side factors which are global in nature. Aggregating the model's impact responses—rents rising 6–7 percent in both areas and non-tradable prices rising 13 percent in the low-cost area and 1 percent in the high-cost area—using expenditure weights consistent with our calibration, results in a policy mix that contributes approximately four percentage points of inflation (21 percent of total inflation). This leaves a residual of two percentage points which may relate to domestic supply shocks or non-policy related demand components. The decomposition supports a view in which global price shocks account for the majority of headline inflation, but the residual is largely attributable to the fiscal and monetary policy mix.

7 Dynamic Welfare Impact of QE

The price responses we document have important implications for welfare, because they redistribute across households and over the life cycle. This benefits some groups while imposing costs on others. This section translates the equilibrium effects of the policies we examine in welfare terms.

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 (four-year) 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 economy 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 $\mathrm{u}(c,h) = \left((1-\alpha)c^\epsilon + \alpha h^\epsilon\right)^{\frac{1}{\epsilon}}$ and the CES aggregator of tradable 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 Welfare 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 start by showing in Figure 9 the aggregate dynamic welfare impact of the policies in the baseline model, and in three counterfactual experiments, which respectively hold housing prices, goods prices, and both of them fixed. When house prices are held fixed, we generally find large and positive welfare effects for most housing segments and regions. The average welfare increases by as much as 18% when housing and goods prices are held at zero at impact. These partial equilibrium results would suggest that QE operates as a broadly progressive policy.

However, this conclusion changes dramatically once equilibrium price adjustment is taken into account. We find that welfare shifts are barely positive at impact, and turn strongly negative in the tightening period, at around 7% of CEV. It takes roughly six periods for the welfare impacts to revert back to baseline.

Looking across the distribution in Figure 10,we see that agents who stay in place (i.e., renters who stay as renters, or owners who stay in place) see welfare loses around 5%, consistent with the inflationary impacts of the model. We observe larger welfare declines for renters who transition into buying, and to a lesser extent for owners of starter homes who buy trade-up homes. This is because households who buy in the period of the rate shock subsequently experience house price reversals. The only agents who see welfare

gains are those owners who sell at high prices and change to renting.

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.

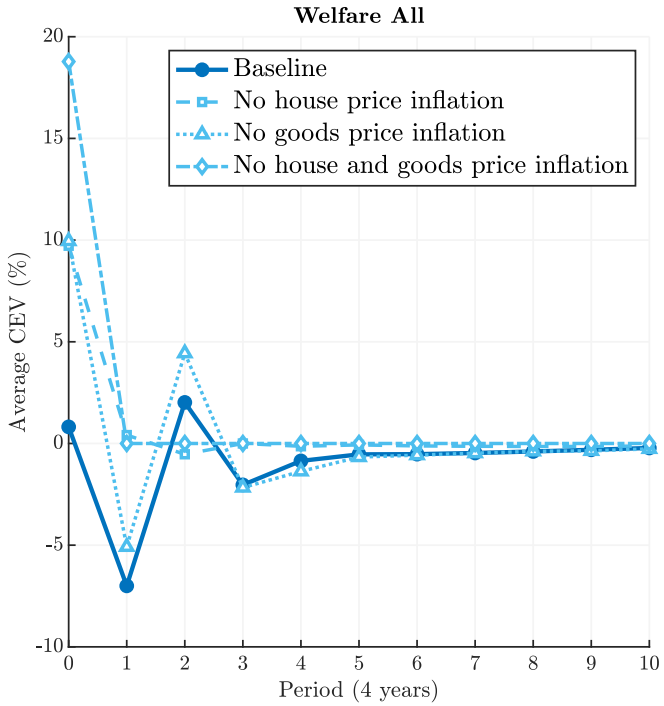
Additionally, the heterogeneous impact of QE policies on household welfare is important to consider. While renters experience some short-term benefit through a less congested rental market, they also face important long-term affordability challenges as rental markets renormalize, consumer goods markets 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. 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.

8 Conclusion

The interventions by the Federal Reserve over the course of the QE4 episode in 2020 had substantial impacts on the functioning of mortgage, housing, and broader consumer goods markets. We document large impacts of QE4 purchases on mortgage rates faced by borrowers in specific mortgage segments. We then exploit segmented effects around loan thresholds to generate regression discontinuity and shift-share designs for quasi-experimental estimates of the causal effects of these rate changes. House prices of affected properties rise at both individual and aggregate levels. We also find meaningful impcats on consumer inflation. We then interpret these effects through the lens of a structural dynamic spatial equilibrium life-cycle model which allows us to aggregate these estimates and evaluate welfare.

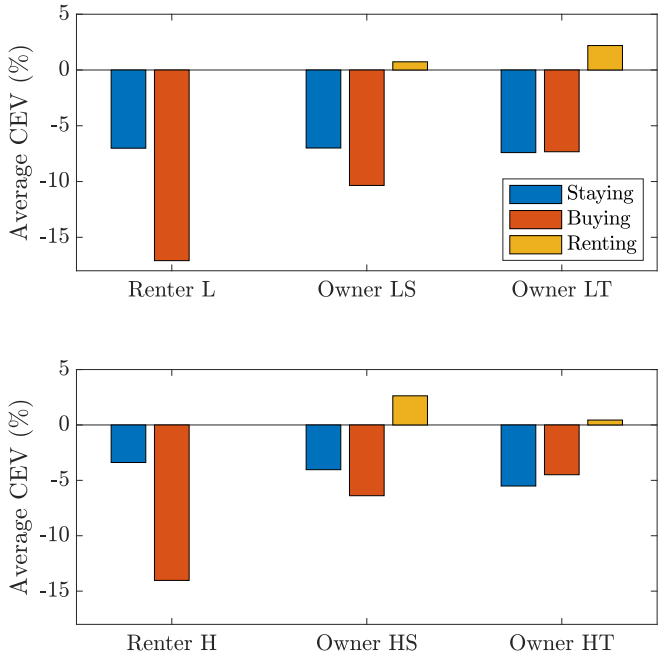
Our paper makes three key contributions to the understanding of the impacts of Quantitative Easing. First, we find that QE4 substantially affected housing markets. Federal Reserve mortgage purchases reduced conforming mortgage rates by 20-40 basis points relative to jumbo rates, generating large house price increases in affected segments. Our aggregate estimates, which account for missing intercept problems with these cross-sectional estimates, suggest economically important aggregate house price increases of around

FIGURE 9: DYNAMIC AGGREGATE WELFARE EFFECTS OF QE



Notes: This figure shows the transition path in response to monetary and fiscal policies, expressed a percentage change from the steady state.

FIGURE 10: TOTAL WELFARE EFFECTS OF QE OVER TIME WITH EQUILIBRIUM PRICES



Notes: This figure shows the discounted sum of consumption equivalent variations over time for the average household in each group, discounted at the model discount rate, in response to monetary and fiscal policies.

8%. This credit supply shock explains a meaningful component of the unprecedented national house price appreciation during 2020–2022.

Second, we find that this housing market stimulus substantially contributed to broader 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). Cash flow effects in particular appear to explain a large component of results. After accounting for the global increase in prices, we find that domestic fiscal and monetary policy can account for the bulk of residual domestic price increases.

Finally, we estimate regressive distributional consequences, with the affordability consequences in the form of higher housing and consumer goods prices lowering welfare for most agents. These results highlight the importance of accounting for general equilibrium effects in assessing the costs of aggregate macroeconomic policy.

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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

TABLE A3: 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 A4: MIGRATION

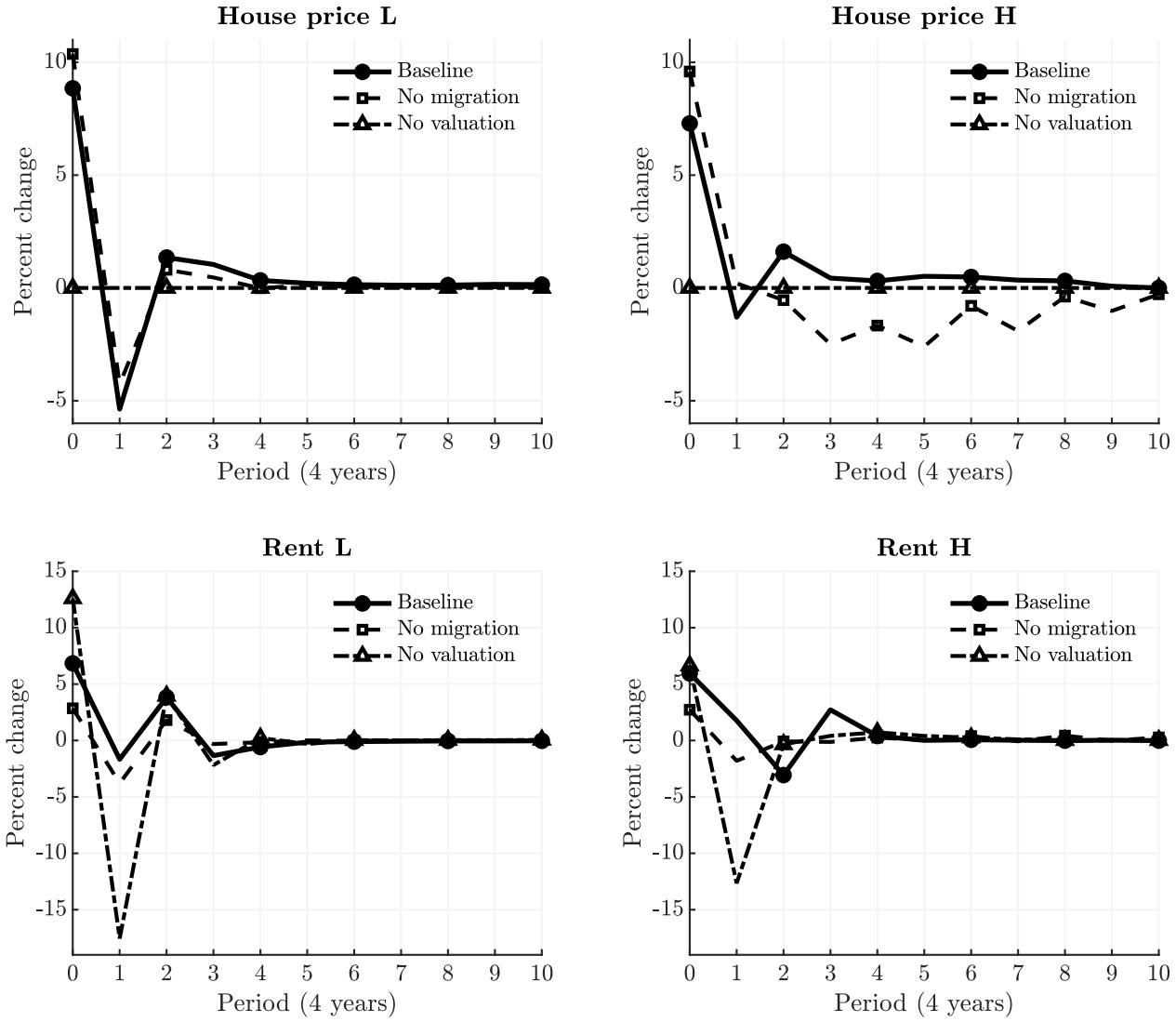
Panel A: Filers (Households)

	(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

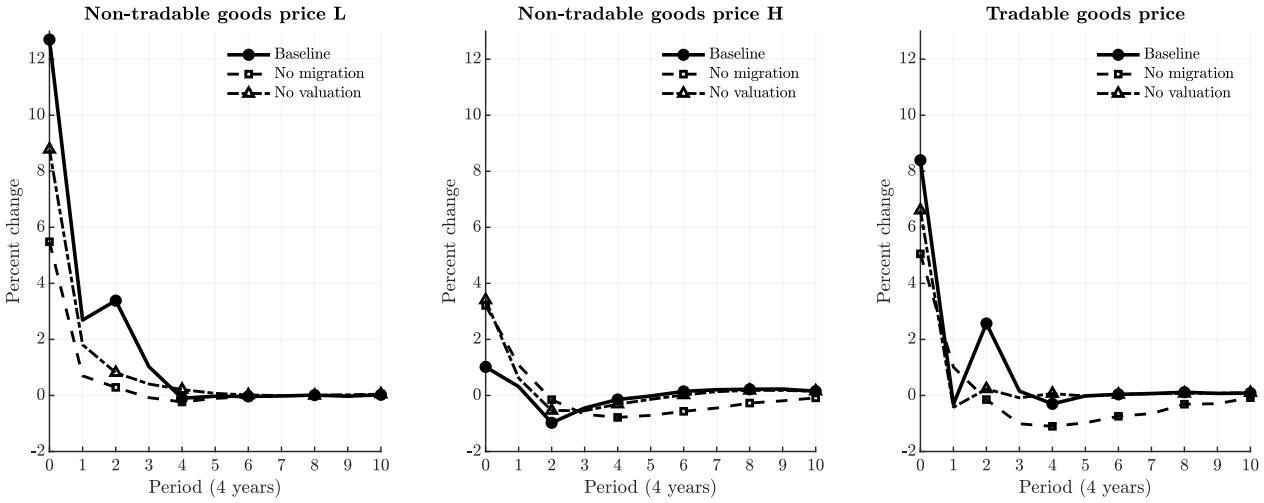
	(1) Net Migration (%)	(2) Net Migration	(3) Net AGI	(4) In Migration	(5) Out Migration
Instrumented Interest Rate	-.0263***	-.0216***	-.0577***	-.00346	.0229***
	(.00749)	(.00741)	(.0139)	(.0043)	(.00463)
Unit of Observation	County	County	County	County	County
N	9,057	9,055	8,949	9,057	9,057
First Stage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

FIGURE A1: DYNAMIC SPATIAL EQUILIBRIUM EFFECTS OF QE ON HOUSE PRICES AND RENTS



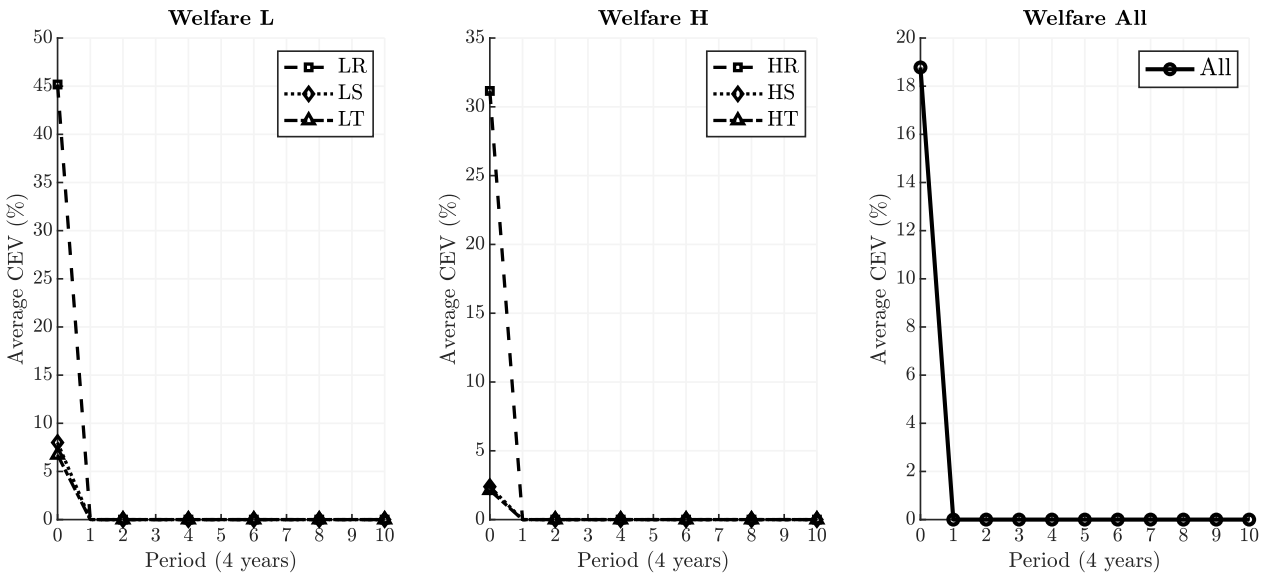
Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

FIGURE A2: DYNAMIC SPATIAL EQUILIBRIUM EFFECTS OF QE ON GOODS PRICES



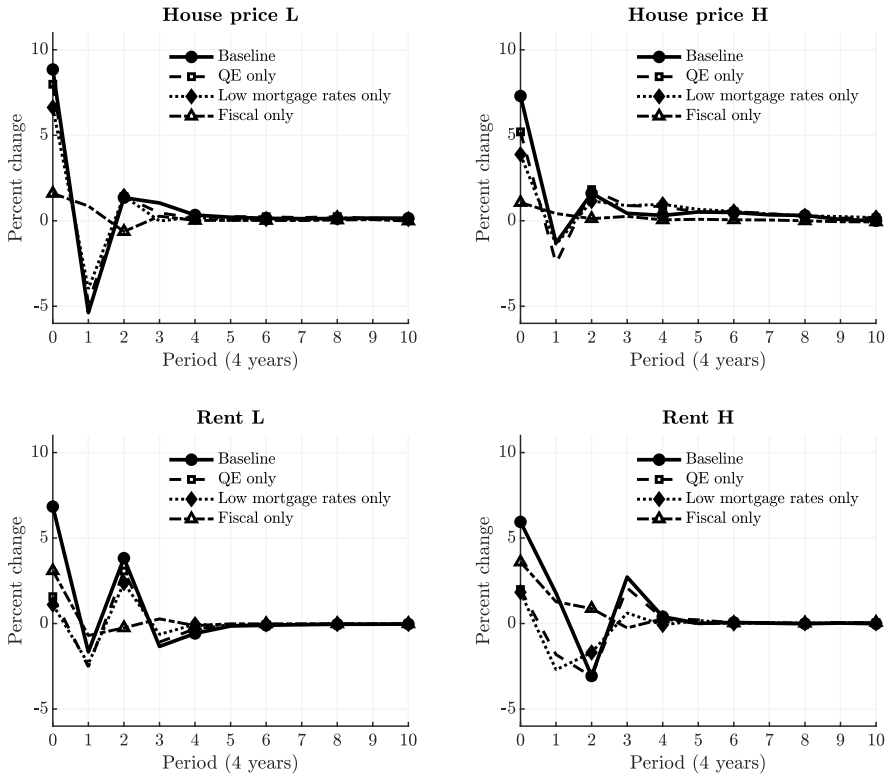
Notes: This figure shows the transition path in response to a transitory unanticipated decrease in mortgage and risk-free rates, expressed a percentage change from the steady state.

FIGURE A3: DYNAMIC WELFARE EFFECTS OF QE WITH FIXED PRICES



Notes: This figure shows the transition path in response to monetary and fiscal policies, expressed a percentage change from the steady state.

FIGURE A4: DECOMPOSITION OF QE VS. FISCAL POLICIES ON LOCAL HOUSE PRICES AND RENTS



Notes: This figure shows the transition path in response to monetary and fiscal policies, expressed a percentage change from the steady state.