Macro Shocks and Housing Markets *

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Abstract

The last two recessions in the United States, linked with the Global Financial Crisis (GFC) and the COVID-19 Pandemic, respectively, caused huge swings in the housing market – but with opposing signs. The GFC was associated with a historic collapse in housing prices, while COVID saw a rapid appreciation. These divergent responses occurred against the background of large scale conventional and unconventional monetary policy and fiscal stimulus in both episodes. With the GFC as a well-studied reference point, we focus on the COVID period and argue that the nature of the shock and macro stability conditions resulted in substantially different housing market outcomes. The pandemic generated a positive demand shock for housing, and strong household balance sheets supported borrowing at the low rates available. However, the COVID housing boom also broadly locked in low rates for existing homeowners. While the rapid rise in mortgage rates that followed increased the cost of ownership at the margin, the lock-in reduced the supply of housing for sale and perpetuated higher prices. We use a transparent modeling framework to illustrate and quantify these dynamics. As long as legacy borrowers remain locked to lower rates, monetary policy transmission is subverted, since higher rates lead to greater lock-in and reduced supply.

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1 Introduction

The last two recessions in the United States, associated with the Global Financial Crisis (GFC) and the COVID-19 Pandemic, respectively, caused huge swings in the housing market – but with opposing signs. The GFC was associated with a historic collapse in national housing prices, while COVID saw a rapid acceleration. These divergent dynamics occurred against the background of large scale conventional and unconventional monetary and fiscal stimulus in both episodes. We argue that the nature of the shock and financial and macro stability conditions contributed substantially to the differential responses of the housing market to policy in these episodes. Notably, the overhang of debt and housing supply in the GFC has been well-studied as a contributor to the persistent stagnation in the housing market throughout the crisis. By contrast, following the initial COVID-19 shock, the housing market boomed.

As was the case with the GFC, the initial COVID-19 shock disrupted financial markets and led to a new round of fiscal stimulus and Fed bond purchases. However, COVID-19 also stimulated demand for single family homes in an environment of new public health concerns and new opportunities for remote work (Mondragon and Wieland, 2022). Rather than being stymied by debt and supply overhang that characterized the GFC, the COVID shock struck in a period of low housing supply and healthy balance sheets. Consequently, the positive demand shock coupled with cyclical fiscal and monetary policy stimulus set off a housing boom, with median sales prices rising by 40% between May 2020 and May 2022. Supply would normally be expected to respond and dampen such a price increase, and in some ways it did. While new construction fell during 2020, the housing stock received a one-time boost from houses brought out of "inventory", as seen by a decline in vacant homes and homes for rent and a corresponding increase in single family owner-occupied homes.[1] Although construction recovered to pre-pandemic levels by 2021, it remained near or slightly below historic trends, and well short of the rapid expansion in demand.

The COVID-19 episode had two distinct monetary policy phases. The initial easing, both in the form of a lower policy rate and asset purchases (QE), sought to shore up consumption and prevent foreclosures through lower mortgage rates (with a substantial assist from fiscal support and forbearance policies). The decline in mortgage rates supported a housing boom, amplified by a preference shock favoring single family homes. This also arguably contributed to inflation through housing services. Ordinarily, this shock to relative demand, or pulling forward of future demand by younger households, might have been met with additional offerings of existing homes for sale or

[1] Whether these homes were occupied by new households or represent greater use of second homes by existing owners is difficult to verify. In principle, the Census data identify primary residence and second homes are "vacant". However, such clear delineation may have been especially difficult during the pandemic. Hence the increase in single family homes may not entirely represent new capacity.

increases in new construction. However, the former was unusually inelastic, as existing homeowners may have stayed in place due to COVID concerns and the larger share of investor properties reduced the response to higher prices (Garriga, Gete, and Tsouderou, 2021). Similarly, new construction never robustly recovered from the financial crisis and productivity in the construction sector remained stagnant at best (Goolsbee and Syverson, 2023). Hence, lower interest rates did little to provide a corresponding increase in the supply of single-family homes for sale.

The second phase – rapid tightening of monetary policy to combat high inflation – succeeded in arresting the rapid growth in house prices, but has not resulted in any meaningful price adjustments that would be suggested by classic user-cost housing valuation models (Poterba, 1984). The Zillow National home value index (Zillow HVI), which peaked in August 2022 after rising 43% relative to its pre-COVID level, fell by less than 1% as of June 2023 from its previous summer peak. As we argue below, ongoing housing supply shortages exacerbated by mortgage lock-in and lesser need to relocate for new jobs all combined to slow down price adjustment and the expected repricing. Ironically, even the slow price downdraft appears to be due, in part, to completion of new housing units started during the ultra-low rate post-covid-lockdowns period.

Although housing remains one of the most interest-sensitive sectors in the US, it is particularly susceptible to constraints by financial market factors. In the post-GFC recovery, housing demand languished despite low rates because of underwater mortgages, leaving relatively unconstrained investors to acquire foreclosed properties. To the contrary, during COVID demand took off, supported by stimulus and an increased preference for single family homes, but supply lagged despite low rates; investor-owners and supply constraints amplified by COVID frictions quashed any meaningful supply response. Later in the cycle, supply bottlenecks eased and more homes reached completion, but rising rates again put downward pressure on new construction. This led to a historic appreciation of home prices and an affordability crisis for new housing market entrants and renters, who did not benefit from holding an initial stock of housing.

Monetary tightening intended to fight inflation would be expected to reverse these trends. However, as in the GFC, frictions in housing markets prevent repricing. Houses stay off the market not because of negative equity but because homeowners have more favorable legacy mortgage terms than the market offers, or "rate lock". Current estimates suggest that more than 90% of homeowners have mortgage rates at least 50 basis points below market rates, with a median gap of nearly 290 basis points. The gap of this magnitude suggests that a refinancing implicit in a home sale and repurchase would cost a household with an average mortgage size of $323,000 an extra $9,300 in interest per year.

By keeping homes off the market, rate lock reduces the effective supply of homes for sale and puts upward pressure on sales prices. Ironically, policies intended to reduce inflation by raising rates, instead increase home prices. This friction can stymie monetary policy transmission when rates are high, especially as it affects one of the most interest sensitive sectors of the economy (David and Gourio, 2023). The mortgage lock effect is in addition to standard frictions from fixed rates which prevent monetary policy and re-pricing pass through (Calza, Monacelli, and Stracca, 2013).

A macro prudential approach could have helped to dampen the booms and busts. It has long been argued that macro prudential policy, both in the form of stricter credit evaluation criteria and rigorous supervisory oversight, could have dampened the mid-2000s housing boom that led to the protracted GFC. Indeed, measures put in place then assured that mortgage quality has since remained relatively high and balance sheets were strong coming into COVID. In the COVID recession, demand unexpectedly expanded due to the pandemic. Policy might have dampened the initial price run up with a different composition or timing of balance sheet policy, for example, as low mortgage rates were particularly supportive of housing demand. Instead, a price boom ensued, exacerbated by a lack of robust supply. The rapid swing in mortgage rates has led to a two tier housing market - incumbents with low rates locked in and aspirants facing both high prices and high rates. *Ex post*, monetary policy has little power to reverse these effects given weak supply from mortgage lock in of existing homeowners and weak construction.

In the next section, we present key empirical features of the housing market, focusing on the COVID-19 period. We elaborate on the broad trends described above to quantify housing market dynamics during this period and discuss potential contributing factors. We then develop a simple model based on Garriga et al. (2021) to connect these house price dynamics to changes in interest rates, demand shocks, supply, and other factors. Calibrating the model to the sub-periods of the COVID experience, we show the crucial role played by mortgage rates and shocks to demand in the house price appreciation from 2019 to 2022. Extending the model, we then show how rate locks can prevent repricing, extending the period of high house prices despite (and partially because of) tight monetary policy.

2 Data trends

U.S. housing prices took a long time to recover from the Great Financial Crisis, as national house price indices did not return to their pre-GFC peak until 2016. Thereafter, national housing prices (as captured by Zillow HVI in Figure 1) grew at an average annual rate of 6.2% through the end of 2019. These dynamics, sustained by historically low mortgage rates, a pickup in rate of household formation by young adults, and tepid pace of new housing construction, were disrupted by the onset of COVID.

The growing threat of COVID in early 2020 led the Federal Reserve to embark on a series of

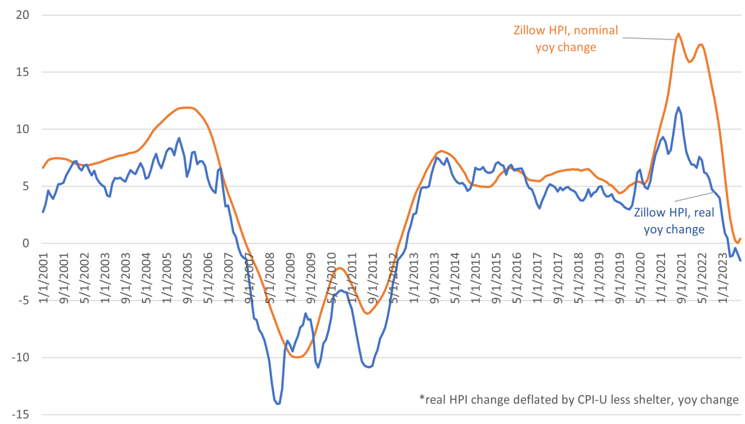


Figure 1: Annual Home Price Appreciation, in nominal and real terms

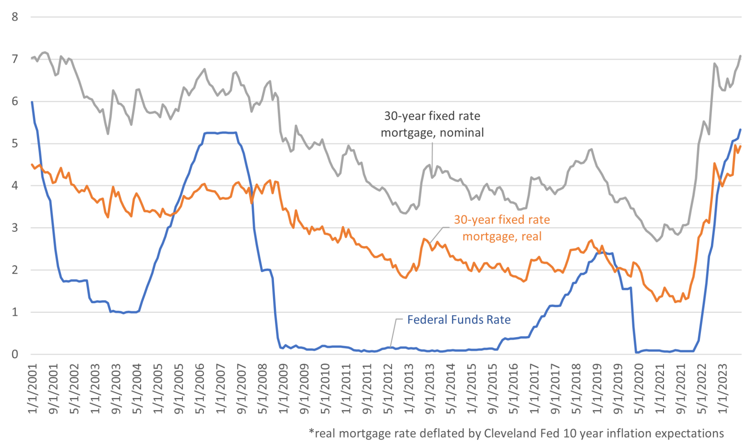


Figure 2: Federal Funds Rate, and 30-year mortgage rate in nominal and real terms

aggressive policy measures aimed at lessening the economic hit from the pandemic. Having already enacted four quarter-point rate cuts in the second half of 2019 in response to weakening economic conditions, the FOMC dropped the policy rate by additional 100 bps in two unscheduled meetings on March 3 and March 15, 2020. This was followed by another 50 bps cut in April that took the policy rate to its zero lower bound (ZLB). Concurrent with these policy actions, the Federal Reserve sought to counteract severe financial market disruptions in March 2020 by launching a number of 13(3) facilities and by ramping up its asset purchase program (QE). A substantial part of the latter effort went towards purchases of mortgage-backed securities (MBS).

These actions had a sizable impact on financial markets, first stemming market disruptions and later providing ongoing accommodation through lower interest rates. In particular, the already low rates on 30-year fixed rate mortgages declined from 3.7% in December 2019 to 2.8% by early 2021. While part of the decline can be attributed to direct effects of lower policy rates, large-scale MBS

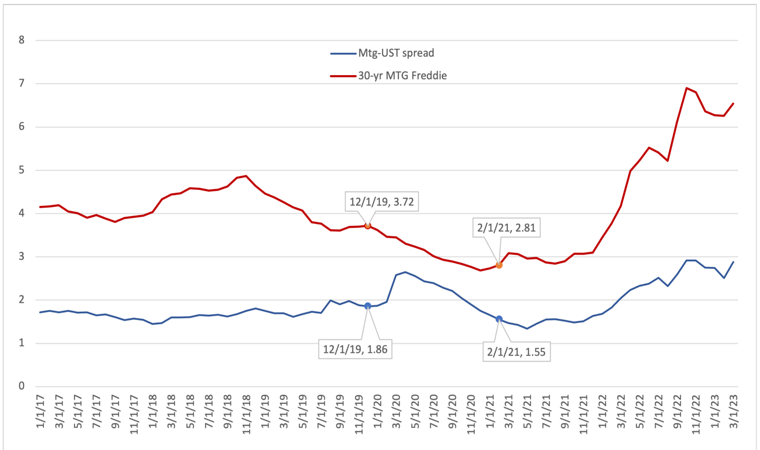


Figure 3: 30-year mortgage rate and Spread to 10-year US Treasuries

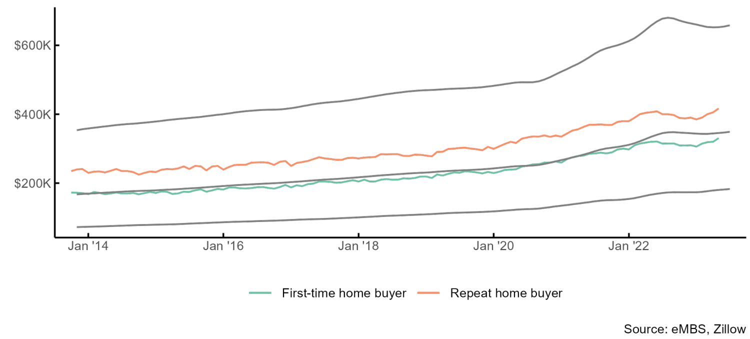
purchases made an additional contribution by reducing market volatility and improving execution of mortgage originations. A simple back-of-the-envelope way to gauge relative contributions of rate cuts and asset purchases is to compare the change in mortgage rates with those in 10-year Treasury rates. Assuming stable originator profits (proxied by the difference in mortgage rates and MBS yields), the observed compression in this spread can be attributed to MBS purchases. This comparison, shown in Figure 3, suggests that about 1/3 of the decline in mortgage rates stemmed from QE purchases of MBS.

Along with monetary policy actions, the Federal government launched a wide array of fiscal support measures, from extended unemployment insurance to forgivable small business loans to direct stimulus payments. Several components of fiscal support were directly relevant to the housing markets. In particular, the CARES Act passed in March 2020 established a mortgage forbearance program that paused mortgage payments on any federally backed loans (Cherry, Jiang, Matvos, Piskorski, and Seru, 2021). This effort was also accompanied by a ban on foreclosures and evictions. Other programs, such as pause on student loan payments, contributed an estimated $5 billion per month to household disposable income (Hong and Lucas, 2023).

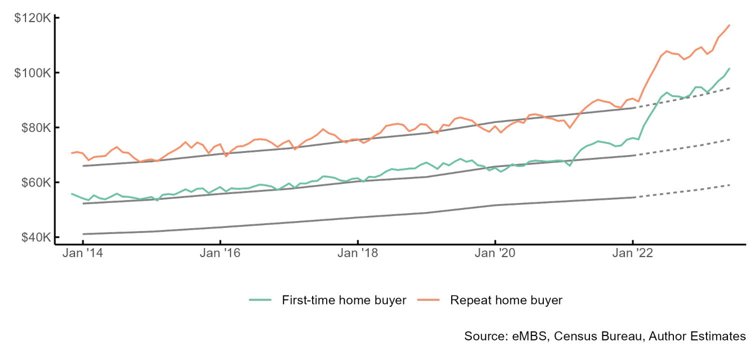
Although these programs shored up household balance sheets, it is less clear that they contributed substantially to a surge in housing demand. The pandemic resulted in substantial loss of income and changes in level and composition of consumption that were unevenly distributed across the U.S. population. While the net effect of these changes was a substantial increase in savings, totaling $2.3 trillion by Q2:2021 and $1.7 trillion by Q2:2022 (Aladangady, Cho, Feiveson, and Pinto, 2022), about 80% of excess savings were held by households in the top half of the income distribution. Historically, first-time homebuyers reported income close to the national median and bought median-priced houses (Figure 4, Gillet and Hull, Chicago Fed Letter, 2023). Using projections from Aladangady et al. (2022), the median income household amassed between $8,000 and $10,000 in excess savings by Q2:2021. Over the same time, house prices went up 20%, suggesting an increase of $65,000 on a pre-pandemic median price house. The accumulated savings were thus not even sufficient to cover the corresponding increase in the down payment. Moreover, income freed up by paused student loan payments or enhanced unemployment benefits could not be considered for underwriting mortgage loans (see, for instance, HUD 2021). On net, disposable income generated by COVID fiscal programs was of little help in satisfying underwriting debt service requirements and accumulated savings were not sufficient to offset the extra down payment demands generated by rapid increase in house prices.

As alluded to earlier, housing prices accelerated rapidly starting in the second half of 2020 (Figure 1). For the full calendar year, house price rose about 10% in 2020 and a further 19% in 2021. These price increases generated enormous gains in household wealth. The Flow of Funds data suggest an increase in homeowner equity of $8.0 trillion, with about 60% of these gains accrued to households in the top income quintile for which the homeownership rate approaches 90%. By definition, none of the gains were realized by non-owners.

Another feature of COVID was a large-scale shift to remote work, necessitated by public health considerations. By June of 2020, nearly 60% of paid work hours were supplied from home, as compared with 5% prior to the pandemic (Barrero, Bloom, and Davis (2021); data available at WFH Research Data). The extent of working from home has declined as pandemic restrictions eased, but throughout the next two years, nearly 1/3 of work continued to be supplied from home. This lasting shift in work arrangements likely increased demand for home working space and, thus, housing. A closely related phenomenon was a desire to leave densely populated urban areas and relocate to areas that allowed more physical space and access to outdoors. These forces translated into demand to re-optimize housing holdings, whether in terms of size, amenities, or location. And this, in turn, also affected house prices. Mondragon and Wieland (2022) attribute more than a half of national price increases over the 2020-2021 time period to shift to work from home.



(a) eMBS Home Prices & Zillow Top-, Mid-, Low-Tier Home Value Indices (black bands)



(b) eMBS Household Income & ACS income estimates at 40th, 50th, and 60th percentiles (black bands)

Figure 4: Home Prices, Interest Rates, and Incomes of First-time and Repeat Home Buyers

Not all households, however, were able to re-optimize. While wealthier households appear to have been able to purchase larger and second residences, there appears to have been some crowding out of first-time homebuyers. According to Redfin estimates, demand for second homes jumped by 89% by the summer of 2020 and remained at similarly elevated levels through the end of 2021 (Anderson, 2023). Real estate investors also picked up the pace of their purchases, increasing their market share from 16% to 20% by Q4:2021 (RedFin Data Center). Unsurprisingly, the share of first-time homebuyers fell by 3.5 percentage points over this period (Lee and Tracy, 2023). As another indicator of crowding out, Figure 4 shows that by 2021 incomes of first-time homebuyers moved up from the median U.S. household income level where they had been for most of the preceding decade, rising by $25000 or about 33%, over the course of 2022 and early 2023.

In contrast to a surge in demand, the supply response of housing during the early stages of the pandemic was subdued. Housing starts and completions returned to their pre-pandemic levels by the end of 2020 after dealing with the disruptions and various supply bottlenecks. Nevertheless, construction remained hindered by high costs of materials and labor shortages. It is worth noting that the stock of owner-occupied structures jumped discontinuously in 2020 (Figure 5) as nearly 2 million previously vacant units (mostly vacation or unused houses) converted to owner-occupied (and second) residencies (U.S. Census 2022). This turned out to be a one-time adjustment, though it coincided with the period where both starts and completions of new houses were at their weakest (Figure 6), smoothing the overall supply of housing.

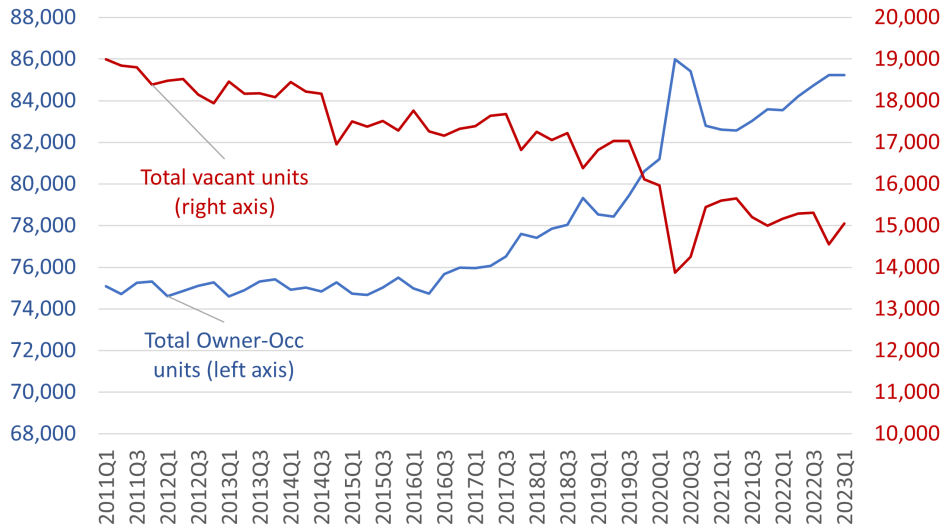


Figure 5: Stock of owner-occupied and vacant units (thousands)

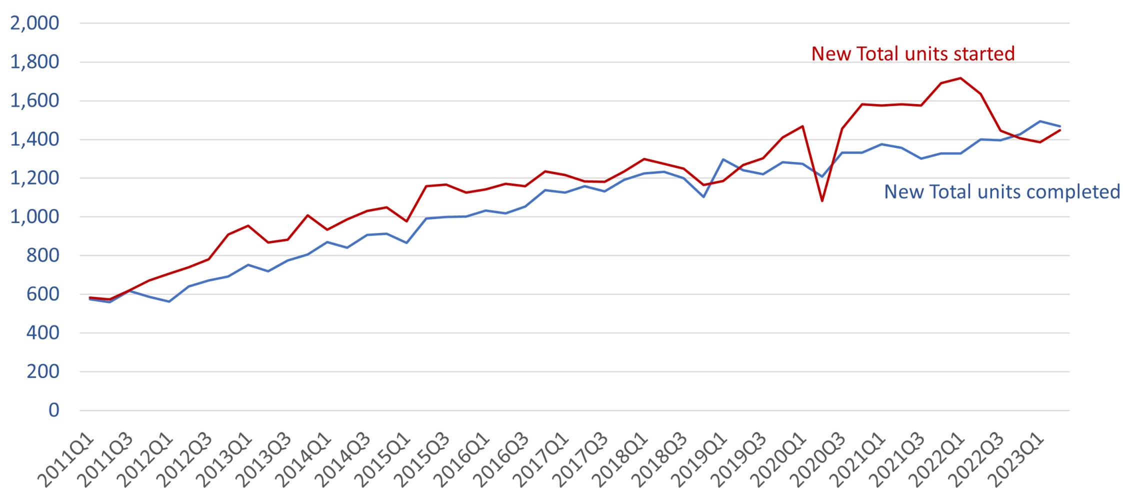


Figure 6: Flows of new owner-occupied units (thousands)

In sum, the first phase of the pandemic and its aftermath – 2020-2021 – was characterized by lower interest rates, a surge in housing demand, and housing supply staying roughly on trend. House prices grew rapidly and a growing share of households were crowded out of the housing markets. Later in the period, higher inflation undermined real house price appreciation, but even in real terms, prices rose near or above 10% year-over-year throughout 2021 (recall Figure 1).

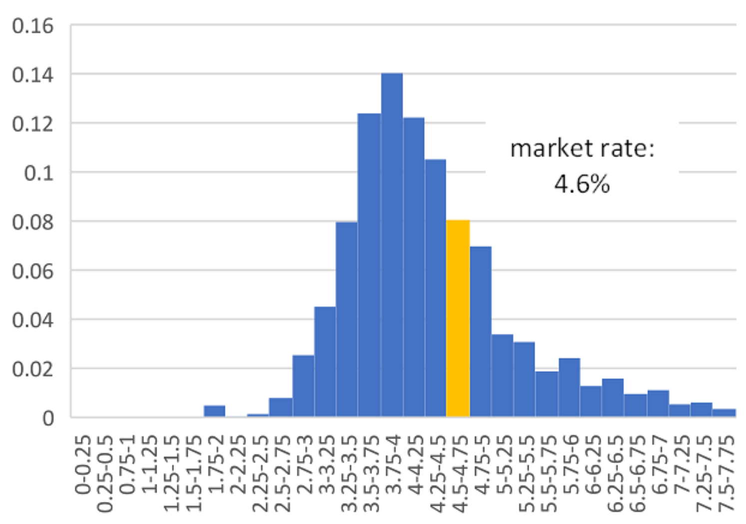
The second phase of pandemic-era policy responses did not come as abruptly but was still fairly emphatic. In particular, the Fed modified its policy stance to combat high inflation through both rate hikes and tapering of asset purchases. The upcoming shift was communicated in a series of public speeches in November of 2021, and FOMC embarked on a sequence of rate hikes starting with the March 2022 meeting. In all, the policy rate increased by 500 basis points over the course of 14 months. The response in mortgage rates, in particular, was equally dramatic. The 30-year mortgage rate skyrocketed from 3% at the end of 2021 to 6.9% by October 2022 before plateauing at about 6.5%, with a similar increase in real terms despite higher expected inflation (see Figure 2).

Although the growth in house prices moderated substantially, higher rates did not translate into meaningful price adjustments that would be suggested by classic user-cost housing valuation models. Neither the repeat-sales measures (Case-Shiller) nor the hedonic and market trends measures (Zillow HVI) suggest price declines of more than a few percentage points since their summer 2022 peaks through the end of 2022 and early 2023.

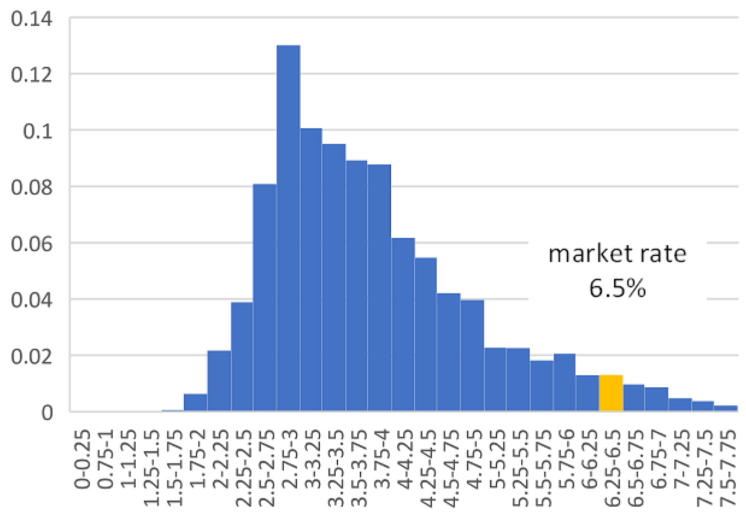
A number of demand and supply side factors can arguably account for observed house price dynamics. On the demand side, strong labor markets and rebounding equity prices translate into robust household income flows. Household balance sheets remain in good health on the strength of remaining pandemic-era excess savings and past housing equity gains. It is further likely that the COVID preference shock for housing – whether driven by public health concerns, demand for leisure amenities or working-from-home – remains persistent (Barrero et al., 2021). An additional demand-side factor derives from pent-up demand by crowded out first-time homebuyers.

On the supply side, healthy household balance sheets and strong labor markets are keeping mortgage delinquencies very low, limiting forced sales and foreclosures. As a result of record low mortgage rates in 2020-2021 and a subsequent rapid reversal, a vast majority of homeowners have fixed rate mortgages with rates well below current market rates, a phenomenon often referred to as "mortgage rate lock".[2]

[2] In the U.S., the share of adjustable-rate mortgage originations has languished well below 10% since the GFC (Urban Institute, 2023). The vast majority of fixed rate mortgages are originated with 30-year terms. Although fixed rate mortgages have become increasingly common in other developed economies, their fixed rate period is much shorter. For instance, in the U.K., 74% of mortgages have fixed rate terms but those do not last more than 5 years, and over half of them only fix interest rates for 2 years (UK Finance, 2023).



(a) December 2018



(b) May 2023

Figure 7: 30-year fixed rate mortgage rate distribution

This situation is depicted in histograms in Figure 7 that capture observed distributions of interest rates on outstanding 30-year fixed-rate mortgage contracts, with the yellow bar showing the current market rate. Although mortgage lock is a common effect of policy-driven rate reversals, its current extent is quite an outlier. This can be readily observed from comparing the panels in Figure 7 that show the rate distributions at the peak of the 2022 and 2016 tightening cycles. Table 1 provides a similar perspective on the uniqueness of the current cycle. The table shows shares of outstanding mortgages locked in various levels below market rates observed at the peak of a given tightening cycle going back to 1999. In the current episode, a median 30-year fixed rate mortgage has a rate that is nearly 300 basis points below market. While rate gaps of 200 basis points and higher were virtually nonexistent in previous cycles, in the current episode they are a reality for 71% of mortgage borrowers.

Table 1: Share of outstanding 30-year FRMs at the peak of the cycle at least X bps *below* the then-current mortgage rate

	At the "peak" of the tightening cycle			
	1999	2004	2016	2022
mortgage rate	8.5	6.7	4.6	6.5
date of "peak"	May 2000	Jun 2006	Dec 2018	May 2023
rate gap for median loan (bps)	113	83	46	288
$>$ 50 bps gap	65%	55%	43%	91%
$>$ 100 bps gap	42%	26%	17%	87%
$>$ 200 bps gap	2%	1%	1%	71%
$>$ 300 bps gap	0%	0%	0%	38%

Put differently, current homeowners who consider trading their home for another property have to take into account the intrinsic value of the house as well as the value of below-market financing. This drives a wedge between the intrinsic and owner-specific valuations, raising their reservation price. A recent study by Fonseca and Liu (2023) estimates that each percentage point gap between the existing mortgage rate and the current market rate translates into 0.68 percentage point reduction in the probability of moving. To use a different metric for comparison, completions of single-family homes have averaged about 1% of housing stock since 2013 (Figures 5 and 6), and have remained relatively stable through the COVID period. Using the Fonseca and Liu (2023) estimates, the current median gap between existing and market mortgage rates suggests about a 2 percentage points decline in moving of existing homeowners, equaling about 2 years of new construction. That is, construction would have to double to make up for the housing availability that is currently lost by the so-called mortgage rate lock. The rate lock thus has the potential to limit the supply of houses for sale and push up prices.

In the next section, we use a model of housing services and prices to articulate the forces described above and their effects on home prices and affordability. In particular, since the preference shock is unobservable, we use the model to back out the implicit increase in relative preference for housing, given the other observable factors, including declining interest rates, income changes, and ultimately, home price appreciation. We then examine a rising rate environment and show that higher rates would be expected to reverse the demand-driven home price appreciation. However, the presence of rate lock reduces the available supply of homes for sale. Seen from a flows perspective, the decrease in available supply puts upward pressure on prices, despite rising rates and tighter monetary policy.

3 A Model of House Prices

3.1 Model

We employ a simple model of demand for housing services and pricing of housing assets using the structure in Garriga et al. (2021). It includes a financial constraint in the form of a loan-to-value (LTV) borrowing limit and allows for heterogeneity in homeowners, which we use to explore affordability and the role of first time home buyers.

We use the model to parse out the effects of interest rate changes, income changes, and shocks to preferences on home prices. In particular, the run up in home prices was abetted by a pandemic-driven change in demand, low interest rates from both conventional monetary policy and QE, and fiscal stimulus that increased incomes. A discussion of the impact of policy requires a quantitative approach to the role of each of these factors and in particular, how much the COVID-19 shock drove demand.

3.1.1 Setup

The economy has a population of heterogeneous consumers denoted by

$$i = 1, 2, 3, \cdots, I$$

The size of each potential buyer group is represented by N_i where.

$$\sum_{i=1}^{I} N_i = \bar{N}$$

Each individual type i has preferences defined over non-housing consumption ($c_{i,t}$, the numeraire) and housing services $h_{i,t}$:

$$\sum_{t=0}^{\infty} \beta^t \left[\ln c_{i,t} + \gamma_i \ln h_{i,t}\right] \tag{1}$$

where the discount rate $\beta \in (0, 1)$ is the same for all consumers. The relative preference for housing, $\gamma_i \geq 0$ can vary across types. For tractability, we consider the case where income levels by type are fixed over time, i.e. $y_i = y_{i,t}$ for all t.

We assume that all buyer types have equal access to credit, consistent with the mortgage rates shown in Figure 4. House purchases are financed via mortgage subject to a maximum loan-to-value restriction, denoted by $\phi_{i,t} = \phi_t \in [0, 1]$.

Let $B_{i,t}$ denote the stock of mortgage debt at the beginning of period t. $b_{i,t}$ is the new loan originated this period and r^m_t is the interest rate on the mortgage loan. Households may borrow or lend via deposits, $D_{i,t}$, earning interest rate r^d_t .

A fraction Δ of the mortgage balance is amortized each period, so the accumulation equation for $B_{i,t}$ for individual i is:

$$B_{i,t+1} = b_{i,t+1} + (1 - \Delta)B_{i,t} \quad \forall i, t. \tag{2}$$

Note that in the absence of an origination cost, borrowing is rebalanced each period. We return to this point in the calibration and in the following section 3.4 where we allow for more limited repricing.

Mortgage borrowing is collateralized subject to the collateral constraint

$$b_{i,t+1} \leq \phi_t p^h_t h_{i,t} - (1 - \Delta)B_{i,t} \quad \forall i, t.$$

With these conditions, the optimization problem for consumer of type i is given by

$$U_i = \max \left[\sum_{t=0}^{\infty} \beta^t \left[\log c_{i,t} + \gamma_i \log h_{i,t} \right] \right] \tag{3}$$

$$\text{s.t.} \quad \underbrace{c_{i,t}}_{\text{cons. spending}} = y_i + \underbrace{b_{i,t+1} - \left(r^m_t + \triangle\right) B_{i,t}}_{\text{mortgage adjustment}} + \underbrace{\left(1 + r^d_t\right) D_{i,t} - D_{i,t+1}}_{\text{deposit portfolio adjustment}} + \underbrace{p^h_t \left(h_{i,t-1} - h_{i,t}\right)}_{\text{housing portfolio adjustment}} \quad , \quad \forall i, t$$

additionally subject to (1), (2) and the standard non-negativity constraints. Note p^h_t is the housing price and $h_{i,t}$ is the housing services demanded by type i at time t.

We focus on equilibria that satisfy

$$r^d_t - r^m_t \geq 0$$

That is, the deposit interest rate r^d_t exceeds the rate at which the rest of the world is willing to hold some amount of domestic mortgage debt. In the calibration, we allow for a tax benefit of mortgage borrowing, which further reduces the effective cost of mortgage debt.

3.1.2 Equilibrium

Housing supply is set at $\{\bar{H}\}$, given

- a path for credit conditions $\left\{r_t^m, r_t^d\right\}_{t=0}^{\infty}$,
- income endowments $\{y_i\}_{i=1}^{I}$, and the credit condition ϕ,

an equilibrium is constituted by

- price paths $\left\{p_t^h\right\}_{t=0}^{\infty}$, and
- sequences of individual decisions $\left\{\{c_{i,t}, h_{i,t}, D_{i,t+1}, b_{i,t+1}, B_{i,t+1}\}_{i=1}^{I}\right\}_{t=1}^{\infty}$

that

(i) solves each household's optimization problem in (3), and

(ii) clears the markets

$$\sum_{i=1}^{I} N_i h_{i,t} = \bar{H} \quad \forall t. \tag{4}$$

In order to solve for housing demand and the price of housing, given the supply above, the problem yields a standard asset pricing equation that includes a user cost component plus a leverage value that depends on the extent to which the consumer can borrow against housing ϕ, emphasized by Garriga, Manuelli, and Peralta-Alva (2019).

$$p_t^h = \frac{U_{h_{it}}}{U_{c_{it}}} + \frac{p_{t+1}^h}{1+r_{t+1}} + \phi_t p_t^h \left(\frac{r_t^d - r_t^m}{1+r_t^d}\right), \quad \forall t. \tag{5}$$

The ability to borrow is limited by the loan-to-value ϕ_t and the relative cost of borrowing captured by the spread

$$r_t^d - r_t^m > 0.$$

Housing demand for each type i is given by:

$$h_{it} = \gamma_i \frac{c_{it}}{p_t^h \left[1 - \triangle_{t+1}^h - \triangle_{t+1}^\phi\right]}, \quad \forall i, t \tag{6}$$

where

$$\begin{aligned} \Delta_t^h &= \left(p_{t+1}^h / p_t^h\right) / \left(1 + r_{t+1}^d\right) \\ \Delta_{t+1}^\phi &= \phi_t \left(r_{t+1}^d - r_{t+1}^m\right) / \left(1 + r_{t+1}^d\right) \end{aligned}$$

represent the value of reselling the home and the ability to borrow multiplying the gains associated with the interest rate spread. Substituting (6) into the market-clearing condition (4) yields:

$$H^d\left(p^h\right) = \sum_{i=1}^{I} N_i \left[\gamma_i \frac{c_{i,t}}{p_t^h\left[1 - \triangle_{t+1}^h - \triangle_{t+1}^\phi\right]}\right] = \bar{H}, \quad \forall t \tag{7}$$

By (7), we can write the housing prices as

$$p_t^h = \frac{1}{\left[1 - \Delta_{t+1}^h - \Delta_{t+1}^\phi\right]} \sum_{i=1}^{I} N_i \frac{\gamma_i c_{i,t}}{\bar{H}} \quad \forall t. \tag{8}$$

3.1.3 Steady-state

Solving for the steady state simplifies the analysis by setting the expected future house price equal to the current price.In the calibration, we will compare across steady states with different configurations of interest rates, income, and preference for housing.

Without aggregate movements in income, the equilibrium interest rate on deposits is determined by the rate of preference:

$$r^d = (1-\beta)/\beta. \qquad \text{i.e. } 1 + r^d = \frac{1}{\beta} \tag{9}$$

In steady state equilibrium, the mortgage balance is stable, though may differ across types

$$B_{i,t+1} = B_{i,t},$$

which implies a constant rate of borrowing, $b_i = \Delta B_i$. The level of borrowing is determined by the equilibrium housing price

$$B_i = \phi p^h h_i.$$

and consumption is given by

$$c_i = y_i - r^m B_i = y_i - \phi r^m \left(p^h h_i\right) \tag{10}$$

Substituting the expression for consumption c_i into (8) gives an expression for home prices:

$$p^h = \frac{1 + r^d}{(1-\phi)r^d + \phi r^m} \sum_{i=1}^{I} N_i \frac{\gamma_i}{\bar{H}} \left(y_i - r^m \phi p^h h_i\right) \tag{11}$$

Rearranging the p_t^h terms on the RHS and rescaling obtains

$$p^h = \frac{r^d}{(1-\phi)r^d + \phi r^m + \phi r^m (1+r^d) \sum_{i=1}^{I} (\frac{N_i \gamma_i h_i}{\bar{H}})} \left(\frac{1+r^d}{r^d}\right) \sum_{i=1}^{I} N_i \frac{\gamma_i y_i}{\bar{H}}. \tag{12}$$

When all individuals have identical preferences w.r.t. housing, i.e. $\gamma_i = \gamma$, we can simplify the expression for home prices as a function of housing supply, household income, and interest rates

$$p^h = \frac{(1+r^d)}{(1-\phi)r^d + \phi r^m + (1+r^d)\,\phi r^m \gamma} \cdot \sum_{i=1}^{I} N_i y_i \gamma \frac{1}{\bar{H}} \tag{13}$$

Later, we will calculate the payment-to-income ratio, given per capita housing demand h, as:

$$DTI(h) = r^m \phi p^h h_i / y_i$$

in order to assess affordability for different parameter specifications and the first time home buyers.

3.2 Calibration

Baseline with Two Types of Households We allow for two types of households: existing home owners and first-time home buyers to allow us to focus on affordability. We denote the first time buyers type 1, and the existing homeowners type 2. We first parameterize the model to a pre-COVID baseline year of 2019. We choose values for the parameters above as described in the data sources Table 2.

Table 2: Data Sources for Parameter Values

Parameter	Symbol	Source
Type 1 &2 Buyer Income	y_i	eMBS data
Share of each type	N_i	FRBNY Consumer Credit Panel
Single Family Owner Occupied Units	$\bar{H}$	CPS/HVS data
Outside Interest Rate	r^d	Bloomberg BB 7 year bond rate
Mortgage Interest Rate	r^m	Freddie Mac 30 year Mortgage rate
LTV constraint	ϕ	GSE Baseline
Tax benefit of mortgage balance	τ	Garriga et al. (2021)
Median income of homeowners	y	2019 Survey of Consumer Finances
Initial Housing Preference	γ	Inferred from Steady State PH/Y

Notes: This table provides the data sources for the parameter values.

Most are directly measurable: homebuyer incomes, shares of first time and repeat purchasers, and interest rates. We do not directly observe preferences, so we calibrate the preference for housing

γ by using the model's implied steady state relationship between housing values and income, given the interest rates for the 2019 calibration. This yields the value of 0.18 in Table 3. Together with the empirical parameters, the calibration gives a baseline home price for 2019, which we discuss in the Results section below. We normalize the "supply" of housing to 100 in 2019, since this index measures a mix of housing size and quality. Home buyers can choose h_i from a continuum of values. Thus, first time homebuyers with lower incomes will choose a lower value of h_i than repeat buyers, representing smaller houses with fewer amenities. We do not impose bounds on the range of house size/quality.

Table 3: Model Baseline Parameter Values

Parameter	Symbol	Baseline
Number of Types	I	2
Type 1 Buyer Income	y_1	65
Type 2 Buyer Income	y_2	80
Number of Type 1	N_1	0.46
Number of Type 2	N_2	0.54
Housing Supply	$\bar{H}$	100
Outside Interest Rate	r^d	0.0387
Mortgage Interest Rate before tax	r^m	0.0372
LTV constraint	ϕ	0.8
Tax benefit of mortgage balance	τ	0.25
Investor Housing Preference	γ	0.18

Notes: This table presents the parameters used in our baseline calibration. Table 2 provides the data sources for the parameter values.

Here we present calibration parameters and results based on nominal values for interest rates and incomes. Conceptually, this approach is consistent with our later model of "rate lock" which is a nominal phenomenon. However, given the impact of higher inflation on real incomes and borrowing rates, we also calibrated a version of the model in real terms. The substantive results are consistent with what we report here, though with adjustments for inflation-adjusted values. In particular, the baseline calibration is almost identical to that reported below, and the increase in demand (γ) is very similar. The path of expected inflation counteracts some of the movements in nominal mortgage rates, so that real movements are somewhat smoother than nominal rates. However, the level of real rates is naturally lower than nominal rates, and hence house prices are more responsive to changes in real rates. These two effects tend to offset each other in the quantitative results.

Starting from this baseline, we examine the effects of the two policy stages of COVID on home prices, considering the roles of interest rate changes, a preference shock for housing, and the incomes of homeowners and first-time buyers. We divide the period into two episodes: i) the stimulus period from April 2020 through December 2021, and ii) the tightening period in 2022. The divisions between the episodes are, of course, somewhat arbitrary. We will also explore timing that allows longer for home prices to adjust, especially to the tightening, and look at home prices and market conditions from Q2 2022 and early 2023.

To examine the stimulus period, we use interest rates from this period, which fell significantly compared to the 2019 baseline. There was also a small increase in the incomes of first-time home buyers. These positive factors for home prices were slightly offset by rising supply of owner-occupied homes. We do not have data to directly quantify the shift in preferences toward single family homes during COVID. Instead, we choose γ to match the observed aggregate home price appreciation from December 2019 to the end of 2021. These parameter choices are laid out in the ”Stimulus” column of Table 4.

For the tightening period, we substitute actual interest rates from 2022, which rose significantly from 2021 and even surpass the baseline rates from 2019. This would be expected to depress home prices, though there are off-setting effects from higher incomes and the preference shock, which we assume to be persistent and maintained at its 2020-2021 level (calibrated from the earlier episode). The resumption of construction also slightly increases the supply of homes, though the net effect is relatively small, as the substitution of housing into owner-occupied status that increased supply in 2020 turned out to be temporary, and reversed by 2022. New construction was mostly just enough to make up this gap. The parameter values are laid out in the final ”Tightening” column in Table 4. The increase in incomes for both repeat and first time buyers is notable in these data. From the stimulus period to tightening in 2022, these household incomes rose by 12.5% and 11.8%, respectively, as we noted in Figure 4 earlier. From January 2014 through 2021, the incomes of first and repeat home buyers track the median and $60th$ percentiles, respectively of the American Community Survey (ACS) income estimates. Starting in 2021 these values diverge, and dramatically so in 2022 and 2023. By later in 2022, the incomes of homebuyers are 25% higher than they were when the year began, or an additional $\$19,000$ for first time buyers. This suggests a highly selected group of households who are able to buy homes during the tightening period, facing both higher mortgage rates and higher home prices. The implied selection leads to our approach in the last section, where we develop a model in which the number of homes for sale is constrained, driving further price appreciation.

3.3 Steady State Results

The calculated steady state house price, housing demand, and the payment-to-income ratio for the baseline period are given in Table 5.

The role of housing and leverage is visible already in the baseline. Existing homeowners have

Table 4: Parameter Values for Alternative Scenarios

Parameter	Symbol	Stimulus	Tightening
Number of Types	I	2	2
Type 1 Buyer Income	y_1	70	76
Type 2 Buyer Income	y_2	85	90
Number of Type 1	N_1	0.42	0.41
Number of Type 2	N_2	0.58	0.59
Housing Supply	$\bar{H}$	104	104
Outside Interest Rate	r^d	0.037	0.0585
Mortgage Interest Rate	r^m	0.030	0.0530
LTV Constraint	ϕ	0.8	0.8
Investor Housing Preference	γ	0.21	0.21

Notes: This table presents the parameters used in our alternative scenarios.

Table 5: Steady State Baseline Solution

Parameter	Symbol	Baseline
House Price	p^h	3.99
Type 1 Housing Demand	h_1	88.92
Type 2 Housing Demand	h_2	109.44
Type 1 Consumption	c_1	57.08
Type 2 Consumption	c_2	70.25
Type 1 DTI increase at mean home	DTI(100)	12.46%
Type 1 DTI increase at median home	DTI(h_2)	23.08%

Notes: This table presents the steady-state baseline solution implied by our model.

18% higher income than the first time home buyers, so first time buyers scale back their home purchases proportionately. If first-time buyers bought the average house in the market, their payment to income ratio (DTI) would rise by 12.46%. If they bought the median home (that of existing homeowners), their DTI would rise by 23.08%. These differences in affordability will become larger as we incorporate the effect of policy stimulus and tightening.

The results for these alternative scenarios are presented in Table 6.

The "Stimulus" scenario considers the effects of lower interest rates, higher incomes, and a boost to the preference for housing. Compared to the baseline results in Table 5, lowering the interest rates r^d and r^m, without changing incomes or preferences, increases the implied price of housing by 19%. This is offset somewhat by higher housing supply, from repurposing existing units to owner occupied and some new construction completions. Adding increased supply reduces implied house price appreciation to 14%. Adding the higher incomes of homebuyers during the stimulus period raises home price appreciation further, to 22%. This is still well below the actual home price appreciation observed through 2021, which reached 41%. The calibration results in the middle

Table 6: Steady State Alternatives Solution

Parameter	Symbol	Stimulus	Tightening
House Price Appreciation (relative to baseline)	Δp^h	40.67%	−10.86%
House Price Appreciation (relative to peak)	Δp^h		−36.63%
Type 1 Housing Demand	h_1	92.57	93.87
Type 2 Housing Demand	h_2	112.41	111.16
Type 1 Consumption	c_1	60.64	65.38
Type 2 Consumption	c_2	73.64	77.42
Type 1 DTI increase at mean home	DTI(100)	12.34%	10.79%
Type 1 DTI increase at median home	DTI(h_2)	21.43%	18.42%
Type 1 DTI increase at mean home over baseline	DTI(100)	23.21%	27.04%
Type 1 DTI increaseat median home over baseline	DTI(h_2)	33.18%	35.79%

Notes: This table presents the steady-state alternatives solutions implied by our model.

column of Table 6 show that with the lower interest rates of this period, slightly higher housing supply, and an increase in γ of 16.7% (to .21), the model can rationalize the observed house price appreciation. This approach gives us an implicit estimate of the increase in demand for housing during COVID-19. The increase in γ alone accounts for almost half of the home price appreciation over this period, or 18 percentage points. This is slightly higher than the 15% estimated based on cross-section data from Mondragon and Wieland (2022), though we calculate price growth over a longer time period than their sample. They argue that work from home accounts for more than half of home price appreciation, consistent with our estimate of γ, using different data and methodology.

This appreciation has important implications for housing affordability. While first-time buyers have a modest increase in income during this episode, their DTI would rise by 12% to 21% if they bought the average or median home purchased during this period. Compared to the baseline, their DTI rises by 23% to 33% - substantially more because of rising home prices. Existing homeowners have about 50% higher consumption and housing services compared to first time home buyers. Even so, the income advantage of existing homeowners is most likely understated in the model, since the steady state income measure does not include the capital gains that current homeowners receive relative to first-time homebuyers. Existing homebuyers are partially insured against home price increases (Sinai and Souleles (2005)) or equivalently, their implied total income rises with home prices. First time home buyers, on the other hand, face higher home prices with no such insurance or implicit income.

The final scenario examines the impact of higher mortgage rates, in particular, since 2022. In this case, we hold constant the preference shock that was realized in 2020-21 and estimated in the stimulus scenario; we assume it is a persistent feature of homebuyers' preferences. Both types of buyers have sharply higher incomes, as noted above, perhaps due to selection of home purchasers in this costly environment. Housing supply continues to rise. Using the new income and interest rate data along with the estimate of γ, the model provides an implied home price change – holding constant the preference shock observed post-COVID and allowing for rising interest rates. Relative to peak prices, this scenario implies a 36.63% decline in home prices, mostly owing to the increase in rates. Because interest rates exceed the 2019 baseline, the implied price is 10.86% below the baseline, despite the increase in preference for housing.

It is also worth noting that at the low interest rates that prevailed in 2019, housing prices in the model are very sensitive to changes in interest rates. For example, if mortgage rates had fallen by 30 basis points less during the stimulus period, prices in the model would have risen by 31% rather than 41%. With this lower peak price, the subsequent policy tightening might have been less severe. Even at the observed increase in mortgage rates in 2022, the implied correction in home prices relative to the peak is still substantial but reduced in magnitude by 5 percentage points.

These implications for a home price correction are in sharp contrast to the observed home prices discussed in the previous section, which fell less than 5% in 2022 from their peak in 2021 (and almost zero as of this writing). It is possible that preference for housing continued to rise in 2022. In an alternative calibration we show that the relative preference for housing would have to rise by 50% – rather than the 16.7% that we estimate in 2020-21 – to overcome the observed increase in interest rates and instead stabilize home prices. If preferences have not continued to trend up (or accelerated), these results create a puzzle as to why home prices have remained so robust in the face of rising interest rates. The market user cost of housing has risen by more than 200 basis points and home prices have moved only slightly. The projected lower home price is a steady state calculation, however, so we next consider selection dynamics that may prevent home prices from falling so dramatically.

3.4 Rate Lock and Calvo Sales

One potential explanation for the surprisingly strong home prices during the tightening episode is a negative effect of rising rates on housing supply. This could occur through weaker construction spending via traditional interest-sensitivity of investment. In addition, higher interest rates may depress homes for sale rather than the underlying housing supply *per se*.

As noted earlier, the share of homes for sale rose during the housing boom and fell dramatically thereafter. In 2019 the share of existing single family homes sold was 6.7%, at about the same levels as in years prior (Figure 3.4). After plummeting in the first months of the pandemic, this share rebounded to 7.3% in 2021, but then fell to 4.2% by late 2022, where it has remained since. The recent decline corresponds to a period in which 90% of homeowners have mortgages with contracted rates less than the market rate. As noted earlier, Fonseca and Liu (2023) estimate a causal effect that for every 1 percentage point increase in the gap between a homeowner mortgage rate and the market mortgage rate, homeowners are .68 percentage points less likely to move and put their home up for sale. At the average rate increases that we use in this exercise, their estimates translate into a decline in moving by existing homeowners of 1.6 percentage points; this rises to 2.2 percentage points using end of period interest rates. The aggregate data show a slightly higher decline of 2.5 percentage points.

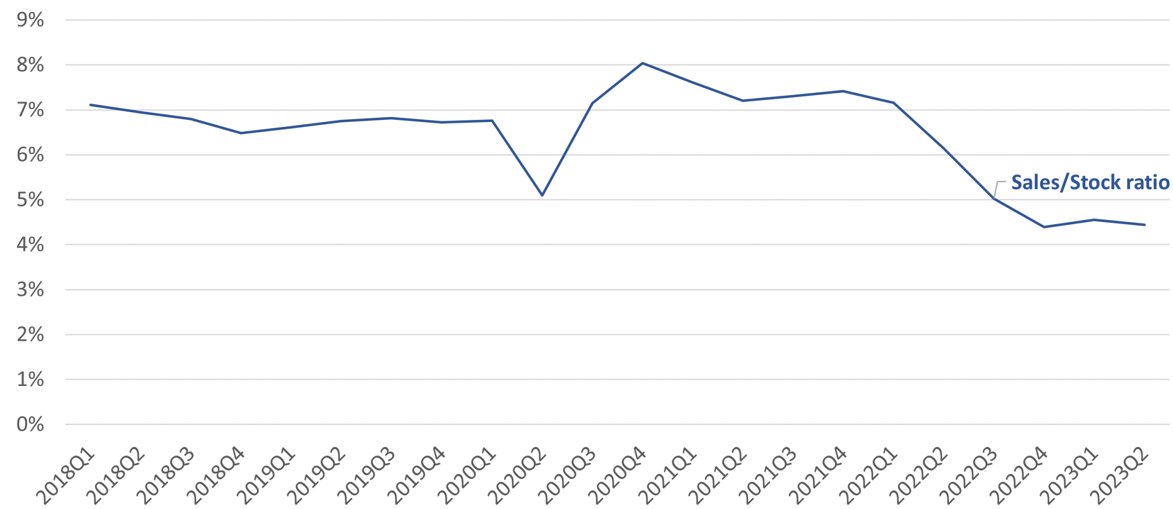


Figure 8: Ratio of existing home sales to stock of owner-occupied housing units

A one-third reduction in homes for sale thins the market for home purchases. However, it also thins those looking to purchase among existing homeowners. The net result (if any) for pricing depends on how many homeowners decide to sell, how many exit the ownership market, and the remaining first-time buyers.

To examine these effects on home prices, we add a moving shock to the model. Pricing is done only among a subset of the homeowners who sell, together with first time buyers. We think of these homeowners as being forced to sell because of a change in job location or other personal circumstances. In the model, homeowners are chosen at random, as in a Calvo model, at rate ρ_1 and forced to sell. Some subset of sellers ρ_2 then exit the market, "making room" for first time buyers. The total measure of home buyers is the sum of home sellers who remain in the market, plus first-time home buyers. The measure of supply to the market is the sum of sales of existing homes plus new homes completed.

Formally, the previous market clearing condition is replaced by

$$N_1 h_1 + (\rho_1 - \rho_2) N_2 h_2 = \rho_1 N_2 h_2 + \Delta H, \tag{14}$$

which equates the demand from first time homebuyers ($N_1 h_1$) plus remaining existing homeowners who sell (share ρ_1) and do not exit (share ρ_2), with the supply from existing homeowners who sell and new home completions. The repeat home buyers net out of this expression to obtain

$$N_1 h_1 = \rho_2 N_2 h_2 + \Delta H, \tag{15}$$

so that first time homebuyer demand is met by exits of existing homeowners and new construction.

We first calibrate the moving shock model to the baseline and stimulus periods, when homeowners freely supplied homes for sale during a period of falling interest rates. This demonstrates the mechanism during a period in which it should not affect home prices, as a form of placebo test.

This probability of forced sales, ρ_1, is chosen to match the share of existing homes sold in the baseline 2019 and the stimulus period 2020-21. The probability of exiting the housing market, ρ_2, is inferred from the difference between sales of existing homes and the number of existing homeowners who buy homes. New home construction is measured as completions of new homes. In this version of the model it is necessary to split out new construction from existing home supply since all new homes are for sale, whereas only a fraction ρ_1 of existing homes are on offer. All of the other homeowner and homebuyer parameters are the same as in the ”Baseline” column of Table 3 and the ”Stimulus” column of Table 4 .

Calculating home prices based only on the homes supplied for sale by existing homeowners plus new completions, and the demand of first time home buyers plus continuing home purchasers, yields prices that are nearly identical to the previous steady state, as seen the last row of Table 7. This is readily seen by the fact that the net housing supply of existing homeowners (row 2) plus new completions is almost identical to the share of first time home buyers, all measured relative to the existing housing stock. This is essentially a flows version of the steady state we examined earlier.

The same logic applies in the stimulus period in the third column of Table 7. In this case, the probability of an existing homeowner selling rises by 6%, but many of these sellers simply repurchase another home. Hence, the probability of exiting the market actually falls slightly along with net supply. This is offset by a small increase in new completions. The share of first time buyers falls, but the total number of purchases rises, so the share of first time buyers in the housing stock is .034, and again almost identical to the supply of homes for sale. Hence, the equilibrium price is nearly identical to the original steady state calculation.

Table 7: Baseline and Stimulus with Moving

Parameter	Symbol	Baseline	Stimulus
Probability of existing sale	ρ_1	0.067	0.071
Probability sale and exit	ρ_2	0.027	0.024
New completions share of existing stock	$\Delta H/H$	0.0087	0.0098
Share of first time buyers/H	N_1/H	0.035	0.034
House Price chg to full turnover steady state	Δp^h	0.84%	0.67%

If we apply this logic to the Tightening scenario, however, the results change. We begin by calibrating a neutral moving model, as above, and then match the actual 2022 data. The probability of forced sales is chosen to match the home price implied in Table 6. All of the other homeowner and homebuyer parameters are the same as in the "Tightening" column of Table 4. This is a neutral case in the sense that the home price is not affected by the limited sales by construction, as shown in Table 8. This exercise gives an implied 5% moving probability. However, the neutrality-implied 5% of sales by existing homeowners does not match the data. As noted earlier, sales of existing homes declined with the increase in mortgage rates, as have the share of homeowners leaving homeownership. This leaves a lower net supply of homes to the market. At the same time, new home completions also declined. Inserting these values into the model, as in the "2022 Supply" column, we find a 16% increase in home prices relative to the full turnover steady state, roughly halving the implied home price contraction following the increase in mortgage rates.

In the final column, we calibrate the income parameters to early 2023, when the market still had limited supply and home purchasers had higher incomes, as noted earlier. Higher incomes increase housing demand among purchasers and further increase the resulting price, so that it is only 4.6% below the peak price in 2021. It is worth noting that prices are sensitive to changes in supply and demand since the market is thin in this scenario. For example, reducing home sales from 4.2% to 4.0% eliminates the home price decline entirely and prices remain at peak levels despite the rate increase, due to the unavailability of homes for sale and the high incomes of successful purchasers.

The first time buyers are further crowded out by high home prices and high interest rates. They buy 14% less housing than they would in the steady state with lower prices. If they were to buy the median house, which is purchased by the incumbents, their payment to income ratio would rise by almost 15%, even accounting for their higher incomes.

These features are consistent with other data reported during this period. In particular, the share of first-time home buyers in 2022 was at an all-time low since measurement began, at just 26%, compared to 34% in 2021, as measured by the NAR. The typical first-time buyer was 36 years old, an all-time high. Interestingly, the median distance between the home that recent buyers purchased

Table 8: Moving Model with Rate Lock

Parameter	Symbol	Neutral	2022 Supply	2023 Income
Probability of existing sale	ρ_1	0.053	0.042	0.042
Probability sale and exit	ρ_2	0.014	0.0062	0.0062
New completions share of existing stock	$\Delta H/H$	0.007	0.007	0.007
Share of first time buyers/H	N_1	0.02	0.02	0.02
House Price chg to full turnover steady state	Δp^h	0.2%	16.3%	32.8%
House Price Apprec from peak	Δp^h	−36.4%	−14.9%	−4.6%
Type 1 Housing per buyer	h_1	95.3	81.9	82.4
Type 2 Housing per buyer	h_2	110.2	94.8	94.5

and the home from which they moved rose to 50 miles, also a record high and more than triple the median of 15 miles from 2018 through 2021.[3] This could imply that moves are more likely to occur when the distance covered is larger, or that potential home buyers are less likely to find a nearby good match. In either case, the pattern suggests either higher moving costs or lower availability of homes, or both, consistent with rate lock of existing homeowners.

In sum, using the steady state comparisons, the run up in home prices following the COVID recession is consistent with observed incomes and interest rates along with a 17% increase in preference for housing. This demand shift accounts for slightly less than half of the increase in home prices. On the contrary, when mortgage rates rose, home prices have not fallen accordingly. Instead homes available for sale have fallen, and this reduction in available supply has supported prices. Alone, this effect accounts for about half of the stickiness in home prices, while higher homebuyer income accounts for the remaining portion.

Throughout this section we have used a steady state version of the pricing model and compared steady states calibrated to different policy episodes. This is also the case in the Calvo model we introduced to study the tightening episode, where the constraints on supply can keep prices elevated despite worse fundamental conditions. To the extent that conditions temporarily deviate from steady state, the steady state model, which assumes permanent changes, will overstate their impact. In the pricing model, the effect of future changes enters through the expectation of future prices relative to current prices in Δ^h_{t+1} in equation 8. Thus, to the extent the prices are temporarily elevated, future prices are expected to fall, negatively impacting prices today – a standard asset pricing result. In the episode we study, prices have so far remained steady, consistent with a steady state, muting this negative feedback, though of course it may be reinstated as both demand and supply evolve.

[3] National Association of Realtors (NAR), Home buyer and seller generational trends https://www.nar.realtor/research-and-statistics/research-reports/home-buyer-and-seller-generational-trends

To better understand these potential effects in the model, in the next section we examine a dynamic model to explore deviations from steady state.

4 Model Dynamics

The previous section compared steady state parameterizations of the model. In this section, we allow for dynamic adjustment to temporary changes in interest rates to examine how endogenous responses to rate changes affect our results. This approach follows naturally from the Calvo-style frictions, where the results suggest pricing that differs from the steady state. In particular, constraints on available housing put upward pressure on prices, despite a substantial increase in interest rates that would suggest price declines.

We solve a dynamic version of the same structure from Garriga et al. (2021) that we used for the steady state analysis. Recall that the model includes a financial constraint in the form of a loan-to-value (LTV) borrowing limit and allows for heterogeneity in homeowners. We allow for stochastic interest rates, which we model using a CIR process and initially assume a constant gap between the r_t^d and r_t^m processes. The equations representing the processes are as follows:

$$r_{t+1}^d = r_{t+1}^m + (\overline{r^d} - \bar{r}) \tag{16}$$

$$r_{t+1}^m = r_t^m + \theta(\bar{r} - r_t^m) + \sigma\sqrt{r_t^m}\varepsilon_t. \tag{17}$$

To specify the dynamic model, we require the following additional parameters:

$$\{y_1, y_2, N_1, N_2, \bar{H}, \phi, \gamma_1, \gamma_2, \Delta, \theta, \bar{r}, \sigma, \overline{r^d} - \bar{r}\},$$

which we calibrate based on the baseline (Jan. 2019 - Dec. 2019), stimulus (Apr. 2020 - Dec. 2021), and tightening (Jan. 2022 - Dec. 2022) phases, respectively. During each phase, we calibrate the r^m and r^d processes using weekly interest rate data. The parameter values are laid out in Table 9.

Table 9: Parameter Values for the Dynamic Model

Parameter	Symbol	Baseline	Stimulus	Tightening
Type 1 Income	y_1	65	70	76
Type 2 Income	y_2	80	85	90
Share of Type 1 Buyer	N_1	0.46	0.42	0.41
Share of Type 2 Buyer	N_2	0.54	0.58	0.59
Single Family Owner Occupied Units	$\bar{H}$	100	104	104
LTV constraint	ϕ	0.8	0.8	0.8
Tax benefit of mortgage balance	τ	0.25	0.25	0.25
Initial Housing Preference	γ_2	0.18	0.22	0.22
Fraction of debt amortized	Δ	0.09	0.09	0.09
Long-run mean of r_t^m	$\bar{r}$	0.0368	0.0293	0.068
Mean Reversion Coefficient of r_t^m	θ	0.0608	0.0794	0.0431
Volatility Coefficient of r_t^m	σ	0.0036	0.0033	0.0084
Interest rate gap between r^d and r^m	$\overline{r^d} - \bar{r}$	0.011	0.000	-0.009

We calculate impulse response functions in the model for each of the three episodes we have considered, since the parameters and estimated interest rate processes vary across time periods. The long run means of the mortgage rate correspond to the rates we used in the steady state analysis. But in the dynamic model, note that the stimulus episode with lower rates exhibits higher mean reversion and lower volatility, while the tightening episode has the opposite - significantly higher volatility and less mean reversion than the other episodes.

The impulse response functions to a one-standard deviation mortgage rate shock are charted below. We graph the stimulus shock as a negative rate shock for ease of interpretation. All shocks are a one-standard deviation shock, so the baseline and stimulus shocks are relatively symmetric, while the tightening shock is larger and more protracted.

Positive (negative) interest rate shocks have the expected negative (positive) initial effect on home prices. Note that mortgage balance is a predetermined variable within a period, so the mortgage payments in the bottom left panels initially move with interest rates. That is, a tightening shock raises mortgage payments discontinuously, until households can rebalance their mortgages. After this "date 0" effect, both debt and payments are initially lower in response to higher rates. However, the change in interest rates also affects the households intertemporal trade-offs and the consumption-savings profiles in the right-hand panels. Higher rates, even temporarily, increase savings and shift consumption toward the future. This also applies to housing consumption, so home prices rise over time, along with mortgage balances and payments, though the latter effect is ameliorated as interest rates mean-revert.

This is in many ways a standard dynamic interest rate effect, augmented by the presence of housing and leverage. In this specification it is driven by the dynamics of r^d, the deposit rate, which is held at a constant spread to r^m.

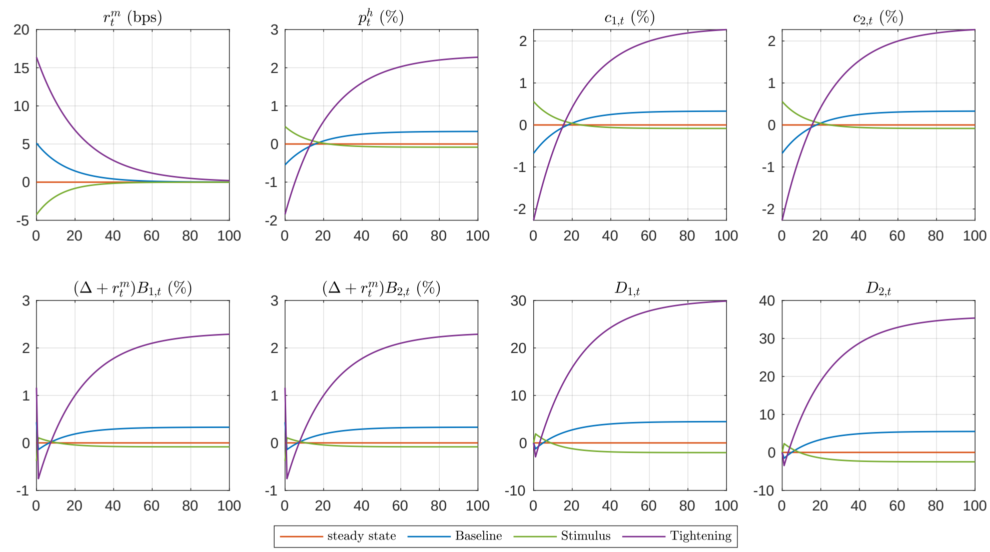


Figure 9: Impulse Responses to a 1-SD Mortgage Rate Shock

Because of the important role of r^d in the dynamic model, we also run a simulation keeping the deposit rate fixed, and allowing for a stochastic mortgage rate. This isolates the effect of the mortgage rate and changes the impulse response functions to a one-standard deviation mortgage rate shock as follows:

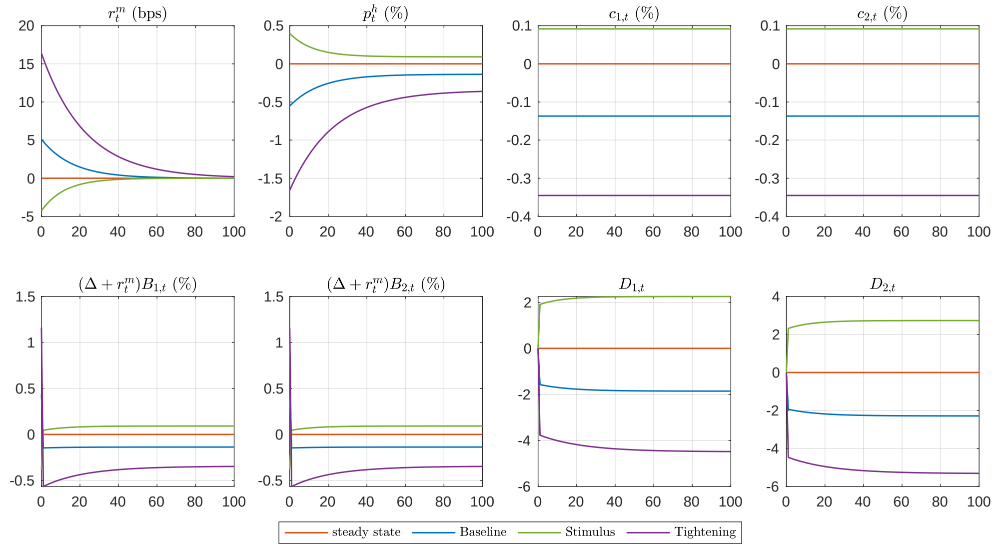


Figure 10: Impulse Responses to a 1-SD Mortgage Rate Shock with Fixed Deposit Rate

The first panel shows that the mortgage rate process remains as above, however, all of the other panels now lack the general shift in interest rates and associated intertemporal trade-offs. House price changes track the mortgage interest rate change (with the opposite sign). Note again that because mortgage borrowing is predetermined, the household has a date zero initial jump in the carrying cost of housing when rates rise, and a windfall when rates decline. Thereafter, the household readjusts housing demand and borrowing, so that housing payments decline after a rate increase and rise (reflecting higher borrowing) when rates decline. The jumps are smoothed out by changes in deposits, in the bottom right panel. This allows consumption smoothing: consumption shifts down (up) persistently for higher (lower) rates.

By focusing only on the change in mortgage rates for given interest rates, these results focus on the housing market. They can be thought of as tracing the effects of a temporary but persistent change in the relative carry cost of housing. These persistent effects are largely in line with the steady state results of the previous section, which also abstract from some intertemporaral tradeoffs, but take into account multiple changes in the economic situation, rather than an isolated change in the mortgage rate.

Interestingly, the IRFs reflect the impact on a homeowner/buyer who faces the market rate, rather than a borrower with a fixed rate who does not move. Hence, the path also illustrates the benefit to the homeowner who locked in a fixed rate mortgage, saving the spike in carrying costs and the decline in other wealth needed to smooth out the effects on consumption.

The chart also reinforces the implied large change in home prices that would ensue if the stock of housing were to immediately reprice following an increase in mortgage rates. The impact effect is very similar in both interest rate experiments: house prices fall 1.5 to 2% in response to a one standard deviation tightening, or 15 *bps*. Rates have risen an order of magnitude more than that in the data, as charted in Appendix Figure A.16 along with the implied effect on home prices. If overall rates rise and then subsequently decline, housing prices more than recover due to higher saving and demand. However, holding overall rates steady, then the increase in mortgage rates leads to in a persistent decline in house prices.

5 Comments

These results focus on at least three important public policy issues.

First, housing affordability has been of heightened concern since the housing boom (and in some cases even earlier) in the early 2000s. The recent boom has exacerbated these concerns as demand for housing rose across all income groups while supply has trended up only modestly since the GFC, and construction was compromised further by COVID supply and cost issues. These issues are particularly pointed for first time buyers, who in addition to having lower incomes, also lack housing equity to reinvest in a time of home price appreciation. Our results imply that first time buyers buy smaller homes, or those with poorer amenities or match, and if they bought the "average" home would face substantially higher DTIs. Allowing for indivisibilities in home purchases or lack of supply of smaller and less expensive homes would exacerbate the magnitude of these effects, since some first time buyers would be completely blocked from the market rather than buying smaller or lower amenity homes.

Secondly, much recent attention has been paid to institutions in the housing sector and their potential impact on monetary policy effectiveness. Most of these have focused on diminishing the stimulus effect of rate reductions or quantitative easing. For example, Berger, Milbradt, Tourre, and Vavra (2021) and Eichenbaum, Rebelo, and Wong (2022) emphasize that while mortgage refinancing propagates monetary stimulus, progressive waves of refinancing with long periods of low interest rates reduce the effectiveness of future rate cuts, since households already have low interest mortgages and little benefit from refinancing. Hence, rate cuts act like a temporary tax cut by pulling forward refinancing and cannibalizing future policy effectiveness.

In the tightening episode, ratcheting up interest rates is ineffective for a different reason. Not only do households not want to refinance, they treasure their existing low cost mortgages. The more rates rise, the more appealing are existing contracts and the lower the incentive to refinance or sell and repurchase (Campbell, 2023). Existing homeowners effectively have both a house and a valuable "subsidized" legacy mortgage. Selling the home requires relinquishing the valuable mortgage, raising the seller's reservation price. Market clearing thus requires the seller to match with a sufficiently motivated buyer – who values the house above its intrinsic price. This rate lock undermines the effectiveness of monetary tightening by inhibiting repricing. There is not only no refinancing channel, there is a rate lock-in until households are forced to move or otherwise reprice to overcome the seller's reservation price premium. Because rates were historically low during COVID and so many households either purchased or refinanced, this lock-in effect is large and likely to be long-lasting unless other events encourage or force more sales or recontracting, or a renaissance in supply overcomes the importance of existing home availability. This effect is particularly important for monetary policy, as residential real estate is one of the largest, if not the largest, transmission sector for monetary policy (David and Gourio, 2023). The effect acts in addition to existing sluggish pass through from fixed rate mortgages relative to variable-rate contracts that have been measured across countries (Calza et al., 2013).

Putting these two effects together, the structure suggests a long corridor where monetary policy will have difficulty moving the housing market. As rates rise, existing homeowners will be locked in and housing will be priced more off new construction and first time buyers. In a thin market, prices tend to be more volatile than otherwise. Similarly, first-time homebuyers are finding housing less affordable until supply effects become stronger and bypass the paralysis in the market for existing homes. Should a recession hit and monetary easing be implemented, current rates will likely remain substantially above the contracted rates of existing homeowners, limiting their incentive to refinance unless rates again fall to historically low levels. Modestly lower rates would improve affordability to the benefit of new buyers and homeowners who took out high rate loans in 2022 and would refinance if rates declined. Currently there are few of these high cost mortgages, so the refinancing channel, while welcome to recent borrowers, may be less potent in the macroeconomy than in previous downturns. This leaves the aforementioned corridor, where rates are not low enough to induce much refinancing and stimulus – but neither does raising rates consistently slow house price inflation.

Finally, these challenges raise the question of whether stronger macroprudential policy might have ameliorated some of these issues. Certainly, the affordability challenge was exacerbated by the decline in mortgage rates and the strength of overall stimulus, especially in the context of the pandemic-driven increase in housing demand. Less support or less prolonged support for the housing market specifically could have reduced the rush for low rate mortgages and the ensuing house price appreciation that left behind first time buyers and renters especially. For example, the additional 30 *bps* mortgage rate reduction potentially attributable to QE would have increased home price appreciation in our model by a third at the peak of the market, from 31% to 41%. Moreover, the long period of very low rates leaves behind a "generation" of home purchasers with locked-in low mortgage rates. The economic benefits of these refinancings have already been accrued as past stimulus. But the opportunity costs of the lock-ins may inhibit future monetary tightening and a repricing of housing assets yet to come.

Returning to the contrast between the GFC recession and the COVID-19 recession, the recession and ensuing policy effects on the housing market could not be more different. The GFC began with weak balance sheets and, if anything, excess housing supply, which were complicit in the recession itself. COVID-19 came from outside the economy, striking when balance sheets were strong and housing supply lagging. Moreover, the nature of the public health shock led to a shift in preferences *toward* housing. Thus the same policies that struggled to support housing in the GFC instead contributed to a historic boom during COVID. Perhaps suitably, the aftereffects of these policies will also creep into the future policy playbook: legacy low rates stand to undermine monetary policy in both tightening and loosening efforts.

Future work to enhance this analysis could tighten its implications for the economy and policy. In particular, explicitly modeling transactions in the housing market as a search process and endogenizing the ”Calvo moving shock” as a trade-off between a lower cost mortgage and the benefits of moving would sharpen and connect our implications to underlying behavior and household characteristics. Similarly, endogenizing supply would help to articulate the role of interest rates and other factors in the incentive to build and satisfy the apparently growing demand for housing.

A Appendix: Steady State and Dynamic Model and Solutions

A.1 Steady State Solutions

Given the parameters in Table 3, we first calculate

$$\begin{aligned}\Delta^h &= 1/\left(1+r^d\right)\\ \Delta^\phi &= \phi\left(r^d-r^m\right)/\left(1+r^d\right)\end{aligned}$$

Then, we calculate the consumption based on

$$\begin{aligned}c_i &= y_i-\phi r^m\left(p^h h_i\right) \quad \forall i.\\ h_i &= \gamma_i \frac{c_i}{p^h\left[1-\Delta^h-\Delta^\phi\right]} \quad \forall i.\end{aligned}$$

Specifically, plugging the formula of housing demand h_i into that of consumption c_i, we obtain

$$\begin{aligned}c_i &= y_i-\phi r^m \gamma_i \frac{c_i}{\left[1-\Delta^h-\Delta^\phi\right]}\\ \Longrightarrow c_i &= \frac{1}{1+\frac{\phi r^m \gamma_i}{\left[1-\Delta^h-\Delta^\phi\right]}} y_i\end{aligned}$$

Plug in the formulae of h_1 and h_2 into the market clearing condition:

$$N_1 h_1+N_2 h_2=\bar{H},$$

and therefore we obtain

$$\frac{N_1 \gamma_1 c_1+N_2 \gamma_2 c_2}{p^h\left[1-\Delta^h-\Delta^\phi\right]}=\bar{H}.$$

That is,

$$p^h=\frac{N_1 \gamma_1 c_1+N_2 \gamma_2 c_2}{\bar{H}\left[1-\Delta^h-\Delta^\phi\right]}$$

Then, we plug the formulae of consumption c_i and housing price p^h into that of h_i to get the the housing demand.

$$h_i=\gamma_i \frac{c_i}{p^h\left[1-\Delta^h-\Delta^\phi\right]}$$

The figures below show simple comparative statics for steady-state housing prices with respect to mortgage rates and the housing taste factor.

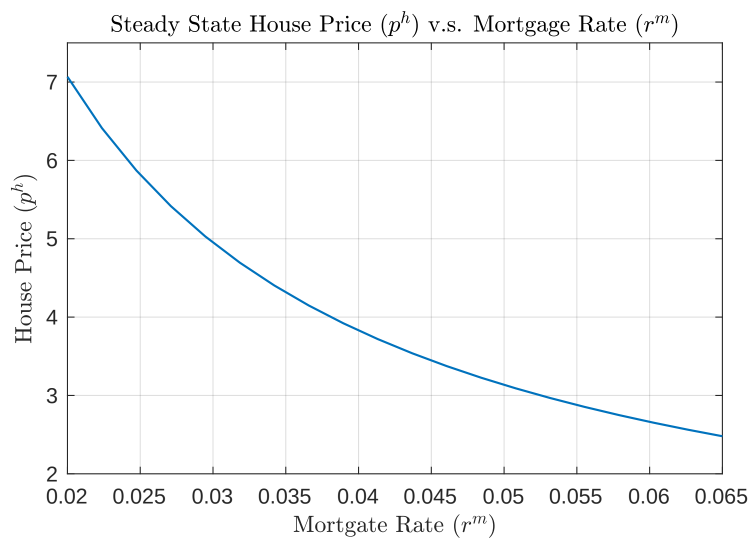


Figure A.11: Steady State House Price (p^h) v.s. Mortgage Rate (r^m)

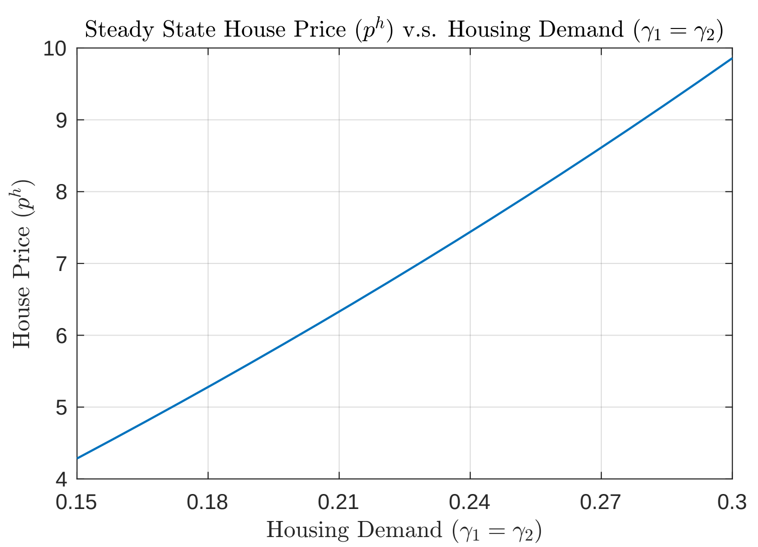


Figure A.12: Steady State House Price (p^h) v.s. Housing Demand ($\gamma_1 = \gamma_2$)

A.2 Dynamic Model Solutions

For the case where the housing supply is fixed $\{\bar{H}\}$, given

- a path for credit conditions $\left\{r_t^m, r_t^d\right\}_{t=0}^{\infty}$,

- income endowments $\{y_i\}_{i=1}^{I}$, and the credit condition ϕ,

an equilibrium is constituted by

- price paths $\left\{p_t^h\right\}_{t=0}^{\infty}$, and
- sequences of individual decisions $\left\{\{c_{i,t}, h_{i,t}, D_{i,t+1}, b_{i,t+1}, B_{i,t+1}\}_{i=1}^{I}\right\}_{t=1}^{\infty}$

that

(i) solves each household's optimization problem in (3), (1), (2).

(ii) clears the markets:

$$\sum_{i=1}^{I} N_i h_{i,t} = \bar{H} \quad \forall t \tag{A.18}$$

With a little abuse of notation, we denote $(1-\tau) \times r^m$ by r^m in our model. We first write the Lagrangian of the optimization problem (3):

$$\begin{aligned}
&\mathcal{L}(c_{i,t}, h_{i,t}, b_{i,t}, B_{i,t}, D_{i,t}, \eta_{i,t}, \zeta_{i,t}, \chi_{i,t}) \\
=&\sum_{t=0}^{\infty} \beta^t \Big[\log c_{i,t} + \gamma_i \log h_{i,t} - \eta_{i,t}\left(c_{i,t} - y_i - b_{i,t+1} + \left(r_t^m + \triangle\right) B_{i,t} - \left(1 + r_t^d\right) D_{i,t} + D_{i,t+1} - p_t^h\left(h_{i,t-1} - h_{i,t}\right)\right) \\
&-\zeta_{i,t}\left(B_{i,t+1} - b_{i,t+1} - (1-\Delta) B_{i,t}\right) - \chi_{i,t}\left(b_{i,t+1} - \phi p_t^h h_{i,t} + (1-\Delta) B_{i,t}\right)\Big]
\end{aligned}$$

Then, we have the first-order conditions for the optimization problem (3).

- FOC with respect to $c_{i,t}$:

$$\frac{1}{c_{i,t}} - \eta_{i,t} = 0 \tag{A.19}$$

- FOC with respect to $h_{i,t}$:

$$\gamma_i \frac{1}{h_{i,t}} - \eta_{i,t} p_t^h + \beta \eta_{i,t+1} p_{t+1}^h + \chi_{i,t} \phi p_t^h = 0 \tag{A.20}$$

- FOC with respect to $b_{i,t+1}$:

$$\eta_{i,t} + \zeta_{i,t} - \chi_{i,t} = 0 \tag{A.21}$$

- FOC with respect to $B_{i,t}$:

$$-\frac{1}{\beta}\zeta_{i,t-1}-\eta_{i,t}(1+r_t^m)=0 \tag{A.22}$$

- FOC with respect to $D_{i,t}$:

$$\eta_{i,t}(1+r_t^d)-\frac{1}{\beta}\eta_{i,t-1}=0 \tag{A.23}$$

By simplifying the system of equations composed of first-order conditions (FOCs) and the binding constraints, we obtain the following result:

$$\eta_{i,t}=\frac{1}{c_{i,t}} \tag{A.24}$$

$$\zeta_{i,t}=-\frac{\beta(1+r_{t+1}^m)}{c_{i,t+1}} \tag{A.25}$$

$$\chi_{i,t}=\frac{1}{c_{i,t}}-\frac{\beta(1+r_{t+1}^m)}{c_{i,t+1}} \tag{A.26}$$

$$h_{i,t}=\frac{\gamma_i c_{i,t}}{p_t^h\left(1-\frac{p_{t+1}^h}{p_t^h}(1+r_t^d)-\phi\frac{r_{t+1}^d-r_{t+1}^m}{1+r_{t+1}^d}\right)} \tag{A.27}$$

$$1+r_t^d=\frac{1}{\beta}\frac{c_{i,t}}{c_{i,t-1}} \tag{A.28}$$

$$c_{i,t}-y_i-b_{i,t+1}+\left(r_t^m+\triangle\right)B_{i,t}-(1+r_t^d)D_{i,t}+D_{i,t+1}-p_t^h(h_{i,t-1}-h_{i,t})=0 \tag{A.29}$$

$$B_{i,t+1}-b_{i,t+1}-(1-\Delta)B_{i,t}=0 \tag{A.30}$$

$$b_{i,t+1}-\phi p_t^h h_{i,t}+(1-\Delta)B_{i,t}=0 \tag{A.31}$$

Solving for the optimal housing demand for individual i yields an asset pricing equation that depends on the traditional fundamental component, which is referred to as the user cost, as well as a credit component, as before

$$p_t^h=\underbrace{\frac{U_{h_{it}}}{U_{c_{it}}}+\frac{p_{t+1}^h}{1+r_{t+1}}}_{\text{Fundamental}}+\underbrace{\phi_t p_t^h\left(\frac{r_t^d-r_t^m}{1+r_t^d}\right)}_{\text{Credit}},\quad \forall t. \tag{A.32}$$

The ability to borrow is captured by the loan-to-value ϕ_t and the relative cost of borrowing captured by the interest rate spread

$$r_t^d-r_t^m>0.$$

For the preference specification, the housing demand for each type i is given by:

$$h_{it} = \gamma_i \frac{c_{it}}{p_t^h \left[1 - \triangle_{t+1}^h - \triangle_{t+1}^\phi\right]}, \quad \forall i, t$$

where

$$\begin{aligned} \Delta_t^h &= \left(p_{t+1}^h / p_t^h\right) / \left(1 + r_{t+1}^d\right) \\ \Delta_{t+1}^\phi &= \phi_t \left(r_{t+1}^d - r_{t+1}^m\right) / \left(1 + r_{t+1}^d\right) \end{aligned}$$

represent the value of reselling tomorrow and the gains associated with the spread between rates tied to the ability to leverage the house purchase. Plugging $h_{i,t}$ into the market-clearing condition yields:

$$H^d\left(p^h\right) = \sum_{i=1}^{I} N_i \left[\gamma_i \frac{c_{i,t}}{p_t^h \left[1 - \triangle_{t+1}^h - \triangle_{t+1}^\phi\right]}\right] = \bar{H}, \quad \forall t \tag{A.33}$$

By the above equation, we can write housing prices as

$$p_t^h = \frac{1}{\left[1 - \Delta_{t+1}^h - \Delta_{t+1}^\phi\right]} \sum_{i=1}^{I} N_i \frac{\gamma_i c_{i,t}}{\bar{H}} \quad \forall t. \tag{A.34}$$

The whole dynamic system is characterized by the following system of eleven equations

$$\begin{aligned}
&1 + r_t^d = \frac{1}{\beta} \frac{c_{i,t}}{c_{i,t-1}} \qquad i \in \{1, 2\} \\
&B_{i,t} - b_{i,t} - (1 - \Delta) B_{i,t-1} = 0 \qquad i \in \{1, 2\} \\
&b_{i,t+1} - \phi p_t^h h_{i,t} + (1 - \Delta) B_{i,t} = 0 \qquad i \in \{1, 2\} \\
&c_{i,t} - y_i - b_{i,t+1} + \left(r_t^m + \triangle\right) B_{i,t} - (1 + r_t^d) D_{i,t} + D_{i,t+1} - p_t^h (h_{i,t-1} - h_{i,t}) = 0 \qquad i \in \{1, 2\} \\
&h_{i,t} = \frac{\gamma_i c_{i,t}}{p_t^h \left[1 - \left(p_{t+1}^h / p_t^h\right) / \left(1 + r_{t+1}^d\right) - \phi_t \left(r_{t+1}^d - r_{t+1}^m\right) / \left(1 + r_{t+1}^d\right)\right]} \qquad i \in \{1, 2\} \\
&h_{1,t} + h_{2,t} = \bar{H},
\end{aligned}$$

with eleven unknowns:

$$\{c_1, c_2, h_1, h_2, p^h, b_1, b_2, B_1, B_2, D_1, D_2\}.$$

We first simplify this system to

$$
\begin{aligned}
&1+r_t^d=\frac{1}{\beta}\frac{c_{i,t}}{c_{i,t-1}} \qquad i\in\{1,2\}\\
&B_{i,t+1}-\phi p_t^h h_{i,t}=0 \qquad i\in\{1,2\}\\
&c_{i,t}-y_i-B_{i,t+1}+\left(1+r_t^m\right)B_{i,t}-(1+r_t^d)D_{i,t}+D_{i,t+1}-p_t^h(h_{i,t-1}-h_{i,t})=0 \qquad i\in\{1,2\}\\
&h_{i,t}=\frac{\gamma_i c_{i,t}}{p_t^h\left[1-\left(p_{t+1}^h/p_t^h\right)/\left(1+r_{t+1}^d\right)-\phi_t\left(r_{t+1}^d-r_{t+1}^m\right)/\left(1+r_{t+1}^d\right)\right]} \qquad i\in\{1,2\}\\
&h_{1,t}+h_{2,t}=\bar{H},
\end{aligned}
$$

with nine unknowns:

$$\{c_1,c_2,h_1,h_2,p^h,B_1,B_2,D_1,D_2\}.$$

Next, we can simplify the system to

$$
\begin{aligned}
&1+r_t^d=\frac{1}{\beta}\frac{c_{i,t}}{c_{i,t-1}} \qquad i\in\{1,2\}\\
&c_{i,t}-y_i-\phi p_t^h h_{i,t}+\left(1+r_t^m\right)\phi p_{t-1}^h h_{i,t-1}-(1+r_t^d)D_{i,t}+D_{i,t+1}-p_t^h(h_{i,t-1}-h_{i,t})=0 \qquad i\in\{1,2\}\\
&h_{i,t}=\frac{\gamma_i c_{i,t}}{p_t^h\left[1-\left(p_{t+1}^h/p_t^h\right)/\left(1+r_{t+1}^d\right)-\phi_t\left(r_{t+1}^d-r_{t+1}^m\right)/\left(1+r_{t+1}^d\right)\right]} \qquad i\in\{1,2\}\\
&h_{1,t}+h_{2,t}=\bar{H},
\end{aligned}
$$

with seven unknowns:

$$\{c_1,c_2,h_1,h_2,p^h,D_1,D_2\}.$$

We solve the system using Dynare and hence use the following time convention. Predetermined variables (such as $D_{i,t}$) appear as dated $t-1$ in the time t equations and as t in the $t+1$ equations. Therefore, we need to shift the FOCs as follows:

$$
\begin{aligned}
&1+r_{t+1}^d=\frac{1}{\beta}\frac{c_{i,t+1}}{c_{i,t}} \qquad i\in\{1,2\}\\
&c_{i,t}-y_i-\phi p_t^h h_{i,t}+(1+r_t^m)\phi p_{t-1}^h h_{i,t-1}-(1+r_t^d)D_{i,t-1}+D_{i,t}-p_t^h(h_{i,t-1}-h_{i,t})=0 \qquad i\in\{1,2\}\\
&h_{i,t}=\frac{\gamma_i c_{i,t}}{p_t^h\left[1-\left(p_{t+1}^h/p_t^h\right)/\left(1+r_{t+1}^d\right)-\phi_t\left(r_{t+1}^d-r_{t+1}^m\right)/\left(1+r_{t+1}^d\right)\right]} \qquad i\in\{1,2\}\\
&h_{1,t}+h_{2,t}=\bar{H}
\end{aligned}
$$

We model r^m using a CIR process and initially assume a constant gap between the r_t^d and r_t^m

processes. The equations representing the processes are as follows:

$$r^d_{t+1} = r^m_{t+1} + (\overline{r^d} - \bar{r}) \tag{A.35}$$

$$r^m_{t+1} = r^m_t + \theta(\bar{r} - r^m_t) + \sigma\sqrt{r^m_t}\varepsilon_t. \tag{A.36}$$

To specify the dynamic model, we require the following additional parameters:

$$\{y_1, y_2, N_1, N_2, \bar{H}, \phi, \gamma_1, \gamma_2, \Delta, \theta, \bar{r}, \sigma, \overline{r^d} - \bar{r}\},$$

which we calibrate based on the baseline (Jan. 2019 - Dec. 2019), stimulus (Apr. 2020 - Dec. 2021), and tightening (Jan. 2022 - Dec. 2022) phases, respectively. During each phase, we calibrate the r^m and r^d processes using weekly interest rate data. The parameter values are laid out in Table 9.

Table A.10: Parameter Values

Parameter	Symbol	Baseline	Stimulus	Tightening
Type 1 Income	y_1	65	70	76
Type 2 Income	y_2	80	85	90
Share of Type 1 Buyer	N_1	0.46	0.42	0.41
Share of Type 2 Buyer	N_2	0.54	0.58	0.59
Single Family Owner Occupied Units	$\bar{H}$	100	104	104
LTV constraint	ϕ	0.8	0.8	0.8
Tax benefit of mortgage balance	τ	0.25	0.25	0.25
Initial Housing Preference	γ_2	0.18	0.22	0.22
Fraction of debt amortized	Δ	0.09	0.09	0.09
Long-run mean of r^m_t	$\bar{r}$	0.0368	0.0293	0.068
Mean Reversion Coefficient of r^m_t	θ	0.0608	0.0794	0.0431
Volatility Coefficient of r^m_t	σ	0.0036	0.0033	0.0084
Interest rate gap between r^d and r^m	$\overline{r^d} - \bar{r}$	0.011	0.000	-0.009

The impulse response functions to a one-standard deviation mortgage rate shock are:

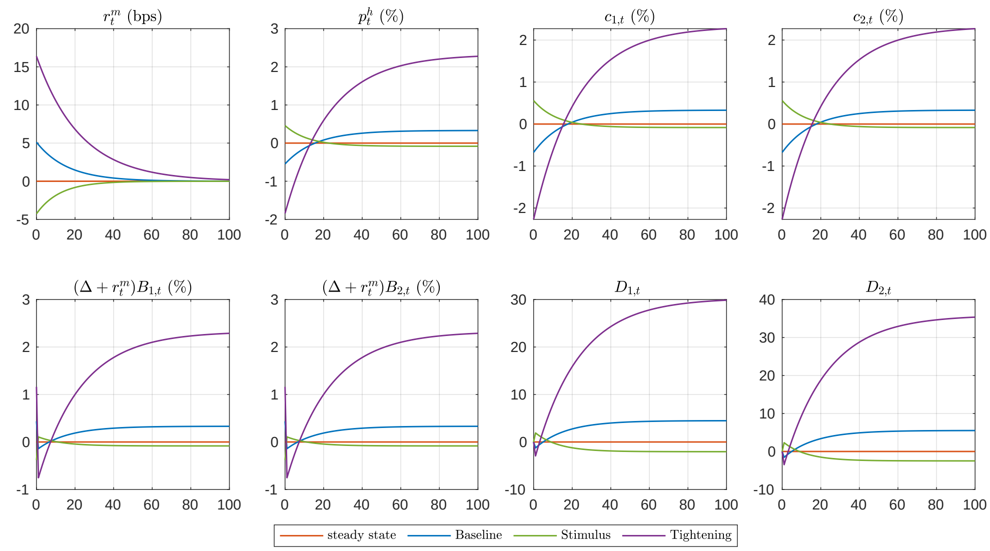


Figure A.13: Impulse Responses to a 1-SD Mortgage Rate Shock

Keeping the deposit rate fixed, the impulse response functions to a one-standard deviation mortgage rate shock are:

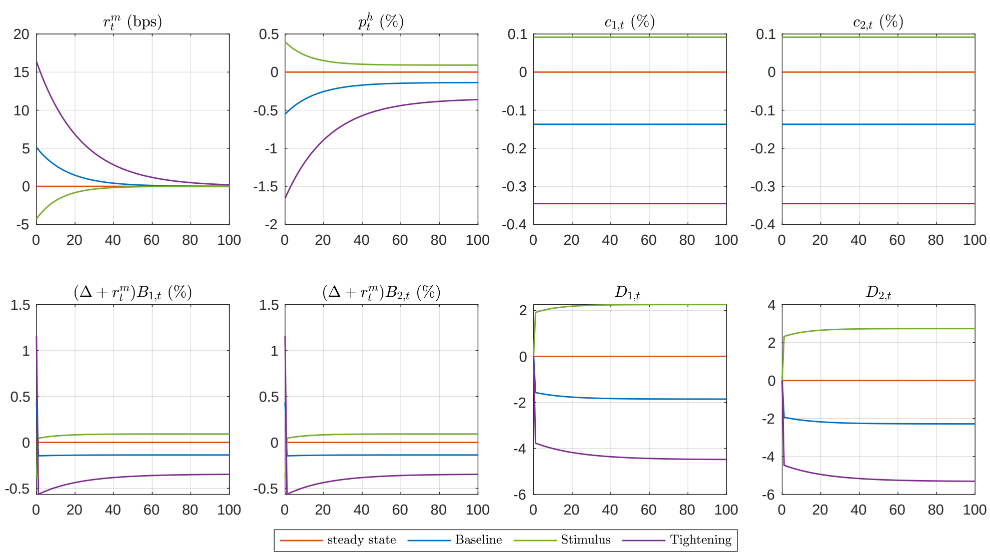


Figure A.14: Impulse Responses to a 1-SD Mortgage Rate Shock with Fixed Deposit Rate

Using the same model, we calculated impulse response functions to a mortgage rate shock sized to the changes from the steady state in the model to the three episodes we examine. Thus the ”baseline” IRF shows the effect of a shock sized to the difference between the baseline and the steady state, which is roughly zero. The stimulus and tightening episodes are more sizeable shocks and the IRF gives a sense of the magnitudes during these episodes, as compared to a one standard deviation shock in the previous IRF panels.

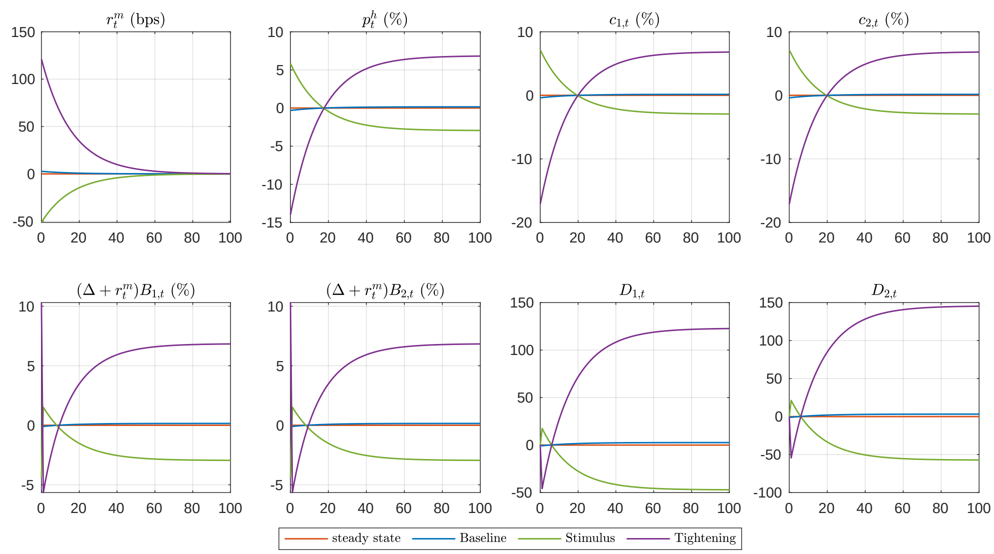


Figure A.15: Impulse Responses to a Mortgage Rate Shock in the Data

Keeping deposit rate fixed, the impulse response functions to a mortgage rate shock in the data are:

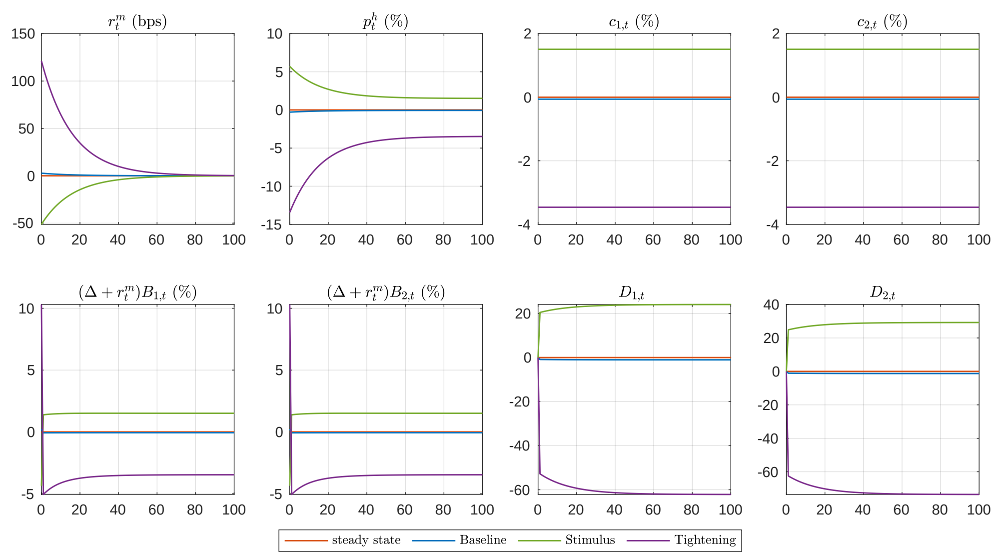


Figure A.16: Impulse Responses to a Mortgage Rate Shock in the Data with Fixed Deposit Rate

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