Long- and Short-run Effects of Interest Rates on Builders and the Housing Market

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Abstract

This paper analyzes the effects of real interest rates on homebuilders and the housing market under fixed-rate mortgages (FRM), both in long-run equilibrium and during transitional dynamics, and finds that the endogenous supply-side response to interest rate increases mitigates short-run housing price declines. I develop a heterogeneous agent model incorporating different mortgage structures, liquid assets, lumpy housing adjustment, and a construction sector with time-to-build constraints to decompose the effects of interest rates on housing prices. The findings demonstrate that in a long-run stationary equilibrium, heterogeneous household policy functions and the corresponding stationary distribution influence housing demand, while increased interest rates consistently suppress construction activity. The calibrated model demonstrates that the interest rate temporarily increases from 0.618% to 6% results in short-run housing prices that exceed those in a counterfactual without endogenous supply by 5 to 7 percentage points of the stationary price. Adjustable-rate mortgages reduce short-run housing prices by 1 percentage point of the stationary price relative to fixed-rate mortgages. The builder's financial constraint has limited impact on housing prices since a temporary increase in interest rates lowers optimal construction levels, hence a looser financial constraint.

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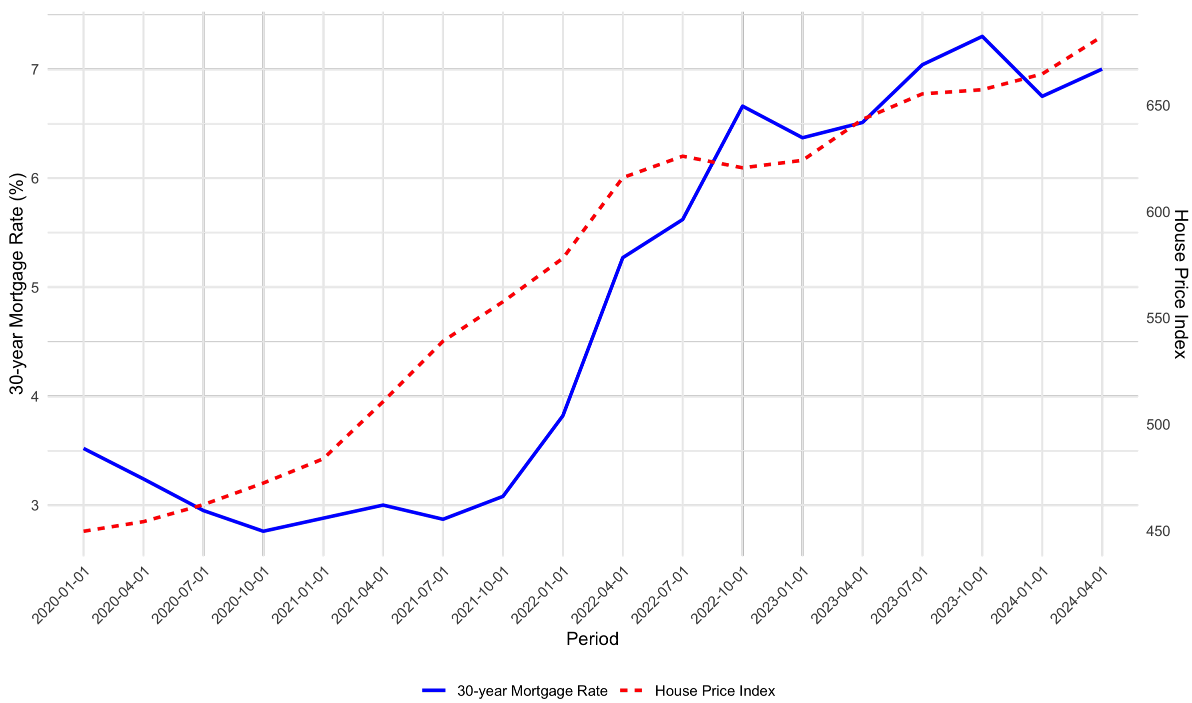
1 Introduction

After 2022, we have witnessed a surge in both housing prices and mortgage rates. Figure 1 depicts a sharp increase in 30-year mortgage rates alongside steadily rising house prices. This leads to an important policy question: the effects of interest rates on housing prices. Surprisingly, existing literature struggles to provide the reasoning for this co-movement, particularly as theoretical frameworks often predict a negative relationship between interest rates and house prices due to declining demand caused by rising mortgage costs. This puzzling pattern motivates a deeper exploration of the housing market dynamics and the channels through which real interest rates affect housing prices.



Note: This figure displays the time series average 30-year fixed mortgage rate by blue real line (left y-axis) and the all-transaction house price index by red dash line (right y-axis) from Q1 2020 to Q2 2024 in the U.S. Source: FRED.

Figure 1: 30-year Mortgage Rate and Housing Price Index (Q1 2020-Q2 2024)

How do real interest rate changes impact the housing market and real house prices in both the short run and long run? This paper addresses this central research question with a particular emphasis on the supply side–builders, a sector often underexplored in literature. Figure 2 shows that the housing permits and the housing starts growth rates are negatively correlated with the real interest rate during the past 2 decades, with correlation coefficients -0.457 and -0.421 respectively . This implies that new construction investment from builders is very interest rate sensitive. In addition, a weak correlation between the housing completion and the real interest rate is displayed in figure E1, implying that construction takes time to build (TtB). The evidence motivates me to consider the builder channel subject to time to build in a rich model of incomplete market and heterogeneous households to investigate the effects of interest rates on the housing price and the housing market.

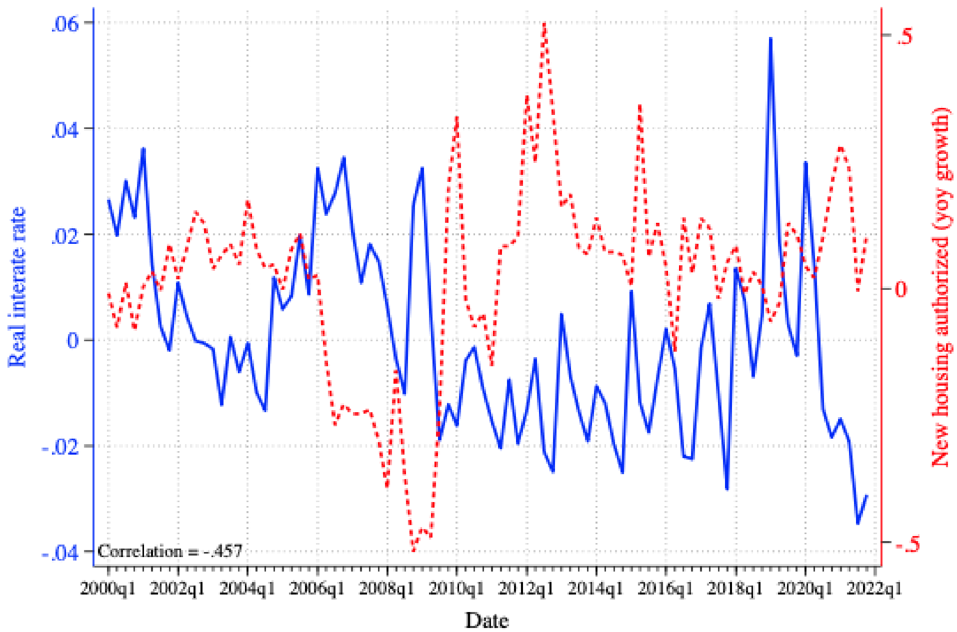
Recent discussions emphasize the lock-in effect as the primary channel of higher housing prices. Lock-in effect refers to the fact that when interest rates increase, homeowners with low mortgage rates are disincentivized to sell or move under a fixed-rate mortgage (FRM) structure.[1] The argument argues that the lock-in effect reduces the quantity of the existing home supply, hence a rising housing price. However, this channel primarily affects housing quantity rather than price.

Why does the lock-in effect not adequately explain higher housing prices? In the housing market, there are three key agents: new buyers, homeowners, and builders. The total housing supply consists of listed existing houses from homeowners and new build from builders. The total housing demand comprises demand from new home buyers and existing homeowners. The lock-in effect suggests that higher prices arise when the housing supply from existing homeowners decreases. That is, there is an inward shift in supply. However, this reasoning overlooks the fact that existing homeowners are not only suppliers of used houses but also demanders of houses. When homeowners decide not to list their used houses, there is a simultaneous reduction in housing demand. Therefore, there is an inward shift in demand. The resulting pattern is clear: the quantity of houses decreases, while the price response remains minimal.

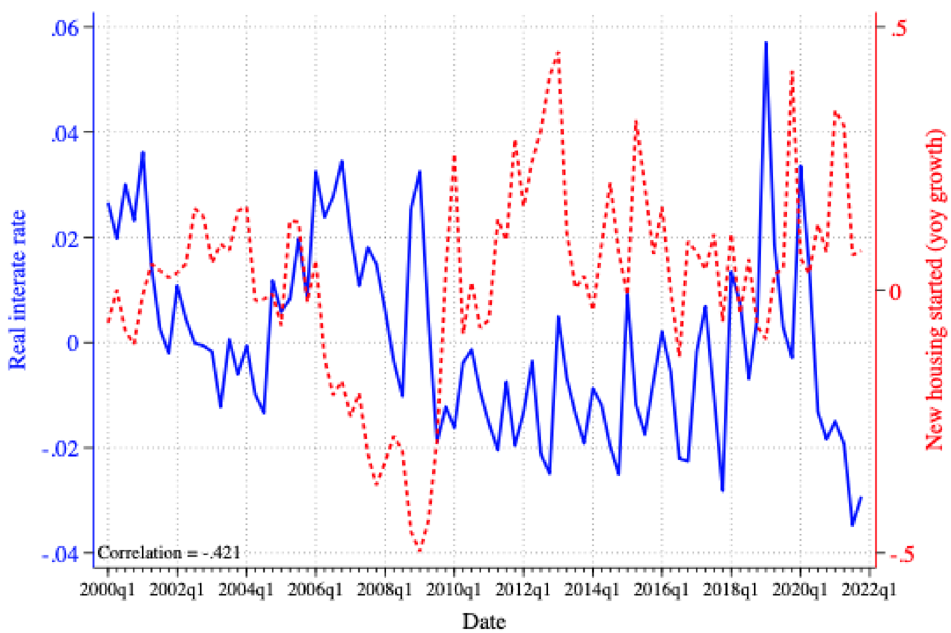
The main contribution of this paper is to develop a more general model that incorporates builders subject to time-to-build constraints and a detailed mortgage structure. Simultaneously, the model preserves key features such as household heterogeneity and incomplete markets. Then I calibrate the model and quantitatively decompose the channels through which the economy responds to changes in interest rates.

This model features overlapping-generation builders subject to time to build, financial constraint of construction loans against partial value of construction projects, and equity-issuance costs. Builders decides construction loans, dividends, construction inputs, and the amount of new construction. I show that the interest rate deters the new construction due to time to build. Thus, a higher interest rate always decreases new housing supply. The model also incorporates heterogeneous households facing idiosyncratic income shocks and choosing consumption and housing subject to financial constraints and adjustment costs.

[1] Another mortgage structure is adjustable-rate mortgage (ARM). The mortgage payments vary with the current interest rate.



(a) Housing Permits and Real Interest Rate



(b) Housing Starts and Real Interest Rate

Note: This figure displays the quarterly time series 1-year real interest rate by the blue solid line (left y-axis) and builder's construction investment growth rate by the red dashed line (right y-axis) from Q1 2000 to Q1 2022 in the U.S. Specifically, the red dashed line in the top panel reports the new housing permits yoy growth rate. The red dashed line in the bottom panel reports the new housing starts yoy growth rate. The correlation coefficient of real interest rates and housing permits yoy growth rate is -0.457. The correlation coefficient of real interest rates and housing starts yoy growth rate is -0.421.

Figure 2: Real Interest Rate and Housing Permit and Starts Growth (Q1 2000-Q1 2022)

The financial constraints take the form of mortgage borrowing limits, which are pledged against the residual future value of housing. I demonstrate that interest rate changes not only discourage housing purchases through the mortgage cost channel but can also increase housing demand from high-saving households. Furthermore, beyond influencing heterogeneous housing choices, interest rates affect the distribution of households, which determines the dominant type of household response. There are overlapping-generation rental companies pinning down the rental rate by Jorgenson user cost formula. In equilibrium, the housing price clears the housing market taking an exogenous interest rate.

After calibrating the model to match key moments in the U.S. economy, I conduct a quantitative analysis of a temporary interest-rate increase and decompose effects through various channels in the short run. First, homebuilders' response to rising interest rates causes housing prices to either decrease by a smaller magnitude or increase comparing to a the counterfactual with fixed housing supply in the short run, primarily due to time to build. Second, the decomposition reveals that rising interest rates (from 0.618% to 6%) contribute a $5-7\%$ of the initial price level increase to housing prices comparing to those in the counterfactual with fixed housing supply in the short run. Third, the mortgage structure plays a significant role: compared to fixed-rate mortgages (FRMs), adjustable-rate mortgages (ARMs) reduce housing prices by approximately 1% of the initial price level while simultaneously decreasing the proportion of homeowners who maintain ownership (stayers) and reducing the overall homeownership rate in the short run. Finally, financial constraints on builders have limited effects on housing prices during periods of rising interest rates, as builders respond by optimally decreasing construction levels, which in turn relaxes their financial constraints.

The rest of the paper is organized as follows. Section 2 discusses the related literature. Section 3 describes a model features builders, heterogeneous households, and rental companies to illustrate interest rate mechanisms in the housing market. Section 4 calibrates the model and analyzes mechanisms in the stationary equilibrium. Section 5 analyzes the transitional dynamics in economies with builders, without builders, ARM structure, and with builder's financial constraint respectively. Section 6 is conclusion.

2 Related Literature

This paper mainly contributes to two branches of literature. One contribution is to investigate the interest rate driver of housing prices. The other is related to literature on housing supply and builder behavior.

Drivers of house prices. A large literature studies aggregate interest rate shocks on housing prices and changes in interest rates on housing prices of different quality (Kiyotaki et al., 2011; Sommer et al., 2013; Hacamo, 2021; Greenwald, 2018; Del Negro and Otrok, 2007; Favilukis et al., 2017). Besides interest rate shocks, literature suggests that the housing price is affected by expectation shocks (Garriga et al., 2019; Kaplan et al., 2020), credit supply (Justiniano et al., 2019), and collateral constraints (Landvoigt et al., 2015; Garriga and Hedlund, 2020). This paper contributes to this strand of literature by investigating interest rate effects in the long run and under ARM and FRM in the short run with the new construction margin.

Housing supply and builders. There is a strand of literature discuss how to measure the elasticity of housing supply (Saiz, 2010; Aastveit et al., 2023; Baum-Snow and Han, 2024; Green et al., 2005). With respect to builders' decisions, Murphy (2018) estimates the price function and the cost structure of builders and determine a dynamic discrete choice of builders to build or delay construction on a lot. van Straelen (2024) shows that public homebuilders cut prices for fire sale in one market when they face a negative price shock in other markets. Oh and Yoon (2020) shows that the uncertainty during construction would delay the timing of an incomplete house when it takes time to build. This paper contributes to the literature of housing supply and builders in considering the construction loan need for builders, and show that how financial constraints affect builders response to changes in interest rates with a sophisticated household side.

3 Model

I now describe a model of household housing decision subject to distinct terms for savings and mortgages and building investment subject to time to build. The model provides a generalized framework to analyze the effects of interest-rate changes on the housing market, explicitly considering builders' decisions while preserving rich features of household behavior. The key feature of this model is the interaction between mortgage structures and interest rates and their effects on housing price dynamics. Specifically, higher interest rates act as a disincentive for new construction, which is the main force to drive short-term fluctuations in housing prices.

The economy is populated by a measure-one continuum of long-lived heterogeneous households, overlapping-generation builders, and rental companies. Households face the idiosyncratic income shock and consume non-durable goods and housing service flow in each period. They gain housing service flow either from buying houses subject to a mortgage borrowing constraint or from renting. Homeowners may either stay in their current houses by making minimum mortgage repayments or sell their properties while incurring adjustment costs.

Households also have access to liquid savings, which, alongside mortgages, feature distinct terms but share the same exogenously determined interest rate. The overlapping-generation builder invests in new construction subject to time to build and financial constraints of external and internal funds. Builders are the sole providers of new housing stock. The overlapping-generation rental company purchases housing units and leases them to households. The housing price is endogenously determined through the housing market clearing condition, while rental prices are set according to the Jorgensonian user cost.

This paper builds upon the foundational framework established by Kaplan et al. (2020). Similar to Kaplan et al. (2020), this model is composed of three main sectors: households, builders, and rental companies. These sectors collectively enable the model to capture the interplay between housing supply and demand under varying interest rates. However, unlike Kaplan et al. (2020), this model simplifies by abstracting from financial intermediaries, aggregate shocks and explicit default options, focusing on steady-state behaviors rather than life-cycle patterns.

This model differs from Kaplan et al. (2020) in several aspects. First, it incorporates a fixed-rate mortgage (FRM) structure, allowing households to lock in their existing mortgage rates and mitigate exposure to fluctuating interest rates. Second, a continuous renting choice enables households to choose arbitrary size of their rental units, beyond certain discrete choices. Third, the model explicitly examines builders' responses to interest-rate changes, emphasizing the impact of the time-to-build property on construction decisions. These innovations enhance the model's ability to capture the nuanced interactions between builder investment strategies, household behavior, and interest rate policies, which generates subtle housing price dynamics. By integrating these features, the model provides a more comprehensive framework for analyzing the broader implications of interest-rate policy on the housing market.

3.1 Environment

Time is discrete and with infinite horizon. There are long-lived households, overlapping-generation builders and overlapping-generation rental companies in the economy. The gross interest rate $R = 1 + r$ is exogenous. It applies to the mortgage rate, the liquid saving rate, and the builders' discount factor. For simplicity, there is no unsecured borrowing and no default option. I assume that there are zero-profit foreign banks taking deposits and lending to households and builders under the exogenous interest rate.[2] In a stationary equilibrium, the interest rate is constant. However, during transitional dynamics, the interest-rate changes

[2]This assumption avoids a banking problem or the credit market clearing condition. It makes the financial intermediary as a shadow sector.

in a MIT-shock flavor; i.e., before any change is realized, sectors in the economy do not have any prior information and will perceive the new interest-rate path immediately when the change is realized. In this section, I consider the stationary equilibrium of a stochastic overlapping generations model of builders with time to build. In a stationary equilibrium, all price variables are constant.

3.2 Builders

I now describe the builder's problem. In each period, a measure $\rho \in (0, 1]$ continuum of overlapping-generations builders are born, and measure ρ of existing builders exit the economy after completing and selling houses. The builder is risk neutral, and her objective is to maximize the net present value of dividends.

Technology. Each builder adopts a construction technology $h_s = \min\{\ell, f(x)\}$, where $f' > 0, f'' < 0, \lim_{x\to 0} f(x) = \infty, \lim_{x\to\infty} f(x) = 0$. Builders build houses h_s with land ℓ and factor x.[3] Houses take time to build–builders buy inputs at current period to build and sell h_s in the next period.[4] The land price p_ℓ and the factor price p_x are exogenous.

Financial Frictions. New builders are endowed with an initial net worth w. A builder can finance through short-term construction loans b, which are external funds, at an exogenous interest rate R. Due to limited enforcement for lenders to continue an incomplete project, builders pledge up to a fraction $\theta_b \in (0, 1)$ of their future home sales to finance through construction loans. A builder can also raise internal funds subject to a convex equity issuance cost $\phi(-d)$, for $d < 0$, and zero otherwise, where d is builders' dividends.[5] A negative dividend implies equity issuance with cost $\phi(-d)$.[6]

Builders' problem. Given initial net worth w, builders maximize the present value of their dividends deducting equity issuance costs by choosing dividends d, construction loan b, land input ℓ, factor x, and new construction h_s to solve

$$V_s(w) = \max_{\{d,\ell,x,h_s,b,w'\}} d - \phi(-d) + R^{-1}\{\rho w' + (1-\rho)V_s(w')\} \tag{1}$$

[3]Different from Cobb-Douglas housing production function in literature, e.g., Kaplan et al. (2020), Leontief production function aims to highlight the specialty of land in housing production. It is simple to decompose the housing value into land value and others.

[4]Note that the house takes time to build. If we bring the time index back, the new construction is $h_s(t+1) = \min\{\ell(t), f(x(t))\}$ and is sold under future price $p_h(t+1)$.

[5]Convex equity issuance cost means $\phi_d > 0$ and $\phi_{dd} > 0$.

[6]This equity issuance cost follows the setting in Lanteri and Rampini (2023a).

subject to current budget constraint

$$d + p_\ell \ell + p_x x \leq w + b, \tag{2}$$

net worth evolution

$$w' = p_h h_s - Rb, \tag{3}$$

the financial constraint

$$Rb \leq \theta_b p_h h_s \tag{4}$$

and the construction technology

$$h_s = \min\{\ell, f(x)\}. \tag{5}$$

At the optimum, builders choose land and the amount of the factor such that $\ell = f(x)$. We can substitute h_s and ℓ with $f(x)$ to solve the problem. For tractability, I assume $\rho = 1$, which implies that builders exist for 2 periods and will exit after selling houses.[7] The complete optimal conditions of a builder are characterized in Appendix A.

The time-to-build flavor is represented in (2) and (3); i.e., the production cost is incurred in the current period, while the sales revenue is collected as an element of future net worth. A key property of time-to-build is that revenue is always discounted, regardless of whether the builder is constrained or unconstrained. Using $R^{-1}\lambda'$ as the multiplier of the financial constraint, the optimal condition of the new construction for unconstrained builders is

$$p_h = R\left(p_\ell + \frac{p_x}{f'(x)}\right). \tag{6}$$

Because of time-to-build, the price is the future value of the marginal cost. For unconstrained builders, $\lambda' = 0$ implies that their borrowing constraints are slack, and they never issue equity. The interest rate affects the optimal construction investment throughout time-to-build property instead of the financing cost. Given the housing price, the first-best construction investment is fixed for all builders. This implies that builders are indifferent to issue current dividends and save for future net worth once they achieve the optimal construction

[7]With this assumption, it is easy to extend to heterogeneous builders. We can assume that the initial wealth follows an exogenous distribution $G(w)$. Tracking evolution of the endogenous net worth distribution is not necessary since only the exogenous distribution $G(w)$ matters.

investment level. The optimal condition of the new construction for a constrained builder is

$$p_h = R\left(p_\ell + \frac{p_x}{f'(x)}\right)\frac{1+\lambda'}{1+\theta_b\lambda'}. \tag{7}$$

Note that $\lambda' = \phi_d$ in equilibrium. That is, a constrained builder always issue equity, while an unconstrained builder relies solely on construction loans or issues dividends.

3.3 Households

There are long-lived heterogeneous households with a continuum of measure 1 in the economy. They gain utility from consuming non-durable goods and housing services. For housing choices, they can choose to move, stay, or rent. They can borrow from long-term mortgages and save in liquid assets. There is no unsecured borrowing and default options for households.

Preference. Households maximize lifetime utility from consumption c and housing service flow h_f. The per-period utility is $U(c, h_f)$, where $U_c > 0$, $U_h > 0$, $U_{cc} < 0$, $U_{hh} < 0$ and $U_{ch} > 0$. The homeowner enjoys the whole owner-occupied housing service flow, while the renter suffers disutility of the rental unit by factor $\xi \in (0, 1)$. Specifically, a household with h_o units of owner-occupied houses implies $h_f = h_o$, while a household with h_r units of rental houses implies $h_f = \xi h_r$. Future utility is discounted at rate $\beta \in (0, 1)$.

Income. Household receives exogenous idiosyncratic income y_i every period. This is the only uncertainty in this economy. It follows a first-order Markov process, which is modeled as an AR(1) process with persistence ρ_y and volatility σ_y:

$$\log(y_i') = \rho_y \log(y_i) + \sigma_y \epsilon_i', \tag{8}$$

where ϵ_i is drawn from a standard normal distribution. Income goods is the numeraire in the economy.

Liquid Asset. Households can save in liquid assets, a, with the rate of return r. The liquid asset is one-period. Saving in one unit of the liquid asset will earn the saver R unit of goods in the next period. We do not allow for negative a, which means that the unsecured borrowing is unavailable.

Housing. Households gain housing service flow via owning or renting houses. Similar to Kaplan et al. (2020), homeowners select owner-occupied housing unit from a finite set $\mathrm{H} = \{h^1, h^2, h^3, ..., h^N\}$, where $h^1 < h^2 < ... < h^N$. When a household moves to a new house, she moves to housing unit $h' \in \mathrm{H}$. However, renters can rent arbitrary size of rental units $h_{rent} > 0$.[8] That is, a household deciding to be a homeowner chooses $h' > 0$ and

[8] In Kaplan et al. (2020), renters can only rent from a finite set of rental units.

$h_{rent} = 0$, while a household deciding to be a renter chooses $h' = 0$ and $h_{rent} > 0$. There is no friction in purchasing and renting houses. Housing price is denoted as p_h, and rental rate is denoted as r_h. Households can purchase or rent houses at the competitive prices without time lag.

If a homeowner currently owns h units of houses, they depreciate with rate $\delta_h \in (0, 1)$ every period. Let i_h denote the subjective change in housing units if the homeowner moves. Housing incurs a proportional adjustment cost $FC_h(p_h h) = \kappa_h(1 - \delta_h)p_h h$ if $i_h \neq 0$. Therefore, the owner-occupied house evolves as

$$h' = (1 - \delta_h)h + i_h, \tag{9}$$

and the household pays adjustment costs and the value gap between existing and new houses $p_h(\kappa_h(1 - \delta_h)h + i_h)$ on moving to new houses.[9]

Mortgage. A homeowner can borrow long-term mortgages with the maturity of $D-$period by pledging up to $\theta_h \in (0, 1)$ of her future undepreciated housing value. The collateral constraint is

$$Rm' \leq \theta_h(1 - \delta_h)p_h h'. \tag{10}$$

This collateral constraint only needs to be satisfied at origination since the mortgage is long-term.[10] Note that p_h in (10) refers to the housing price in the future. It equals to the current housing price because we focus on the stationary equilibrium. After origination, the household with mortgage balance m is required to repay the minimum amount $r_m = \frac{r}{1-(1+r)^{-D}}$ based on amortization. If the homeowner does not move, she needs to repay the minimum required payment. The mortgage balance evolves as

$$m' \leq (R - r_m)m. \tag{11}$$

The household is free to repay more to decrease the amount of rolling-over principal. If the household chooses to move, she must pay off all mortgages and can borrow a new mortgage contract with the new house. There is no default on mortgages in this economy.

Household's problem. I now describe the household problem for movers, stayers, and renters. A homeowner can choose to move to a new house, stay in the existing house, or

[9] I assume that $i_h \neq 0$ implies moving to another house. The household has to pay off the mortgage attached to the old house.

[10] Literature often assumes a positive spread between the mortgage rate and the risk-free rate, such as Kaplan et al. (2020) and Fonseca et al. (2024). Here we do not have any micro-foundation of default option or other origination costs, so we have the same mortgage rate and saving rate.

sell the existing house to rent. A renter can keep renting or become a homeowner. Since a household can rent an arbitrary rental unit ($h_{rent} \geq 0$, renting is always an option for households.[11]

State variables at the beginning of each period are $s = (m, h, a, y)$, where m is mortgage, h is housing position, a is liquid asset, and y is income. A household solves

$$V(m, h, a, y; r) = \max\{V^m(m, h, a, y; r), V^{stay}(m, h, a, y; r), V^r(m, h, a, y; r)\}, \tag{12}$$

where V^m, V^{stay} and V^r are value functions for movers, stayers and renters respectively.

The problem for movers is

$$V^m(m, h, a, y; r) = \max_{\{c,h',a',m'\}} U(c, h') + \beta \mathbb{E} V(m', h', a', y'; r),$$

s.t.

$$\begin{aligned} & c + p_h[h' - (1 - \delta_h)h] + FC_h(p_h h) + a' + Rm \leq y + Ra + m', \\ & Rm' \leq \theta_h(1 - \delta_h)p_h h'. \end{aligned}$$

When a household move, she needs to pay off all mortgages and choose the new housing position. Since the term of assets and mortgages are different, it is not sufficient to track net saving solely. The reason is that if one save and borrow 1 unit at the same time, she earn R from saving and is required to repay r_m. The difference $R - r_m$ can provide liquidity premium if she is constrained in some future states. Therefore, we need to separate the mortgage and the liquid asset as two state variables.

The problem for stayers is

$$V^{stay}(m, h, a, y; r) = \max_{\{c,a',m'\}} U(c, (1 - \delta_h)h) + \beta \mathbb{E} V(m', (1 - \delta_h)h, a', y'; r),$$

s.t.

$$\begin{aligned} & c + a' + Rm \leq y + Ra + m', \\ & m' \leq (R - r_m)m. \end{aligned}$$

Stayers are not involved with housing transactions. They keep their existing houses and consume the undepreciated housing service flow $(1 - \delta_h)h$, which is also the future housing

[11] Optimally, households never choose zero housing service flow because of standard properties of the utility function. Then $h_{rent} \geq 0$ implies that a household is always able to rent when she has positive wealth.

state.

The problem for renters is

$$V^r(m,h,a,y;r) = \max_{\{c,a'\}} U(c, \xi h_{rent}) + \beta \mathbb{E} V(0,0,a',y';r),$$

s.t.

$$c + a' + Rm + FC_h(p_h h) + r_h h_{rent} \leq y + Ra + p_h(1-\delta_h)h,$$

where $\xi \in (0,1)$ denotes the disutility of renting. A renter does not own any house, so their future housing and mortgage states are zeros by definition. Since the only uncertainty is the idiosyncratic shock on y, the random variable of the future value function is y', and the expectation is taken upon future income state y' conditional on current income state y.

3.4 Rental Companies

Overlapping-generation rental companies are risk-neutral. They buy houses and rent to renters in the current period, sell the undepreicated houses in the next period, and exit the economy. The discount factor for future resale value is R. Following Jorgenson (1963), the rental rate is determined by Jorgenson user-cost:

$$p_h = r_h + R^{-1}(1-\delta_h)p'_h. \tag{13}$$

The LHS refers to the cost of purchasing a house, and the RHS refers to the benefits, which include rental revenue r_h and the resale value $(1-\delta_h)p'_h$. The resale value is discounted by the interest rate. In a stationary equilibrium, housing prices are constant. We have

$$r_h = \frac{r+\delta_h}{1+r} p_h. \tag{14}$$

3.5 Equilibrium

In equilibrium, the housing price p_h clears the housing market. Note that F is the stationary distribution over states s. Housing price p_h depends on this distribution F. The distribution evolves as

$$F_{t+1}(s_{t+1}) = \Gamma(F_t(s_t)), \tag{15}$$

where Γ is the law of motion of state variables. Under a fixed housing supply economy with exogenous housing quantity $\bar{H}$, the market clearing condition is

$$\int (h'(s) + h_{rent}(s))dF(s) = \bar{H}. \tag{16}$$

In a economy with builders, the market clearing condition is

$$\delta_h \int (h'(s) + h_{rent}(s))dF(s) = h_s(w). \tag{17}$$

The housing demand contains owner-occupied and rental houses. In a fixed supply economy, the depreciation of houses is automatically rebuilt, while in an economy with builders, builders inject new housing flow to refill the depreciation in a stationary equilibrium.[12]

Definition 1 *A recursive competitive equilibrium of the economy with builders is a set of prices $\{p_h, r_h\}$, a set of value functions $\{V, V^m, V^{stay}, V^r, V_s\}$, a set of policy functions $\{c, a', m', h', h_{rent}, h_s, b, d, \ell, x\}$, a time-invariant distribution F, a distribution law of motion Γ, given the exogenous interest rate r, Markov process of the income, and initial net worth of builders w,*

1. *V,V^m, V^{stay}, V^r satisfy household's Bellman equations, and V_s satisfies builder's Bellman equation.*
2. *Functions $c(s), a'(s), m'(s), h'(s), h_{rent}(s)$ are optimal policy functions for households given p_h and r_h.*
3. *Functions $h_s(w), b(w), d(w), \ell(w), x(w)$ are optimal policy functions for builders given p_h.*
4. *p_h and r_h satisfy rental companies' zero-profit condition.*
5. *p_h clears the housing market-clearing condition.*
6. *The law of motion Γ defines the evolution of time-invariant households' state-variable distribution, which is $F = \Gamma(F)$, according to households' policy functions and the Markov transition process of the income.*

Solving this model is computationally challenging. The main challenge is the number of state-space dimensions and different terms between mortgages and liquid assets. In appendix

[12]The market clear condition for a economy with heterogeneous builders will be $\int h_s(w)dG(w)$ if builder's initial net worth is drawn from distribution $G(w)$.

D.1, I describe the process of the numerical solution and the methods to resolve challenges above.

I then characterize the properties of builder's problem in stationary equilibrium.

Proposition 1 *Characterization of builders' optimal strategy: Given a housing price,*

1. *there exists a net worth threshold $\bar{w}$ such that a builder is constrained if and only if $w < \bar{w}$, and a builder is unconstrained if and only if $w \geq \bar{w}$.*
2. *a higher interest rate qualitatively decrease the new construction level $h_s(w)$ for constrained and unconstrained builders.*
3. *given an interest rate, unconstrained builders build more than the construction level of constrained builders. Specifically, $h_s(w)$ is a non-decreasing function.*

Higher interest rates deter unconstrained builders' building unit throughout a smaller present value of discounted future revenue with concave $f(x)$. Constrained builders borrow to the limit to build. A positive λ' implies a positive liquidity premium of the financial constraint relaxation. A higher interest rate directly tightens constrained builders' borrowing constraint, hence a lower construction investment level from fewer construction loans.

In a stationary equilibrium, the rental rate endogenously determined by the Jorgenson user cost simultaneously with an exogenous interest rate and an endogenous housing price is higher under a higher housing price p_h, a higher depreciation rate δ_h, and a higher interest rate r. The required return r_h for rental companies is higher under a higher purchasing cost p_h, a higher lost value of houses from δ_h, and a higher alternative rate of return r. This user-cost formula (13) captures the fact that the rental rate comoves with the housing price. These properties match observations in Kiyotaki et al. (2024).

4 Calibration and Quantitative Analysis

This section describes the choice of parameter values and analysis of the stationary equilibrium. Some parameters are determined based on external evidence, while others are internally calibrated to fit with key cross-section moments of the U.S. economy in 2022. This is the year when the FED raised interest rates to fight inflation.[13] The datasets I use to generate moments are mainly from the Survey of Consumer Finances (SCF) and the American Community Survey (ACS).[14] After calibrating the baseline model, I provide a quantitative analysis of the stationary equilibrium under different interest-rate regimes.

[13]The Fed raised interest rates 11 times between March 2022 and July 2023.

[14]ACS data is from "2022: ACS 5-Year Estimates Data Profiles, DP04 Selected Housing Characteristics."

4.1 Calibration

All variables are normalized by the mean family income in SCF 2022, which is \$141.39 thousand. Table 1 reports parameter values of the model. Internal parameters are jointly calibrated to match targeted moments in the data. Targeted and non-targeted moments are shown in table 2. A period in this model represents one year, which coincides with the length of data used to generate moments.

Preferences. Household utility function is $U(c, h_f) = \frac{\left[c^{1-\alpha}h_f^{\alpha}\right]^{1-\gamma}-1}{1-\gamma}$. I set $\gamma = 2$, which implies that elasticity of intertemporal substitution is 0.5. I internally calibrate the discount factor $\beta = 0.936$, the share of housing service in total consumption $\alpha = 0.16$, and disutility of renting $\xi = 0.85$ to normalize aggregate housing stock to 1 and match the share of owner-occupied houses 64.8% and the share of homeowners with mortgages 61.5%.

Income. The idiosyncratic income shock follows an AR(1) process in logs. I set the persistence parameter $\rho_y = 0.97$ and the standard deviation $\sigma_y = 0.2$ following Kaplan et al. (2020). In the quantitative analysis, I discretize it to a two-state Markov chain and normalized the mean of income to 1.

Interest rate. The real interest rate data is sourced from FRED and is set at 0.618%, which is calculated as the average quarterly 10-year real interest rate over the period from 2013 to 2019. This time frame spans the years between the aftermath of the Great Recession and the onset of the COVID-19 pandemic, during which the interest rate remained relatively stable.

Housing and Mortgage. The housing depreciation $\delta_h = 0.0364$ is motivated by Internal Revenue Service (IRS) Publication 946 (2023)[15], which illustrates the property depreciation method. It suggests a depreciation rate 0.0364 for a residential rental property in table A6. The variable adjustment cost of selling houses is $FC_h(p_h h) = \kappa_h(1-\delta_h)p_h h$. Following Boar et al. (2022), I set the housing adjustment cost $\kappa_h = 0.06$, which is a common estimate of the housing transaction cost.

Based on Fonseca et al. (2024), the 95th percentiles of the mortgage loan-to-value in Home Mortgage Disclosure Act is 0.9, and the spread between 30-year mortgage rate and the treasury yield is 2.5%. Hence, I set the loan-to-value ratio of the mortgage borrowing constraint at $\theta_h = 0.9$ and mortgage maturity at $D = 20$. This implies that the periodic payment for a 20-year mortgage with zero mortgage spread is equivalent to the periodic payment for a 30-year mortgage with 2.5% mortgage spread when the interest rate is 0.618%.

Builder. The production factor x is assumed to be labor, so the cost of labor is set at the mean income, which is normalized to $p_x = 1$. Sourced from updated land value dataset from

[15]Source: `https://www.irs.gov/publications/p946#en_US_2023_publink1000270861`

Davis et al. (2021), standardized $\frac{1}{4}$ acre land value is $215,700$.[16] The land price is normalized to $p_\ell = 1.5256$. Following Kaplan et al. (2020), I set the return to scale of the construction labor at $\alpha_h = 0.6$. The TFP of builders $A_h = 0.2563$ is calibrated to match the housing price. The equity-issuance cost and the builder's loan-to-value ratio θ_b are not reported here. I focus on the unconstrained builder for the baseline analysis, so the equity-issuance cost and builders' loan-to-value ratio do not provide any information on matching moments.[17] The effect of the financial constraint is discussed in section 5.4.

Parameter	Description	Value	Target/Source
	External		
γ	Risk aversion	2	Kaplan et al. (2020)
δ_h	Depreciation rate of house	0.036	IRS
κ_h	Housing variable adjustment cost	0.06	Boar et al. (2022)
θ_h	Mortgage loan-to-value ratio	0.9	HMDA (Fonseca et al., 2024)
D	Mortgage maturity	20	30-y 2.5% mortgage spread
ρ_y	Autocorrelation of endowment	0.97	Kaplan et al. (2020)
σ_y	Standard deviation of endowment shock	0.2	Kaplan et al. (2020)
r	Real interest rate	0.618%	Avg 10-year real rate
α_h	RTS of construction labor	0.6	Kaplan et al. (2020)
p_ℓ	Land price	1.526	FHFA
p_x	Cost of labor	1	Normalized
	Internal		
β	Discount factor	0.936	
α	Share of housing service in total consumption	0.164	
ξ	Disutility of renting	0.85	
A_h	TFP of builders	0.256	

Note: The table reports the externally and internally calibrated parameter values used in the quantitative analysis.

Table 1: Baseline Parameter Values

In table 2, the model matches the targeted moments well. The model-implied and data-generated new construction sales share are not consistent. This discrepancy can be addressed by introducing moving shocks to create existing home sales (Fonseca and Liu, 2024). Since the transactions of existing homes are not the primary drivers of housing price dynamics, I focus on the effects of interest-rate changes and abstract from the moving shock.

4.2 Long-run Stationary Equilibrium Analysis

This subsection elaborates the effects of interest rate on the housing demand and supply in a stationary equilibrium and shows the numerical results given the calibration in the previous section. In literature, such as Kiyotaki et al. (2011), Sommer et al. (2013), andGeng

[16] Source of the dataset: `https://www.fhfa.gov/research/papers/wp1901`.

[17] This can be achieved by assuming an extremely large initial net worth, such as $w = 10^{100}$.

Targeted Moment	Data	Model
Avg house price/Avg income (SCF)	3.332	3.332
Share of owner-occupied houses (ACS)	64.8%	64.8%
Share of owners with mortgages (ACS)	61.5%	61.5%
Avg residential housing stock (Normalized)	1	1.01
Non-targeted Moment		
Avg wealth for homeowners to renters (SCF)	9.94	10.997
Avg housing debt for homeowners (SCF)	3.57	3.81
Avg income for homeowners to renters (SCF)	2.47	3.43
Avg wealth (SCF)	7.49	4.64
New construction sales share (AEI-Zillow)	12.9%	31.4%

Note: The table reports the targeted moments used in calibration and non-targeted moments for model validation.

Table 2: Targeted and Non-targeted Moment

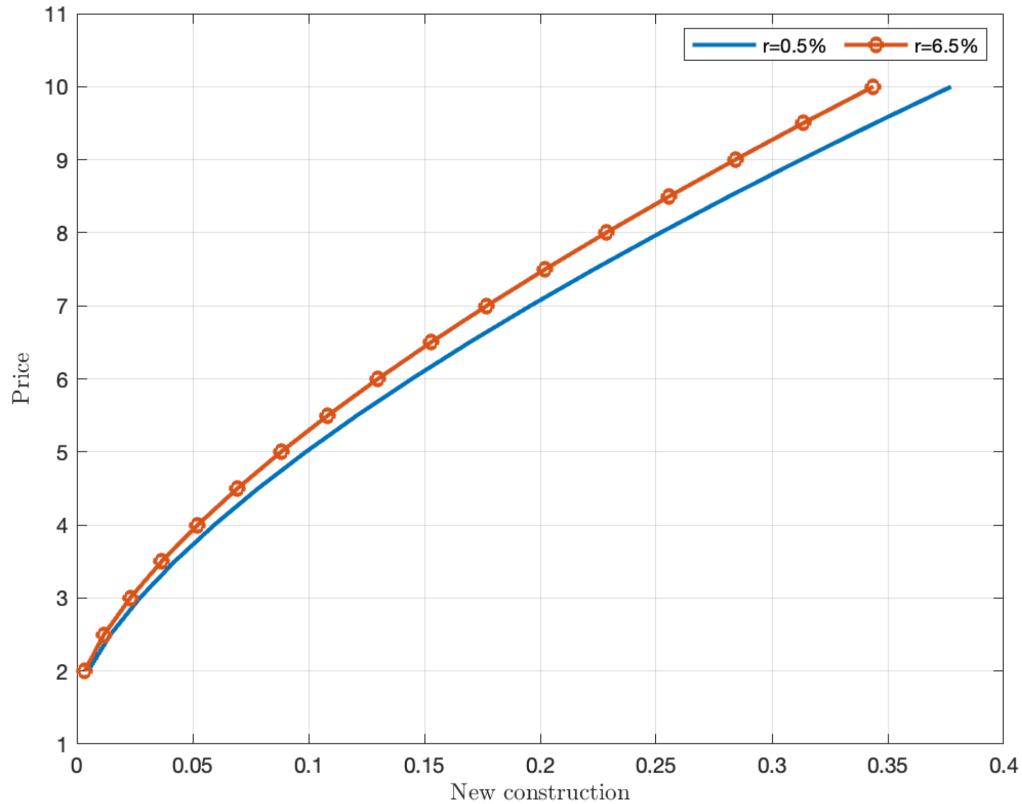
(2018), declining interest rates fuel the housing demand and housing prices via a looser mortgage constraint. The mortgage effect governs how households respond to the interest-rate change. With respect to the housing supply, interest rates do not affect construction strategies since builders are solving a static problem (Kaplan et al., 2020). Different from literature, interest rates have richer effects on the housing demand side and affect builder's construction investment because of time to build in this model. All these effects jointly pin down how interest rates affect the stationary equilibrium.[18]

Housing Supply. Figure 3 shows the new construction level for unconstrained builders. Since builders are unconstrained, the effect of interest rate results from the time-to-build property. It implies that builders inject more new housing stocks to the economy under a lower interest rate. Without time to build, an unconstrained builder's optimal construction investment is a constant across different interest rates. In addition, with time to build, it is the future housing price determining the current construction investment strategy. Without time to build, current housing price affects builder's strategy. With or without time to build will imply a different transitional housing price path although it does not matter in a stationary equilibrium since housing prices are constant.

The magnitude of the new construction seems to be small. However, focusing on the amount of housing transactions and canceling out sales and purchases from existing homeowners, the effect of new construction level is more significant. Furthermore, new construction will be accumulated as future housing stocks and not just affect the current period. Since builders respond to interest rates immediately, in the short run, the new construction

[18]Appendix B shows that homogeneous households cannot obtain rich housing demand properties described above. This is a reason for modeling household heterogeneity.

matters for housing dynamics when interest rates change.



Note: This figure displays builder's new construction investment (new housing supply curve). Specifically, the blue solid line depicts builder's construction level under different housing prices given $r = 0.5\%$. The orange line with circle depicts builder's construction level under different housing prices given $r = 6.5\%$.

Figure 3: New Housing Supply Curve

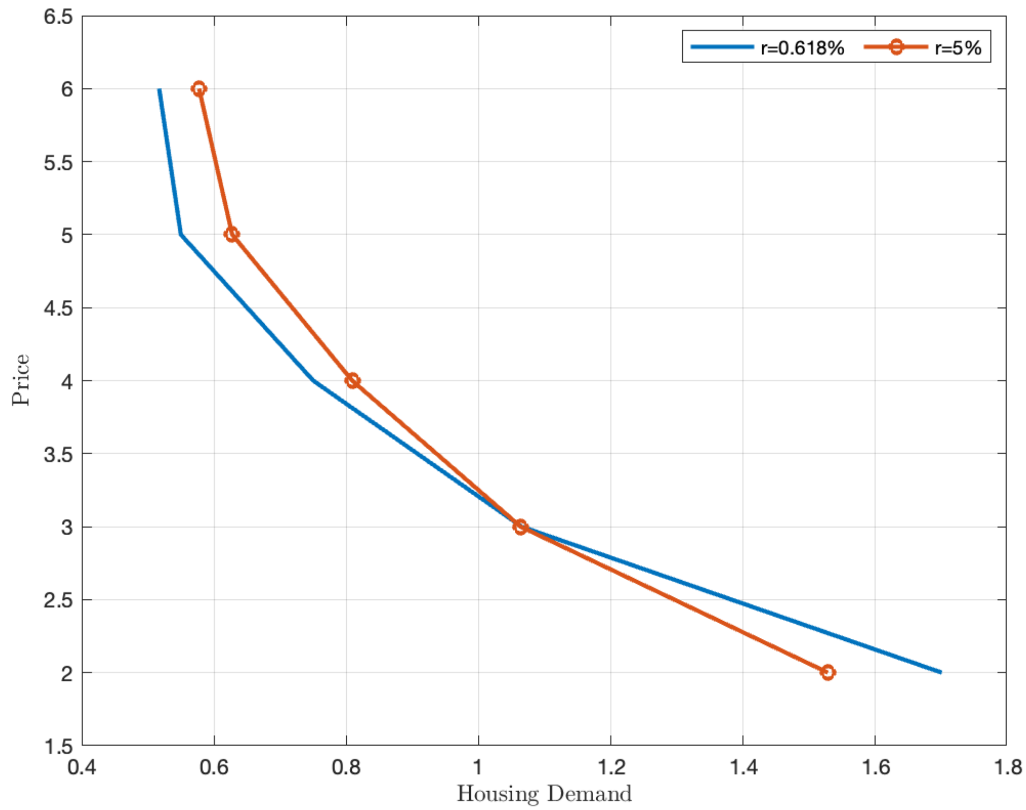
Housing Demand. Figure 4 shows a numerical result of the aggregate housing demand given different prices and interest rates. It shows that a higher interest rate does not always decrease the housing demand, which contradicts with the result in literature. There are two main forces governing the effects of interest rates on the housing demand: heterogeneous housing response and the distribution effect. Heterogeneous housing response refers to different interest-rate-induced wealth effects on households with different mortgage-asset portfolio. High-saving households increase housing demand since they enjoy a positive wealth effect under higher interest rates. Households who rely on mortgages suffer from higher mortgage costs and decrease housing demand. Therefore, heterogeneous housing response includes not only the mortgage effect in literature. It also considers the positive wealth effect for high-saving households. Additionally, the distributional effect illustrates the allocation of heterogeneous households across varying interest-rate regimes, highlighting the significance of heterogeneity in household housing policy functions. That is, there are more high-saving households in a high-rate regime.

In figure 4, we observe a more significant distribution effect at a higher housing price. Specifically, when the housing price is higher, it is more beneficial to save in liquid assets to accumulate wealth under a higher interest rate. Eventually, households on average are wealthier, hence a higher housing demand when the interest rate increases. On the contrary, a lower housing price incentivizes households to purchase house with mortgages. Therefore, a lower interest rate fuels the housing demand, which implies that the mortgage effect dominates.

Suppose we fix the housing price at $p_h = 3$. The equilibrium net saving in low-rate (0.6%) and high-rate (5%) regimes are -0.135 and 8.282. This implies that the stationary distributions are very different between two regimes. The implied non-housing consumption are different–0.8464 in the low-rate economy and 1.2921 in the high-rate economy. Households in the low-rate economy rely on mortgages to purchase houses and consume less, while they save and accumulate wealth to purchase houses and consumption. Although the housing stocks in two economies are similar, household behaviors and the asset portfolio are very different.

The total housing demand contains owner-occupied houses and rental units. I decompose them in figure E2 and E3. From these two figures, the impact of interest rates on aggregate housing demand is mainly driven by the owner-occupied house. Given a housing price, a higher interest rate decreases renters' rental housing demand for a higher rental rate implied in (13). However, a higher interest rate affects the extensive margin between renters and homeowners through the distribution effect. Therefore, the effect of interest rates on total rental houses is ambiguous.

Figure 5 shows the simulation of a household for 1000 periods given housing price $p_h = 3$ in the low-rate ($r = 0.618\%$) regime. The five panels of the figures are Markov chain simulation of idiosyncratic income shocks, owner-occupied housing choice, rental housing choice, liquid asset choice, and non-housing consumption. We observe that households will buy houses when they are in a high-income state, and start to downsize housing size when a low-income state hits. They will become renters when they are stuck in the low-income state.



Note: This figure displays household aggregate housing demand curve. Specifically, the blue solid line depicts housing demand under different housing prices given $r = 0.618\%$. The orange line with circle depicts housing demand under different housing prices given $r = 5\%$.

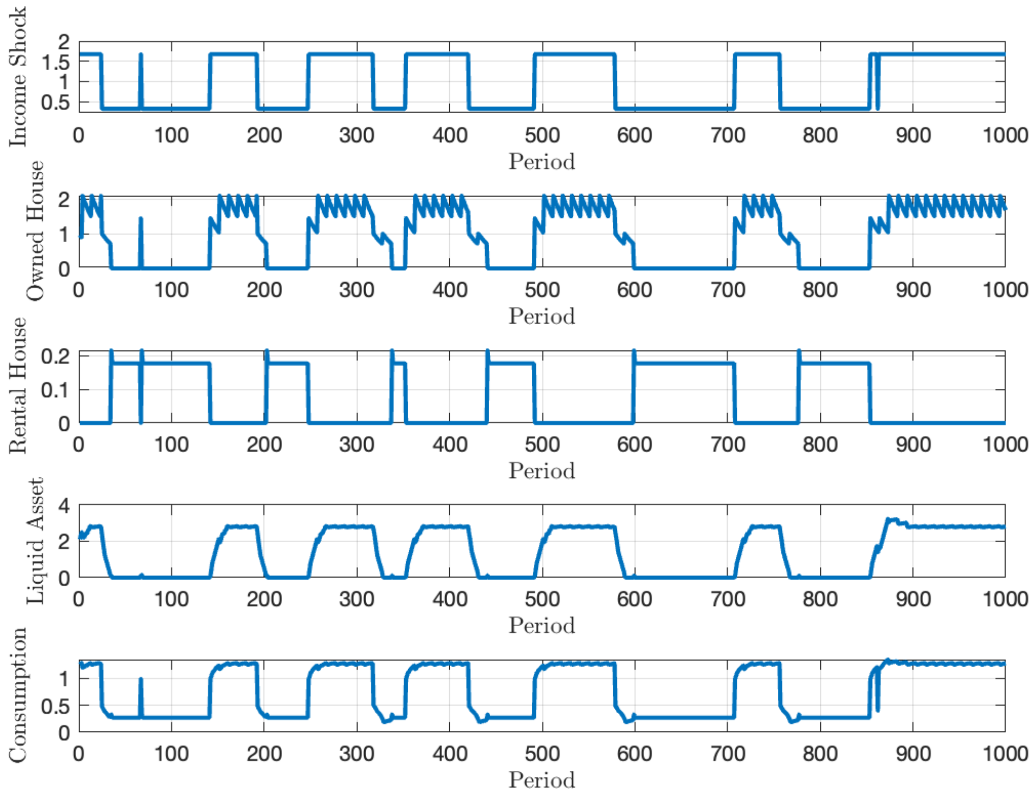
Figure 4: Aggregate Housing Demand Curve

5 Transitional Dynamics–the Effects of Interest Rate Shocks

This section provides the analysis of housing price dynamics of temporary increase in interest rates. At $t = 1$, the economy stays at the stationary equilibrium. The interest rate is assumed to temporarily increase to 6% for 4 periods starting from $t = 2$ and drop back to the original level 0.618%. That is, the interest rate path after $t = 2$ is

$$r_t = \begin{cases} 6\%, & \text{if} \quad 2 \leq t \leq 5 \\ 0.618\%, & \text{if} \quad t \geq 6 \end{cases}.$$

This change is an MIT shock, which means that the change is not realized until $t = 2$. After the realization, the new interest rate path is full information for all agents and sectors in



Note: This figure displays simulation of an individual household for 1000 periods given housing price $p_h = 3$ and interest rate $r = 0.618\%$. The first panel plots a simulation of the idiosyncratic income shock. The second panel plots the owner-occupied housing choice h'_o. The third panel plots the rental housing choice h_{rent}. The fourth panel plots the liquid asset choice a'. The fifth panel plots the non-housing consumption choice.

Figure 5: Individual Household Simulation under $p_h = 3$ and $r = 0.618\%$

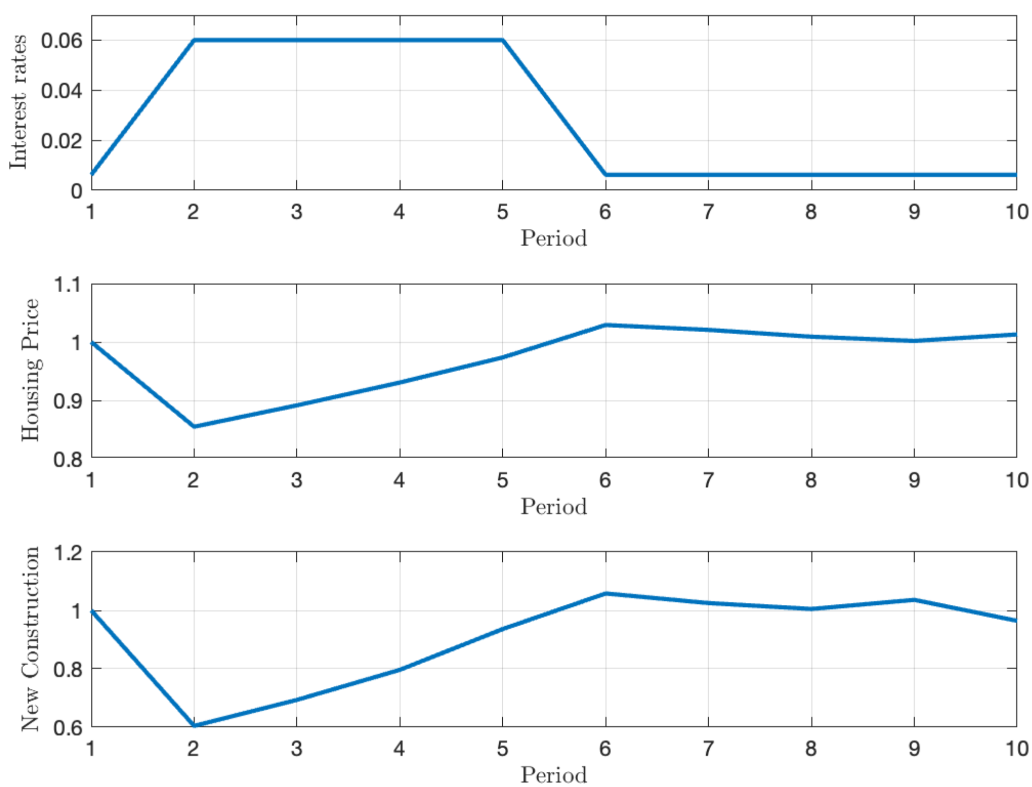
the economy.[19] To be clear, the interest rate r_t at time t is the rate of return of the saving at t. The saver will receive $1 + r_t$ at $t + 1$. I will first discuss the baseline environment, the FRM economy with builders. Then I will compare the result in FRM economy without builders, ARM economy with builders, and FRM economy with constrained builders. This will highlight the effect from builders, mortgage structures, and financial constraints respectively. The steps of transitional dynamics computation is specified in appendix D.2.

5.1 Interest Rate Shocks in Baseline: FRM with Builders

Figure 6 shows the transitional housing price path of the temporary interest-rate increase in an economy with FRM and builders. Housing prices are normalized by the stationary

[19] We can also interpret the "realization" as an expectation. Then at least the solution at the date of the realization is correct. That is, this model can replicate solution for arbitrary combination of interest-rate expectations and realizations.

price, so the price path starts from and ends at 1. The housing price significantly drops by 14.52% at $t = 2$. The new construction investment is determined at $t = 1$ when builders make decisions based on the originally low interest rate level, so builders overbuild with the benefit of hindsight. In addition, the distribution effect is almost impotent since households cannot immediately utilize the high interest rate to adjust portfolio and become extremely wealthy. The distribution at the beginning of the transition stays at a low-saving or high-leverage state since the original rate is low. Hence, the heterogeneous housing response for households dominates and decreases the housing demand. Combination of responses from builders and households at $t = 2$ implies excess supply at the stationary price, which leads to a housing price slump.



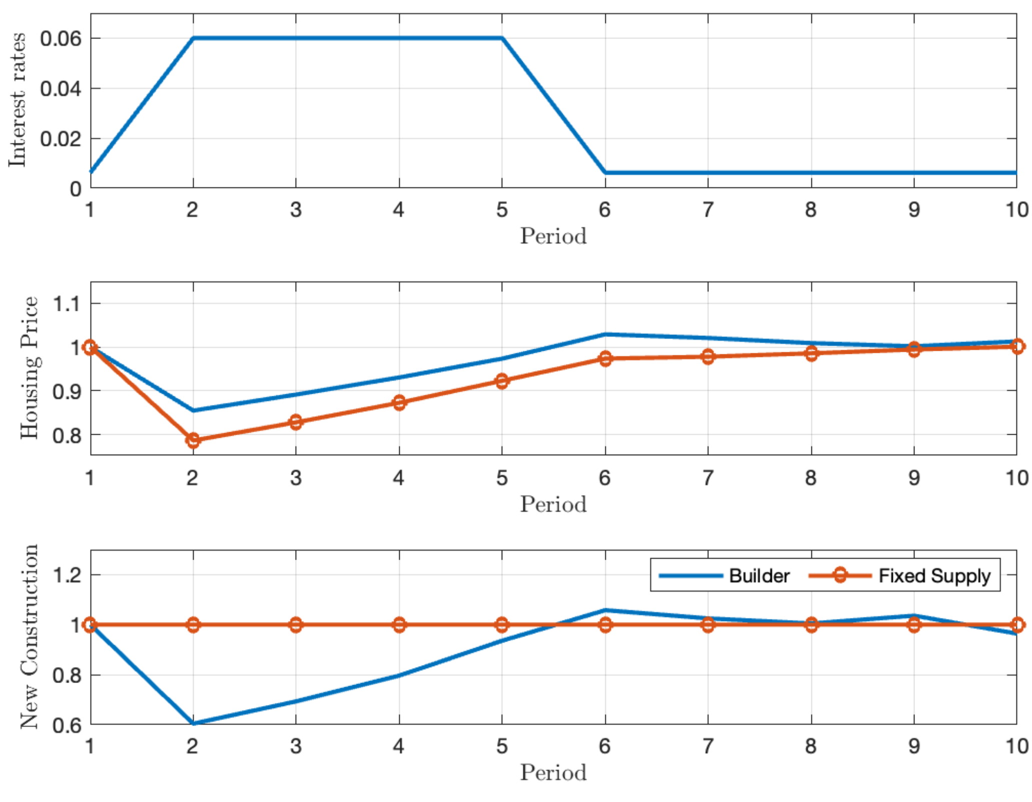
Note: This figure illustrates the aggregate response of the economy with FRM and builders to a temporary increase in interest rates. The top panel plots the exogenous change in the interest rate. The middle panel plots the transition of housing prices normalized by the stationary price. The bottom panel plots the transition of the new construction normalized by the stationary new construction level from builders. All sectors and agents have perfect foresight of dynamic path of all variables after the unexpected interest shock is realized.

Figure 6: Transitional Path to Interest Rate Shock–Baseline with FRM and Builders

The housing price is increasing during the high-rate periods and decreasing after the interest rate return to the original level. The direction coincides with the builder response, which is characterized in proposition 1.[20] Figure 6 also depicts dynamics of the new construction and shows that patterns of housing prices and new construction are similar. Therefore, the effect of new construction dominates in the early stage of the housing price path.

5.2 Counterfactual with Fixed Supply: the Role of Builders

This subsection shows the housing price path of an economy without builders and compare with the result with the baseline result. Comparing to literature without focus on the supply side, the housing price falls by less magnitude or even increases when the builder's response to interest rates is considered.



Note: This figure illustrates the aggregate response of the economy with builders and with fixed housing supply respectively under FRM to a temporary increase in interest rates. The top panel plots the exogenous change in the interest rate. The middle panel plots the transition of housing prices normalized by the stationary price in an economy with builders (blue solid line) and with fixed supply (orange dashed line). The bottom panel plots the transition of the new construction normalized by the stationary new construction level in an economy with builders (blue solid line) and with fixed supply (orange dashed line). All sectors and agents have perfect foresight of dynamic path of all variables after the unexpected interest shock is realized.

Figure 7: Transitional Path to Interest Rate Shock–Builders and Fixed Supply

[20]Note that the new construction at $t = 6$ depends on r_5, which is still at the temporary-increase level.

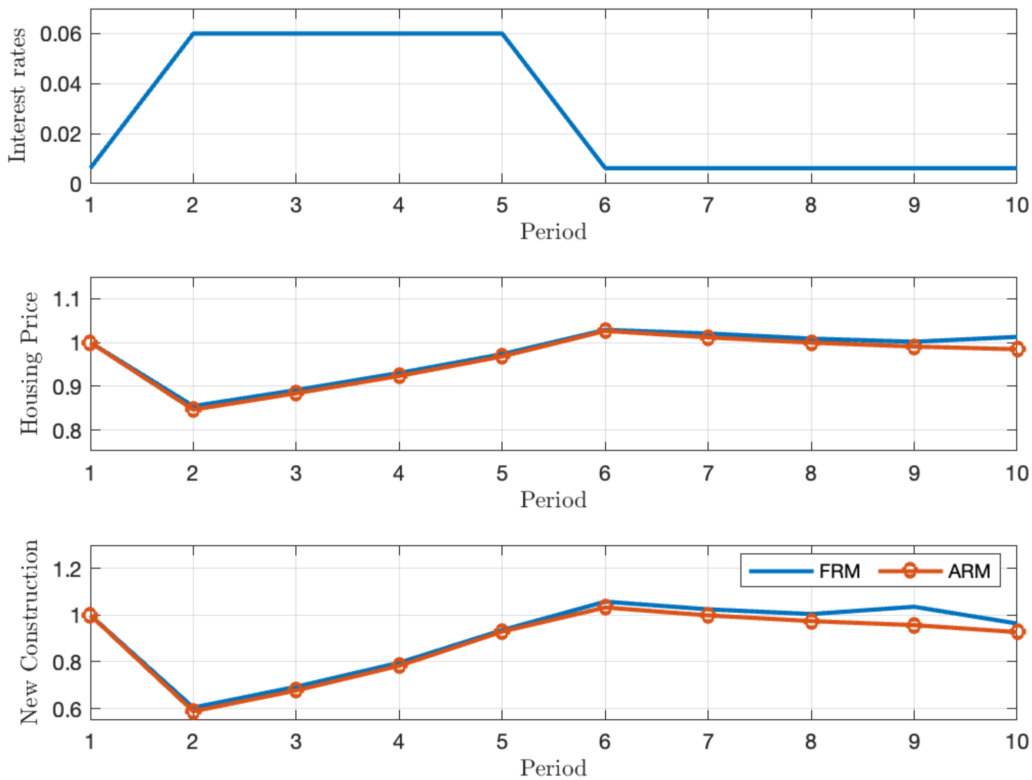
Figure 7 shows the housing price and the new construction paths in economies with and without builders respectively. The housing price falls by a larger magnitude in the economy without builders in the short run. This difference is mainly driven by new construction response from builders. That is, the new construction level cannot refill the depreciation. It is equivalent to treat a constant new construction investment in a fixed supply economy. Builders respond to the interest-rate change immediately. Therefore, less new construction at the beginning makes the price fall less and exceed by 2.9% of the stationary housing price at $t = 6$. Moreover, the housing price starts to fall right after the interest rate returns to the initial level. In a fixed supply economy, instead, housing price dynamics is completely driven by the housing demand. The housing price never exceeds the stationary housing price during the high-rate period and keeps increasing after the interest rate falls because the housing demand is fueled by the interest-rate drop.

Table 3 presents the decomposition of the contribution from households and builders to the housing price dynamics. I normalize all numbers by the stationary housing price. "Total" denotes total effect, which is the gap between the stationary price and the price in the economy with builders. "Demand" is the contribution from the household, which is the gap between the stationary price and the price in the fixed supply economy. "Builders" is the additional contribution from the builder, which is the price gap between economies with and without builders. Builders' responses during high-rate periods mitigate the decline in housing prices: prices fall by $5 - 7$ percentage points less relative to the initial price level compared to a counterfactual scenario with fixed housing supply in the short run. Even after the interest rate drops, builders are still propellers of housing price since the accumulated new construction has not overtaken the level in the fixed supply economy. Builders, in the short run, make the housing price fall less or increase because they negatively respond to interest rates and serve as the only providers of new housing stock.

Period	2	3	4	5	6	7	8	9	10
Total	-0.1452	-0.1085	-0.0695	-0.0265	0.0290	0.0207	0.0090	0.0018	0.0129
Demand	-0.2135	-0.1719	-0.1273	-0.0770	-0.0264	-0.0221	-0.0143	-0.0057	0.0008
Builders	0.0684	0.0634	0.0579	0.0506	0.0554	0.0427	0.0233	0.0074	0.0121

Note: The table presents the effects of interest rate shocks on housing prices and decomposes these effects into demand-side and builder-side responses.

Table 3: Housing Price Dynamics Decomposition



Note: This figure illustrates the aggregate response of the economy with builders under FRM and ARM respectively to a temporary increase in interest rates. The top panel plots the exogenous change in the interest rate. The middle panel plots the transition of housing prices normalized by the stationary price in an economy with FRM (blue solid line) and with ARM (orange dashed line). The bottom panel plots the transition of the new construction normalized by the stationary new construction level in an economy with FRM (blue solid line) and with ARM (orange dashed line). All sectors and agents have perfect foresight of dynamic path of all variables after the unexpected interest shock is realized.

Figure 8: Transitional Path to Interest Rate Shock–FRM and ARM

5.3 Counterfactual with ARM: the Role of Mortgage Structure

Figure 8 displays the housing price paths in economies adopting FRM and ARM with builders. The housing price paths are similar in the two economies since builders are discouraged by the higher interest rates. The new construction paths of the two economies are also similar, which is shown in figure 8. The ARM structure decreases housing prices under a temporary increase in interest rates in the short run by around 1-percentage of the stationary price compared to a counterfactual with FRM.

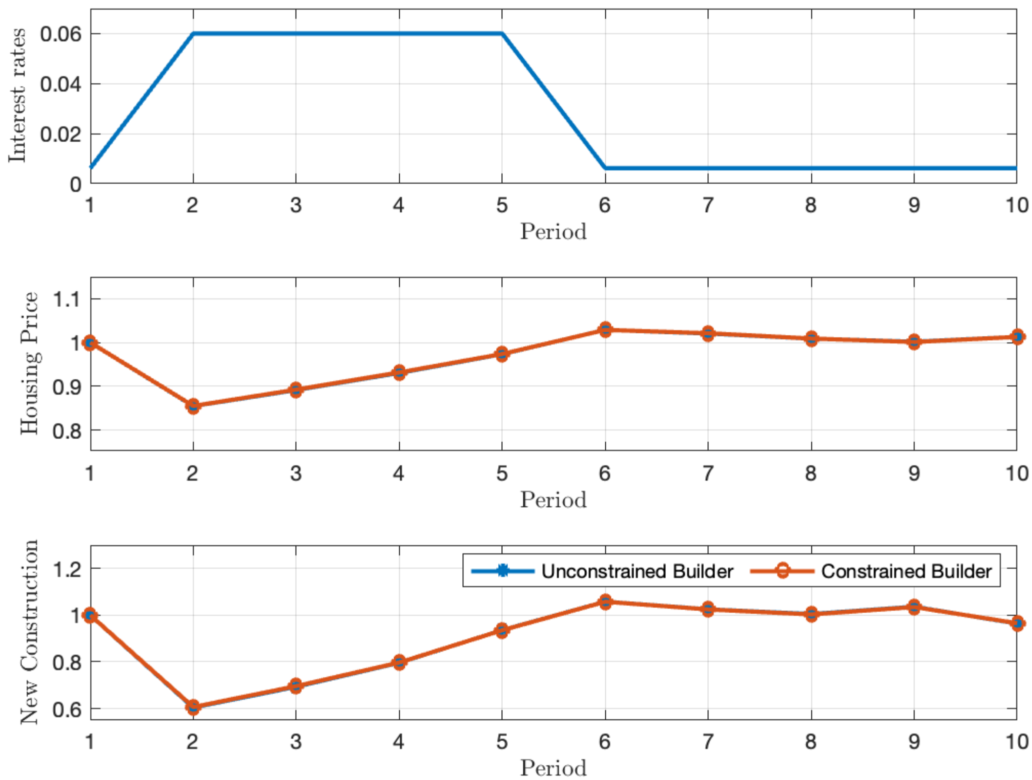
The main difference between FRM and ARM economies is the housing status. FRM serves as a role of insurance when the interest rate increases. Homeowners can stay at their existing houses without suffering from higher mortgage costs. The lock-in behavior mentioned in literature happens here as well and is shown in figure E4. The share of stayers increases at the beginning of the interest-rate change and is generally higher in the economy adopting ARM in the short run. Under an ARM structure, homeowners with mortgages directly face a raise in periodic mortgage payments. Then there are homeowners who cannot or unwilling to pay a higher mortgage cost deciding to swich their housing status to renters. Figure E4 shows that the homeownership rate drops in both economies at the beginning of the transition and becomes lower in the short run in an economy with ARM structure. Because of different housing status response between FRM and ARM, comparing two housing paths more carefully, the prices in the economy adopting ARM is smaller by 1 percentage of the stationary price than the prices in the economy with FRM in the short run. This gap results from the insurance provided by FRM, which lead to a slightly larger housing demand from owner-occupied houses having bigger size than rental houses. This implies that the mortgage structure mainly affects the housing status of the economy but has little difference in housing price dynamics.

5.4 Counterfactual with Builder's Financial Constraint: the Role of Financial Friction

This subsection shows that builder's financial constraint, surprisingly, does not affect housing price dynamics under a temporary interest rate increase. A higher interest rate implies a higher construction loan rate, hence a tighter financial constraint (4) given the price and the amount of new construction. To implement the quantitative analysis, the equity-issuance cost and the builder's loan-to-value ratio need to be defined and parameterized. Following Lanteri and Rampini (2023b), the equity-issuance cost function is assumed to be $\phi(-d) = \phi_0(-d)^{\phi_1}$ for $d < 0$ with parameter $\phi_0 = 0.3$ and $\phi_1 = 2$. The builder's loan-to-value ratio is set at $\theta_b = 0.5$. From proposition 1, there exists a net worth threshold $\bar{w}$ between constrained and unconstrained builders. Given the same set of parameters in table 1, I assume the net worth of constrained builders is $w = \bar{w} = 0.0347$, which is the net worth threshold given the calibrated parameters and the stationary equilibrium price. Other things being equal, the unconstrained builder becomes a constrained builder under an increase in the interest rate.

Figure 9 depicts the housing price path of economies with and without financial constraint respectively. The two paths almost overlap with each other, meaning that the financial constraint almost has no impact on the housing price. Further checking the tightness of the financial constraint, which is the marginal cost of equity issuance ϕ_d in figure E5, it shows that builders are unconstrained in the short run ($t \leq 5$). Specifically, along the transitional path, the marginal value of net worth is never larger than 0.15% in the short run.

The key factor is the effect of interest rates on the optimal new construction level $h_{s,unc}$.



Note: This figure illustrates the aggregate response of the economy under FRM and builders with and without builder's financial constraint respectively to a temporary increase in interest rates. The top panel plots the exogenous change in the interest rate. The middle panel plots the transition of housing prices normalized by the stationary price in an economy without builder's financial constraint (blue solid line) and with builder's financial constraint (orange dashed line). The bottom panel plots the transition of the new construction normalized by the stationary new construction level in an economy without builder's financial constraint (blue solid line) and with builder's financial constraint (orange dashed line). All sectors and agents have perfect foresight of dynamic path of all variables after the unexpected interest shock is realized.

Figure 9: Transitional Path to Interest Rate Shock–with and without Builder's Financial Constraint

In appendix A, equation (23) shows that the optimal new construction level is decreasing in the interest rate R. Given the stationary housing price and new construction, an increase in the interest rate directly forces the builder with $\bar{w}$ constrained. However, the new optimal new construction level is smaller than the originally stationary new construction, so the financial constraint is not necessarily binding. Specifically, a higher interest rate does not necessarily make the builder more constrained. On the contrary, the constraint might be slacker since builders can build to the new and smaller optimal level. Figure 9 displays that the optimal new construction level in each period are similar in the two economies. That is, a temporary increase in interest rate mainly affects the optimal construction level and loosens the financial constraint.[21]

6 Conclusion

This paper provides a more general framework to evaluate the effect of interest rates on the housing price by considering the builder side. I develop a model of builder's new construction investment subject to time to build while keeping rich properties of the demand side. In the model, the builder responds negatively to a higher interest rate. When interest rates temporarily increase, the decrease in new construction makes the housing price fall by less magnitude or even increase in the short run.

I further numerically decompose the effect from the household and the builder side. By comparing the housing price bath between economies with and without builders respectively, I show that builders' responses during high-rate periods mitigate the decline in housing prices by 5-7 percentage points less relative to the initial price level compared to a counterfactual scenario with fixed housing supply in the short run. Thus, we should consider the response from builders when we discuss the effects of interest rates on the housing market.

In addition to the role of builders, I show how a temporary increase in interest rates affect housing market under different mortgage structure. Housing price paths are not significantly different between ARM and FRM. The difference lies in the household's housing choice and the housing status. Under a FRM structure, homeowners tend to lock-in their original houses, while under an ARM structure, homeowners cannot keep their cheaper mortgage rates leading to a decrease in the homeownership rate.

Furthermore, the financial constraint on builders is not intuitively effective in housing price dynamics when interest rates temporarily increase. A lower optimal construction level under a higher interest rate loosens the financial constraint and can further surpass the tightness interest rates.

My theoretical and quantitative work suggests that builders' response to interest rates has significant effect on housing prices. The builder is the sole provider of the new housing stock. Therefore, it is important to consider the effect from builders in housing policy-related evaluations. Literature normally focuses on the housing demand, which is the household side. In the future, we should notice that builders might have significant impact, and this paper provides a general framework for the housing market analysis.

[21] The financial constraint might have a larger effect when the interest rate decreases since the optimal construction level increases.

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Appendix

A Builder's Problem

The multipliers of current budget constraint, the net worth evolution and the financial constraint are μ, $R^{-1}\mu'$ and $R^{-1}\lambda'$ respectively. The first-order conditions are:

$$\begin{aligned}
d: &\quad 1+\phi_d=\mu, && (18)\\
w': &\quad \mu'=1, && (19)\\
b: &\quad \mu=1+\lambda', && (20)\\
x: &\quad p_h-R\left(p_\ell+\frac{p_x}{f'(x)}\right)=\left\{R\left(p_\ell+\frac{p_x}{f'(x)}\right)-\theta_b p_h\right\}\lambda'. && (21)
\end{aligned}$$

With a functional form $\phi(-d)=\phi_0(-d)^{\phi_1}$ if $d<0$ and $f(x)=A_h x^{\alpha_h}$, given p_h and R, the equilibrium building strategy for unconstrained builders is:

$$\begin{aligned}
&p_h=R\left(p_\ell+\frac{p_x}{f'(x)}\right)\\
\Rightarrow &x_{unc}=\left(A_h\alpha_h*\frac{p_h-Rp_\ell}{Rp_x}\right)^{\frac{1}{1-\alpha_h}} && (22)\\
&h_{s,unc}=\ell_{unc}=f(x_{unc})=A_h^{\frac{1}{1-\alpha_h}}\left(\alpha_h*\frac{p_h-Rp_\ell}{Rp_x}\right)^{\frac{\alpha_h}{1-\alpha_h}}. && (23)
\end{aligned}$$

We first observe $\lambda'=\phi_d$; i.e., a constrained builder always issues equity, and vice versa. Let $x=x_{unc}$, $d=0$, and $b=R^{-1}\theta_h p_h h_s$ in (2), we get a threshold $\bar{w}$ of constrained and unconstrained builders:

$$\begin{aligned}
\bar{w}&=(p_\ell-R^{-1}\theta_b p_h)A_h^{\frac{1}{1-\alpha_h}}\left(\alpha_h*\frac{p_h-Rp_\ell}{Rp_x}\right)^{\frac{\alpha_h}{1-\alpha_h}}+p_x^{\frac{-\alpha_h}{1-\alpha_h}}\left(A_h\alpha_h*\frac{p_h-Rp_\ell}{R}\right)^{\frac{1}{1-\alpha_h}}\\
&=\left[p_\ell(1-\alpha_h)+R^{-1}p_h(\alpha_h-\theta_b)\right]A_h^{\frac{1}{1-\alpha_h}}\left(\alpha_h*\frac{p_h-Rp_\ell}{Rp_x}\right)^{\frac{\alpha_h}{1-\alpha_h}}
\end{aligned}$$

From (21), a constrained builder with initial net worth $w<\bar{w}$ solve $x(w)$ and $h_s(w)$ satisfying

$$p_h=R\left[p_\ell+\frac{p_x x^{1-\alpha_h}}{\alpha_h A_h}\right]\frac{1+\phi_0\phi_1[(p_\ell-R^{-1}\theta_b p_h)A_h x^{\alpha_h}+p_x x-w]}{1+\theta_b\phi_0\phi_1[(p_\ell-R^{-1}\theta_b p_h)A_h x^{\alpha_h}+p_x x-w]}.$$

It is worth mentioning that a builder builds new construction only if $p_h>Rp_\ell$; i.e., the revenue should at least cover the future value of the land cost.

B Representative Household and Exogenous Housing Supply

In this appendix, I show that representative households cannot provide a rich analysis as a heterogeneous household setting. I assume a constant income, a short-term mortgage, and housing adjustment with adjustment costs. I also assume that the initial condition is $m_{-1} = 0$.

$$V(h, m; r) = \max_{\{c, h', a', m'\}} \frac{[c^{1-\alpha} h'^{\alpha}]^{1-\gamma} - 1}{1-\gamma} + \beta V(h', m'; r)$$

s.t.

$$\begin{aligned} & c + p_h[h' - (1-\delta_h)h + \kappa_h(1-\delta_h)h] + (1+r)m \leq y + m', \\ & (1+r)m' \leq \theta_h(1-\delta_h)p_h h'. \end{aligned}$$

Let μ and λ be the multiplier of the budget constraint and the collateral constraint respectively. The FOCs are

$$\begin{aligned} c: \quad & U_c = \mu, \\ h': \quad & U_h + \theta_h(1-\delta_h)p_h\lambda + \beta V_{h'} = p_h\mu, \\ m': \quad & \mu + \beta V_{m'} = (1+r)\lambda \end{aligned}$$

Envelope Conditions are:

$$\begin{aligned} h: \quad & V_h = -p_h(1-\kappa_h)(1-\delta_h)\mu, \\ m: \quad & V_m = -(1+r)\mu. \end{aligned}$$

The market clearing condition is:

$$h' = \bar{H},$$

where $\bar{H}$ is the exogenous housing supply.

We consider the steady-state equilibrium. After rearranging equations, the equilibrium conditions are:

$$\begin{aligned} \text{MCC:} \quad & h = \bar{H}, \\ \text{FOC of c/h:} \quad & \frac{\alpha}{1-\alpha}\left(\frac{c}{\bar{H}}\right)^{\alpha} = p_h\left[1 + \beta(1-\kappa_h)(1-\delta_h) - \theta_h(1-\delta_h)\left(\frac{1}{1+r} - \beta\right)\right], \\ \text{BC:} \quad & c + p_h[\delta_h + \kappa_h(1-\delta_h)]\bar{H} = y - rm, \\ \text{Borrowing Constraint:} \quad & (1+r)m \leq \theta_h(1-\delta_h)p_h\bar{H}. \end{aligned}$$

Note that for the existence of the equilibrium, $\beta(1+r) \leq 1$.

Case 1: $\beta(1+r)=1$

This implies that the household is unconstrained in the steady state. Since the household is endowed with a constant amount of goods, y, the steady state $m=0$. (This argument needs to be proved) That is, the household does not have to smooth consumption throughout the mortgage/saving. The equilibrium becomes:

$$\begin{cases} h' = \bar{H}, \\ m' = 0, \\ c = \left\{p_h \frac{1-\alpha}{\alpha}\left[1+\beta(1-\kappa_h)(1-\delta_h)\right]\right\}^{\frac{1}{\sigma}} \bar{H}, \\ \left\{\left\{p_h \frac{1-\alpha}{\alpha}\left[1+\beta(1-\kappa_h)(1-\delta_h)\right]\right\}^{\frac{1}{\sigma}} + p_h[1-(1-\kappa_h)(1-\delta_h)]\right\} \bar{H} = y. \end{cases}$$

The last equation solves p_h. Since the left-hand side is increasing from 0, there exists a unique p_h.

Case 2: $\beta(1+r)<1$

This implies $\lambda>0$ and the collateral constraint is always binding. It seems that the household borrows to the limit when the economy starts, and she always wants to borrow more. However, she is capped by the borrowing limit. She will repay only the interest expense and keep the debt level at the borrowing limit. The equilibrium is:

$$\begin{cases} h' = \bar{H}, \\ m' = \frac{\theta_h(1-\delta_h)p_h\bar{H}}{1+r}, \\ c = \left\{p_h \frac{1-\alpha}{\alpha}\left[1+\beta(1-\kappa_h)(1-\delta_h) - \theta_h(1-\delta_h)\left(\frac{1}{1+r}-\beta\right)\right]\right\}^{\frac{1}{\sigma}} \bar{H}, \\ c + rm' + p_h[1-(1-\kappa_h)(1-\delta_h)]\bar{H} = y. \end{cases}$$

By analyzing the equilibrium conditions, p_h decreases while r increases. Given p_h, an increase in r will increase rm' and c, so p_h will decrease to hold the equality of the last equation.

If households are representative and homogeneous, there is no heterogeneous response in policy functions. The distribution effect is degenerate to one point. Therefore, we need heterogeneity in the household side.

C Details of Moments

This section specifies the calculation of moments from data in table 2. I first summarize moments generated from SCF in 2022. The average house price is the mean primary residence \$471.06 thousand. Normalized by the average income, it is 3.3316. The average wealth for homeowners and renters are \$1525.16 thousand and \$153.47 thousand, so the ratio is 9.94. The average housing debt for homeowners is from aggregation of mortgages or home-equity loans \$215.3 thousand, home-equity lines of credit \$44.33 thousand, and other residential real estate debt \$245.21 thousand, which is \$504.84.[22] It equals to 3.57 after being normalized. The average income for homeowners and renters are \$177.2 thousand and \$71.71 thousand, so the ratio is 2.47. The average wealth is \$1059.47 thousand, which is normalized to be 7.49.

There are two moments generated from ACS. The number of total occupied housing units and owner-occupied units are $125,736,353$ and $81,497,760$, so the share of owner-occupied houses is 64.8%. Among owner-occupied units, there are $50,148,459$ housing units with a mortgage. Therefore, the share of owners with mortgages is 61.5%.

I calculate the new construction sales share from AEI-Zillow new construction index. We can get 12.9% from taking average of quarterly new construction share of sales.

D Numerical Computation

This section elaborates how I implement the numerical solution of the stationary equilibrium and transitional dynamics.

D.1 Stationary Equilibrium

There are three main challenges of the computation. First, there are four state variables– income, liquid, housing position, and mortgage balance the non-uniqueness solution of liquid assets and mortgages. In transitional dynamics, the interest rate attached with the existing mortgage is an additional state variable. Second, the different terms between long-term mortgages and liquid assets cause non-uniqueness portfolio in the solution. Third, the endogenous mortgage borrowing constraint causes problems in assigning mortgage grids and interpolating the objective function. To resolve these problems, I assume that households can only move to $h_o \in \mathrm{H} = \{h^1, h^2, h^3, ..., h^N\}$, where $h^1 < h^2 < ... < h^N$, and the duration of the house $h_{dur} = 10$.[23] These two assumptions ensure that the households' housing state space is a finite set with $h^N * h_{dur} + 1$ elements.[24] Without loss of generality, I can assume that the mover always borrows to the limit, and the stayer always repay the minimum repayment. The reason lies in the fact that they can always save the amount exceeding the optimal mortgage balance. For example, if a household borrows 1 dollar more in her mortgage balance, she can always save this dollar in the liquid asset and use the gross return R to repay the additional borrowing next period. This assumption reduces one state variable, mortgages, since the mortgage balance attached with each housing state is certain. It simultaneously resolves the dimensionality problem and the interpolation problem.

The numerical exercise solves the stationary problem as the following:

1. Given exogenous r, first guess a housing price p_h and assign mortgage balance for each housing grid.

[22] The structure of SCF debt variables can be found here.

[23] The duration assumption does not affect the result significantly when it is not too small. It is always applicable to assign a higher duration. Here, I assume $h_{dur} = 10$ considers both the reality and the computation efficiency.

[24] The additional one means that a household does not own a house; i.e., $h = 0$.

2. Inner loop (Value function iteration): Guess an initial value function V_0. Solve household optimality under choice of moving to $h' \in \mathrm{H}$, staying, and renting separately, and find the maximum as the optimal housing choice. The corresponding value function V_1 is obtained. Check $||V_1 - V_0||$. If the difference exceeds the tolerance level, update the initial value function and keep implementing the process until the difference is smaller than the tolerance level.

3. Use the policy function from the inner loop to get the stationary distribution F. To get a finer distribution, we find out the threshold of liquid asset $\bar{a_n} \in [a_{n-1}, a_n]$ when $h'(m, h, a_{n-1}, y) \neq h'(m, h, a_n, y), \forall n \in \mathbb{N}$ such that $V(m, h, \bar{a_n}, y)$ is indifferent between choosing $h'(m, h, a_{n-1}, y)$ and $h'(m, h, a_n, y)$. With this refinement, we get a more continuous distribution mass along with liquid asset a. Check the market clearing condition.

4. If the absolute value of the excess demand is smaller than the tolerance level, we claim that the equilibrium price is found. Otherwise, adjust the price and redo the process above with the updated price until the market clears.

D.2 Transitional Dynamics

The transitional dynamics of the fixed-rate mortgage structure needs to track the existing mortgage rate. This would not be a problem because we can make the same assumption as in D.1 and pin down the attached mortgage balance for each housing grid during the transition. The only concern is that repaying the minimum repayment might not be optimal when the current rate is smaller than the existing mortgage rate. Therefore, I assume that the existing mortgage rate is automatically refinanced to the current rate if the current rate is lower than the existing mortgage rate.[25]

The numerical exercise solves the transitional dynamics as the following:

1. Guess a price sequence along the transitional path.

2. Backward: Given the price sequence, back out the value function sequence along the transitional path.

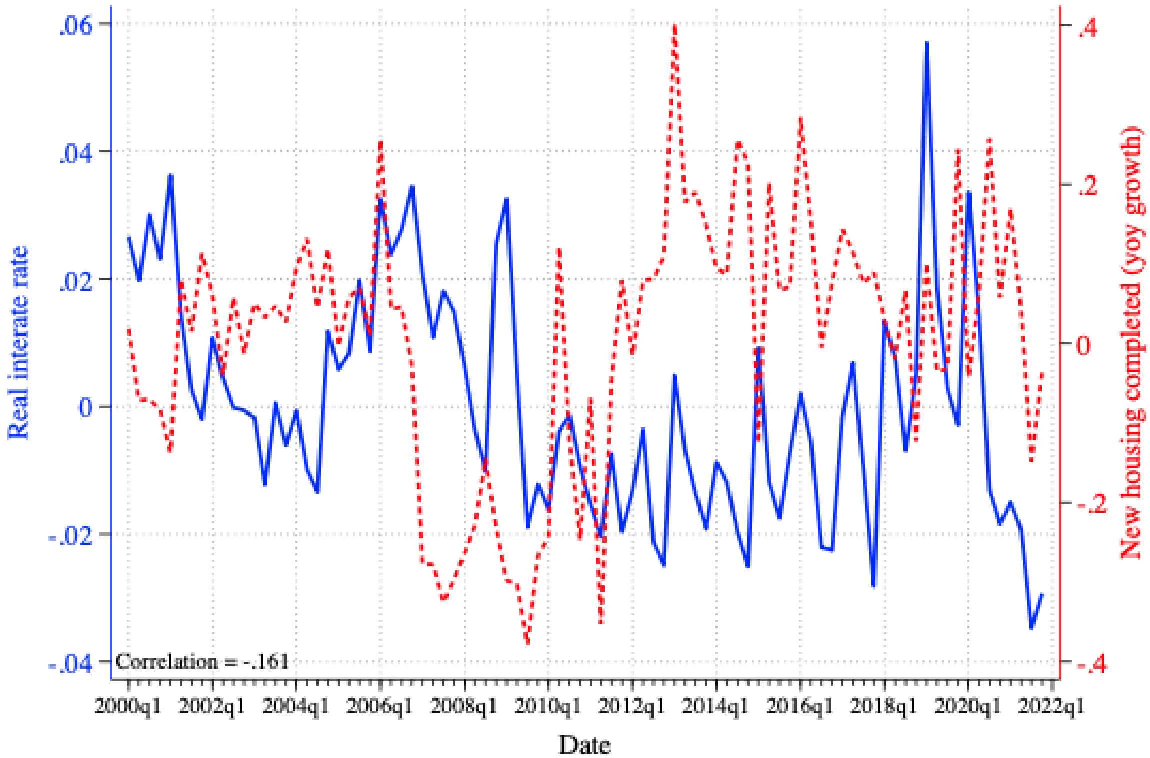
3. Forward: Given the derived value function sequence, clear the market by solving the policy function, updating distribution, and updating the price period by period from the beginning of the transition.

4. Check the distance between the new price sequence and the old price sequence. If the distance is smaller than the tolerance level, we claim that we find the transitional dynamics path.

5. Otherwise, redo the above process until the price sequence converges.

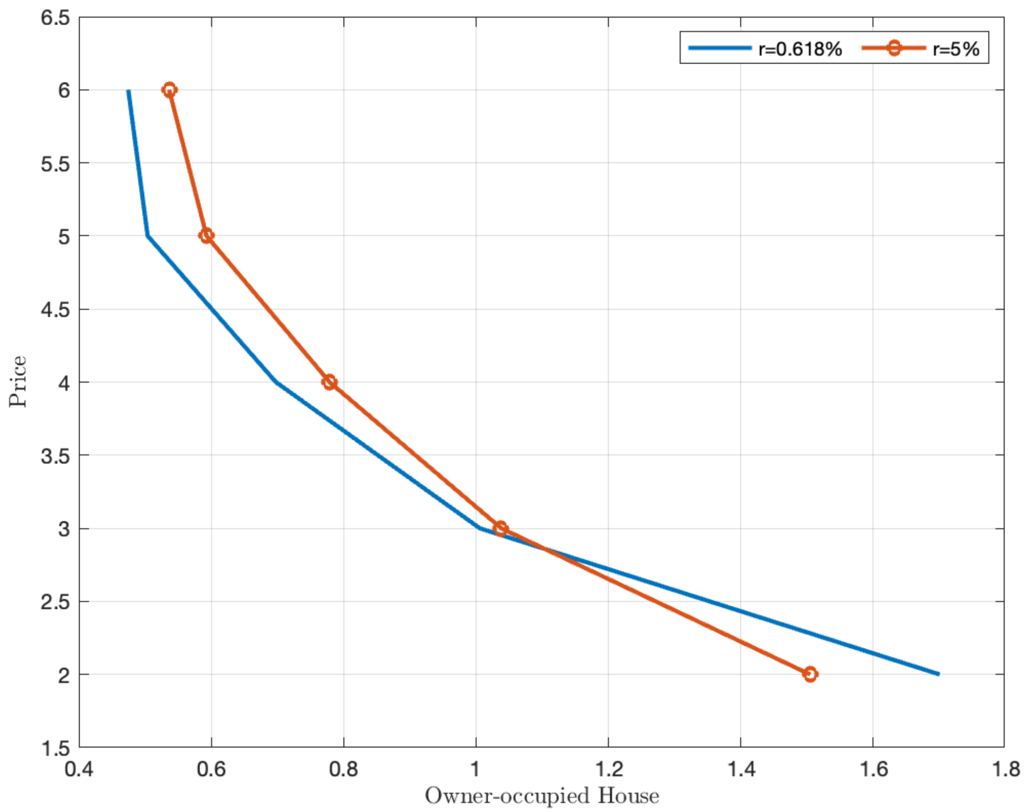
[25]For a more detailed discussion about refinance behaviors, we can check Berger et al. (2024) and Boar et al. (2022).

E Figures



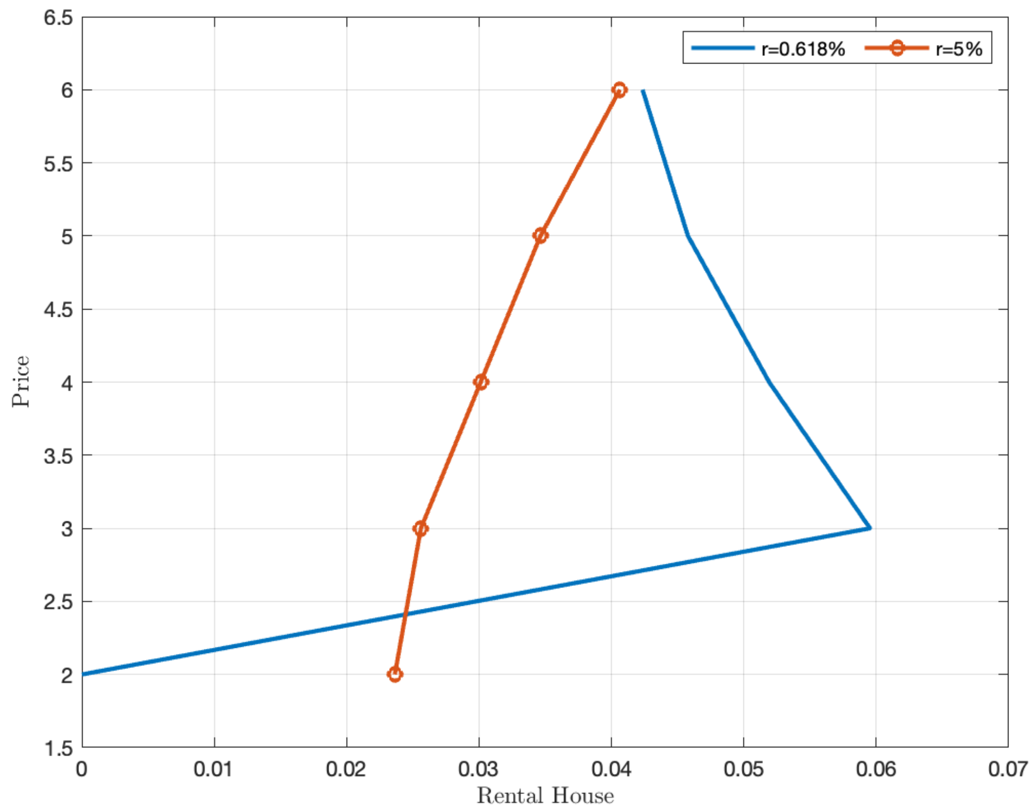
Note: This figure displays the quarterly time series 1-year real interest rate by the blue solid line (left y-axis) and builder's housing completion growth rate by the red dashed line (right y-axis) from Q1 2000 to Q1 2022 in the U.S.

Figure E1: Real Interest Rate and Housing Completion Growth (Q1 2000-Q1 2022)



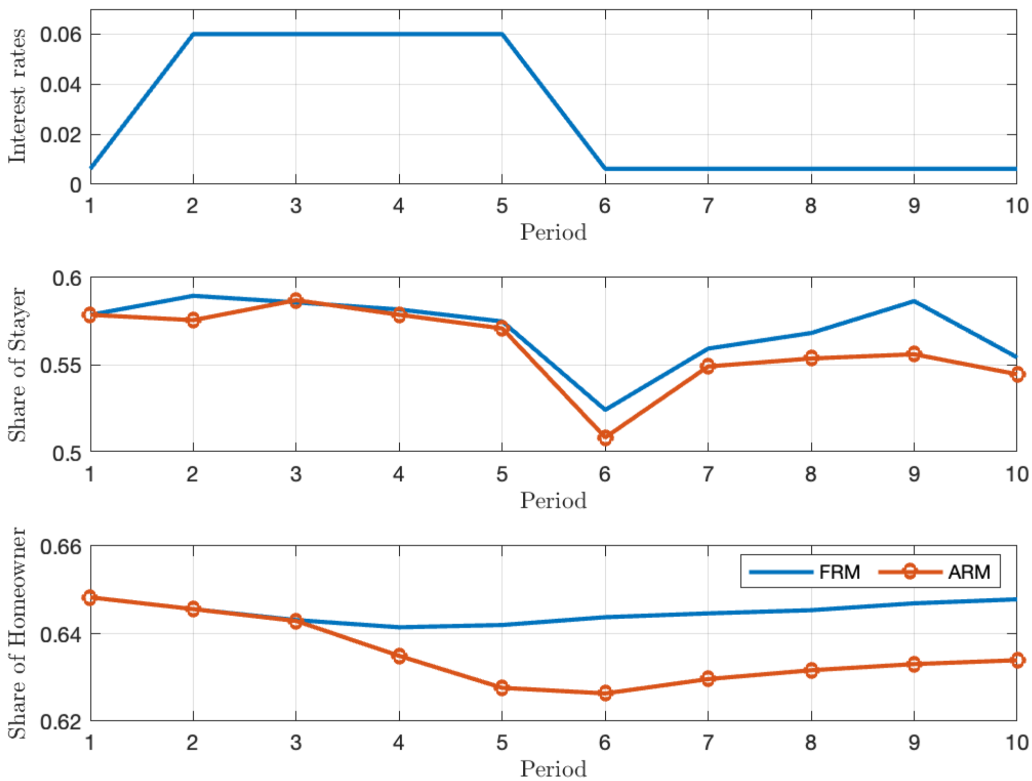
Note: This figure displays household aggregate owner-occupied housing demand curve. Specifically, the blue solid line depicts owner-occupied housing demand under different housing prices given $r = 0.618\%$. The orange line with circle depicts owner-occupied housing demand under different housing prices given $r = 5\%$.

Figure E2: Owner-occupied House



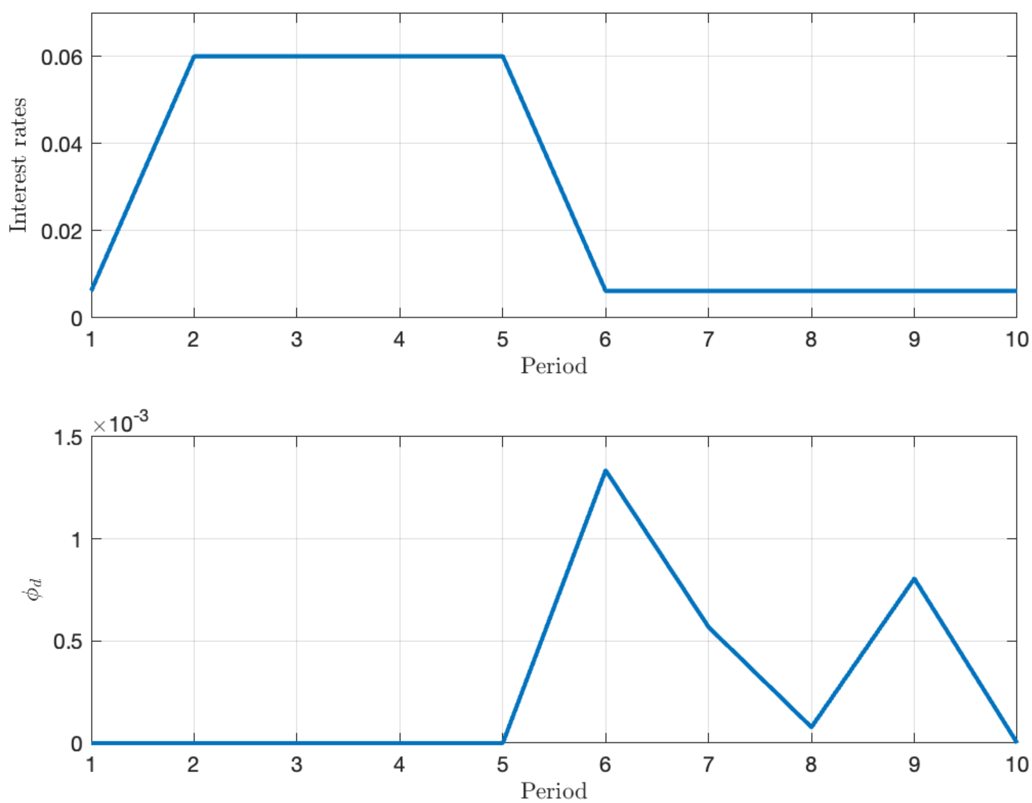
Note: This figure displays household aggregate rental housing demand curve. Specifically, the blue solid line depicts rental housing demand under different housing prices given $r = 0.618\%$. The orange line with circle depicts rental housing demand under different housing prices given $r = 5\%$.

Figure E3: Rental House



Note: This figure illustrates the aggregate response of the economy with builders under FRM and ARM respectively to a temporary increase in interest rates. The top panel plots the exogenous change in the interest rate. The middle panel plots the transition of share of stayers in an economy with FRM (blue solid line) and with ARM (orange dashed line). The bottom panel plots the transition of the new construction in an economy with FRM (blue solid line) and with ARM (orange dashed line). All sectors and agents have perfect foresight of dynamic path of all variables after the unexpected interest shock is realized.

Figure E4: Transitional Path of Share of Stayer and Homeowner to Interest Rate Shock–FRM and ARM



Note: This figure illustrates the aggregate response of the economy under FRM and builders with and without builder's financial constraint respectively to a temporary increase in interest rates. The top panel plots the exogenous change in the interest rate. The bottom panel plots the transition of marginal cost of equity issuance without builder's financial constraint (blue solid line) and with builder's financial constraint (orange dashed line). All sectors and agents have perfect foresight of dynamic path of all variables after the unexpected interest shock is realized.

Figure E5: Transitional Path of Marginal Cost of Equity Issuance to Interest Rate Shock–with and without Builder's Financial Constraint