Essays in Housing and Macroeconomics

by

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Abstract

This dissertation contains three self-contained chapters, which all use calibrated lifecycle models with equilibrium in housing markets to answer questions at the intersection of housing and macroeconomics. The first chapter is about the long-run effects of restrictions on buy-to-let investment property purchases. I find that transaction taxes on investor purchases can lower house prices and increase homeownership rates a little, but that higher interest rates on investor mortgages or loan-to-value restrictions have little effect. The second chapter is about the causes of the housing boom in the US during the COVID-19 pandemic. We find some empirical evidence that regions where households spent more time at home during the pandemic experienced faster house price growth. Our model suggests that these stay-at-home shocks explain around half of the rise in house prices in 2020, while lower interest rates explain one-third. The final chapter explores how the trend decline in real interest rates, and the ensuing rise in house prices, has affected homeownership rates in Australia. Our model suggests that lower rates and rising prices more than explain decline in the under-40 homeownership rate and the fall in homeownership in the bottom income quintile since 1995. We find that higher loan-to-value limits could have supported ownership rates along the transition to the low interest rate equilibrium, and that some households could benefit a lot from higher loan-to-value limits in the current low-rate, high-price economy.

Chapter 1

Tighter Regulation of Investment Property Purchases

I use a quantitative life-cycle model to study how permanently tighter regulation of household investment property purchases affects who invests, and explore possible equilibrium effects on house prices and home ownership. I analyze three large policy changes: (1) a 10 percentage point reduction in the loan-to-value (LTV) limit on investor mortgages; (2) a $\frac{1}{2}$ percentage point increase in the investor mortgage rate; and (3) a 5 per cent transaction tax on investment property purchases. Quantitatively, the higher mortgage rate and transaction tax produce large shifts in the distribution of investors towards older, higher-income, and more wealthy households, and reduce investor indebtedness. In contrast, lowering the LTV limit has little effect in the model because most investors are not constrained by the larger downpayment requirement. In an equilibrium exercise, where the house price is allowed to fall in response to the policy changes but rents are held constant, I find the investor transaction tax raises home ownership among young mid-income households.

1.1. Introduction

In the past decade or so several countries have tightened regulation of 'buy-to-let' investment property purchases – in other words, housing purchases by buyers who will rent out the property. For example, in late 2008 Fannie Mae and Freddie Mac lowered the loan-to-value (LTV) limit on investor mortgages that they would be willing to purchase or guarantee from 90 to 85 per cent, with this lower limit still in place. From 2014–2018 Australia's banking regulator imposed a quantitative limit on banks' mortgage lending to investors, which lead to higher interest rates on investor mortgages.[1] And in 2016, the UK government increased its transaction tax rate on investment property purchases by 3 percentage points. Obviously, these specific examples were implemented in different contexts and were designed to achieve different things. But, at the same time, these (and other) examples suggest that policy makers increasingly view tightening regulation of investors as a way to reduce risk and/or inequality in housing markets.[2] How do these type of policies affect who invests? And to the extent that tighter regulation of investors reduces housing demand, what are the possible effects of these kind of policies on house prices, home ownership and the overall level of debt in the economy? In this paper, I try to get at these questions using a quantitative model, which extends an otherwise standard incomplete markets life-cycle model to include housing investors and investor mortgages, and incorporates other realistic features of the US housing market.

I study three hypothetical permanent policy changes targeted at housing investors that are loosely related to the real-world examples mentioned above: (1) a 10 percentage point reduction in the LTV limit on investor mortgages; (2) a $\frac{1}{2}$ percentage point increase in the investor mortgage rate; and (3) a 5 per cent transaction tax on investment property purchases. I find that raising the investor mortgage rate or imposing an investor transaction tax substantially reduce investment demand. By making it more costly to invest, these two policies shift the distribution of investors to older, higher-income and wealthier households. However, in equilibrium, only the transaction tax policy causes the house price to fall sufficiently to raise the home ownership rate, which increases by 2 percentage points, reflecting higher home ownership among young mid-income households. In contrast, I find that permanently lowering the LTV limit on investor mortgages has little effect on investment demand, and the characteristics

[1]For an overview of this policy and an analysis of its effects on bank lending see Garvin, Kearney, and Rose (2021).

[2]More recently, the US Treasury has required Fannie Mae and Freddie Mac to limit purchases of investor and second home loans to 7 per cent of their total single-family mortgage acquisitions. In 2021, the New Zealand government introduced various reforms aimed at reducing incentives to invest in housing. These include an increase in the holding period required to be exempt from capital gains tax, and a proposal to remove the mortgage interest deduction for investors (for details see Inland Revenue (2021)). At the same time, the Reserve Bank of New Zealand implemented restrictions on lending to investors with LTVs above 60 per cent.

of investors, because most investors are not constrained by the higher down-payment requirement. The low LTV, high mortgage rate and transaction tax lower the level of mortgage debt (as a percentage of aggregate income) in the economy by 3, 7 and 5 percentage points, respectively. Under the transaction tax, an increase in mortgage debt taken out by young first-home-buyers partly offsets the decline in investor mortgage debt.

My model builds on a large and growing class of models that embed an illiquid housing asset and long-term mortgage financing in an incomplete markets life-cycle economy.[3] I extend the workhorse environment to include investment property and an associated mortgage product. Households face idiosyncratic income shocks during their working life, and make decisions about about nondurable and housing consumption, whether to own or rent, liquid savings and long-term mortgage debt. In addition, home owners can purchase an investment property, which earns rental income, delivering a higher return than the liquid bond. However, home owners face two key frictions which affect their ability to invest. First, the investment property is of a fixed size and is quite large, which implies households must have sufficient cash-on-hand for the mortgage down-payment, or to make an outright cash purchase. Second, a new investor incurs a one-time stochastic utility cost when they invest, which can be thought of as a stand-in for non-pecuniary costs of investing, such as search effort. The indivisibility of the investment property and the utility cost together imply that investing is out-of-reach for most home owners in the calibrated model. In the model and in the data, investment ownership is skewed towards older and higher-income households.

Using the calibrated model, I conduct three policy experiments, separately varying the investor LTV limit, investor mortgage rate and the transaction tax on investment property, solving for a new steady state in each case. To highlight the direct effects of the tighter regulations on the characteristics of investors, I first conduct the experiments in partial equilibrium – assuming the house price remains fixed. I find that raising the investor mortgage rate or imposing a transaction tax substantially reduces the probability that a home owner invests at all stages of life, but especially during the peak-investment ages of 50–55. These policies produce substantial changes in the

[3] For recent examples, see Boar, Gorea, and Midrigan (2021), Graham (2020), Kaplan, Mitman, and Violante (2020), Guren, Krishnamurthy, and McQuade (2021), Hu (2021) and Wong (2021). These models have much in common with models of household consumption where households can save in a liquid and illiquid asset, such as Kaplan and Violante (2014).

distribution of investors by age, income and wealth. In contrast, lowering the LTV limit has little effect on the probability of investing, and as a result barely affects who invests.

In the final part of the paper I explore the equilibrium consequences of tighter regulation of investors by letting the house price adjust in response to the permanent policy changes. Throughout the analysis I assume that rents are fixed. Since the policies reduce investment demand, the house price and the price-to-rent ratio fall. The model suggests that under the investor transaction tax the price-to-rent ratio to falls by enough to generate an increase in the home ownership rate 2 percentage points. The increase in home ownership is wholly concentrated among young mid-income households, whose tenure decisions are most sensitive to the price-to-rent ratio. In contrast, lowering the investor LTV limit or raising the investor mortgage rate do not lower the price-to-rent ratio enough to produce any meaningful change in home ownership.

Related literature. My paper adds to the literature that studies the role of household property investors in housing markets. In an important contribution, Chambers, Garriga, and Schlagenhauf (2009b) use a quantitative model to study the impact of various tax changes on home ownership and property investment in general equilibrium. For example, their model suggests that taxing owner-occupiers' imputed rent in a revenue neutral manner increases home ownership and investment ownership in the model's steady state. Seemingly crucial to this result is how they model investors: in their model households can only own one property, but home owners can rent out a portion of their home if they pay a fixed cost.[4] I model investors quite differently, but consistent with their results, I find that asymmetric reglatory treatment of owner-occupied and investment property can have quantitatively important effects on the distribution of property ownership. In contrast to Chambers, Garriga, and Schlagenhauf (2009b) I focus on the effects of dialling-up this asymmetry, while they study what happens when some tax asymmetries are removed.

The main technical innovation in my model is that I allow investors to hold separate mortgages on their owner-occupied and their investment properties. Existing quantitative models that feature investors assume that investor mortgagors have a single mortgage secured against the combined value of their home and investment property (e.g.

[4] Accordingly, in Chambers, Garriga, and Schlagenhauf's (2009) model, when imputed rent is taxed, home owners reduce their consumption of housing services and a larger fraction choose to rent out a portion of their home.

Chambers, Garriga, and Schlagenhauf (2009a), Chambers, Garriga, and Schlagenhauf (2009b), Graham (2020)). Allowing separate owner-occupier and investor mortgages – with possibly different LTV limits and interest rates – is challenging because it implies that households can have up to five assets on their balance sheets. But it opens the door to studying realistic regulations that specifically target investor mortgages, which are the basis of two of my policy experiments.

Roadmap. The rest of the paper proceeds as follows. Section 1.2 lays out the quantitative model. Section 1.3 describes how I parameterize the model. In Section 1.4 I outline how households behave in the model using a numerical simulation, and assess how well the calibrated model matches some features of the data not targeted in the calibration. Section 1.5 uses the calibrated model to explore how tighter regulation of investment property purchases affects the characteristics of investors. Section 1.6 explores the possible equilibrium consequences of these tighter regulations. Section 1.7 concludes.

1.2. Model

1.2.1. Household environment

Time is discrete. The economy is populated by households, which I also refer to as agents.

Demographics. The economy is populated by overlapping generations of households. The population (i.e. number of households) is constant and has measure 1. A household's age is index by $j = 1, ..., J$. Households split their life between working and retirement, commencing retirement at age J^{ret}, and die with certainty at the end of age J.

Preferences. Household's maximize their expected lifetime utility, which takes the form:

$$\mathbb{E}_0 \sum_{j=1}^{J} \beta^{j-1} \frac{(c_j^{\alpha} s_j^{1-\alpha})^{1-\sigma}}{1-\sigma} + \beta^J B \frac{(1+w_{J+1})^{1-\sigma}}{1-\sigma}, \tag{1.1}$$

where c denotes non-durable consumption, s is consumption of housing services, and w_{J+1} is end-of-life wealth (defined below). Agents obtain housing services by either renting or owning their house (see below). As usual, β is the discount factor, $1-\alpha$ measures the taste for housing services relative to non-durable consumption, $1/\sigma$ is the intertemporal elasticity of substitution, and B measures the strength of the bequest motive.

Income. Each period, households receive income y_j. During working life, household income is the sum of an age-dependent deterministic component (common to all households of the same age), and an idiosyncratic stochastic component. During retirement, households receive a constant pension equal to a fraction of their income in the last period of their working life. Log income is given by:

$$\log y_j = \begin{cases} \chi_j + z_j & \text{if } j < J^{ret} \\ \log \zeta + \log y_{J^{ret}-1} & \text{if } j \geq J^{ret} \end{cases} \tag{1.2}$$

where χ_j is the deterministic component, and z_j is a stochastic idiosyncratic component that follows an AR(1) process:

$$z_j = \rho z_{j-1} + \epsilon_j, \quad \epsilon_j \sim \mathcal{N}(0, \sigma_\epsilon^2). \tag{1.3}$$

The constant retirement pension is given by $\zeta y_{J_{ret}-1}$, where $\zeta \in (0,1)$ is the replacement rate, common to all households.

Liquid Saving. Households can save in a one-period bond a, with an exogenous interest rate r. Unsecured borrowing in the liquid account is not allowed, so $a \geq 0$.

Rental Services. Housing services s can be obtained by renting at a per-unit price p_r. Rental house sizes are chosen from a discrete grid $\mathcal{S} = \{\underline{s}, ..., \bar{s}\}$..

Owner-occupier Housing. Households can also obtain housing services by owning the house that they live in. The per-unit price of owner-occupied housing is p_h. A household lives in an owner-occupied property of size h recieves a service flow equal to the size of their house; i.e. $s = h$. Owner-occupied house sizes are also chosen from a discrete grid $\mathcal{H} = \{\underline{h}, ..., \bar{h}\}$ that overlaps with the rental housing grid. We assume that the smallest owner-occupied property is larger than the smallest rental property: $\underline{h} > \underline{s}$. Owner-occupiers pay a per-period maintenance cost δ, which is proportional to the value of their home. Owner-occupiers face a transaction cost κ_s when selling their home, which is proportional to the value of the property being sold. For example, a homeowner who wants to change the size of their home from h to h' pays $\kappa_s p_h h + p_h(h' - h)$ units of the final good.

Investment Housing. Homeowners can purchase an investment property of size i at an after-tax per-unit price $(1+\tau)p_h$. I assume that renters cannot do this. τ is the transaction tax rate levied on investor property purchases, which I set to zero in the baseline calibrated economy. Investors can transform their investment property into i units of rental services, which generates rental income $(1 - \gamma)p_r i$. However, they cannot transform their investment property into owner-occupied housing for their own consumption; i.e. investors cannot live in their investment property. To manage the computational cost of solving the household's problem, I assume that there is only one investment property size available, and that homeowners can own at-most one investment property: $i \in \{0, \underline{i}\}$, where $\underline{i}$ is the fixed size of the only available investment property. γ is a 'monitoring cost', which controls the rental return earned by investors. Like owner-occupiers, investors incur a maintenance cost so that their total per-period maintenance expense is $\delta p_h(h + i)$, and a transaction cost κ_s when they sell their investment property. Note that investors cannot live in their investment property themselves (and by assumption they must own the home they live in); they can only buy the property rent it out to other households, and sell it.

In addition to the monetary cost of purchasing an investment property, I assume that new investors incur a one-time utility cost ξ. I assume that ξ is an iid draw from an exponential distribution with mean λ.[5] The stochastic utility cost can be thought of as capturing non-pecuniary barriers to investing, such as time costs or other behavioral factors, but is primarily a modelling device that makes the probability of investing a smooth function of the gains from investing.[6] Without a stochastic utility cost (or

[5]This utility cost is akin to the stochastic utility cost of mortgage refinancing in Boar, Gorea, and Midrigan (2021), who in turn draw on the early use of stochastic adjustment costs in the (S, s) models of Dotsey, King, and Wolman (1999), Khan and Thomas (2008) and others.

[6]As explained in Boar, Gorea, and Midrigan (2021), the parameter λ controls the rate at which the probability of investing increases in the gains from investing.

equivalently, setting $\lambda = 0$), homeowners would invest so long as there are positive gains from investing. In contrast, with a sufficiently large λ some households will not invest even if there are positive gains from investing. A model without the stochastic utility cost has a very volatile investor rate (i.e. one that is very sensitive to parameters and prices). Accordingly, the stochastic utility cost makes calibration easier, since the investor rate does not necessarily jump around too much following small changes to parameters.

Mortgages. Households can finance property purchases using long-term, non-defaultable, constant-repayment mortgages. I allow investors to have separate mortgages on their owner-occupied home and their investment property, which is the main technical innovation of this paper. A household's owner-occupied and investor mortgage balances are denoted as m_h and m_i, respectively. At origination all new mortgages are subject to a fixed origination cost, κ_m, as well as loan-to-value (LTV) and payment-to-income (PTI) constraints. I allow mortgage rates and maximum LTV ratios to differ for owner-occupier and investor mortgages. I denote the mortgage rates on owner-occupier loans and investor loans as r_h and r_i, respectively. The maximum LTV ratios for owner-occupier and investor loans are denoted θ_h and θ_i, respectively.

I assume that mortgages fully amortize over the remaining lifetime of the mortgagor, so that agents cannot die with any debt outstanding. The constant repayment faced by an age-j mortgagor with current mortgage balance m_l and associated interest rate r_l is:

$$\bar{\pi}_l = \frac{r_l(1+r_l)^{J-j}}{(1+r_l)^{J-j}-1} m_l, \quad l \in \{h, i\}. \tag{1.4}$$

The PTI constraint says that the minimum repayment on a new mortgage cannot exceed a fraction θ_y of the agent's labor income in the period of origination:

$$\bar{\pi}_l \leq \theta_y y_j, \quad l \in \{h, i\}. \tag{1.5}$$

I assume that mortgagors make the minimum repayment while following the amortization schedule, so that their mortgage balances evolves according to:

$$m_l' = (1+r_l)m_l - \bar{\pi}_l, \quad l \in \{h, i\}. \tag{1.6}$$

Mortgagors have the option to refinance. When refinancing, the mortgagor must repay the outstanding balance on their existing loan and originate a new mortgage, incurring the origination cost κ_m. In stationary equilibrium interest rates are constant so refinancing into a lower mortgage rate is not possible. However, mortgagors may choose to refinance in order to pay down their mortgage faster than the constant repayment schedule, or to extract equity. When a household sells its home or investment property, it must pay off any outstanding mortgage balance associated with the property.

Interest Rates. The model represents a small open economy. The risk-free bond rate, r, is exogenous (determined by the net supply of safe financial assets from the rest of the world). I assume that the owner-occupied and investor mortgage rates have constant and exogenous spreads above r, with $r_h = r + \kappa_h$ and $r_i = r + \kappa_i$. These mortgage spreads reflect un-modeled risk premia. Accordingly, I treat all three interest rates as exogenous parameters of the model, rather than equilibrium prices with associated asset market clearing conditions.

1.2.2. Household's decision problems

Below I cast the household's problem recursively. An age-j household enters the period with individual state vector $\mathbf{x} = (a, h, m_h, i, m_i, z)$, where $a \in \mathcal{A}$ is liquid assets, $h \in 0 \cup \mathcal{H}$ is owner-occupied house size (zero for renters), $m_h \in \mathcal{M}_h$ is their outstanding owner-occupied mortgage balance, $i \in \{0, \underline{i}\}$ is investment property size (zero for renters and non-investor owner-occupiers), $m_i \in \mathcal{M}_i$ is their outstanding investor mortgage balance, and $z \in \mathcal{Z}$ is the current period's idiosyncratic component of income. Each period households make a discrete choice over whether to rent, retain their current housing portfolio and make any require mortgage repayments, invest, adjust their owner-occupied house siz or refinance their owner-occupied mortgage, refinance their investor mortgage, or sell their investment property. Let:

$$V_j(\mathbf{x}) = \int_0^\infty \max \left\{ \begin{array}{ll} \text{Rent:} & V_j^{\text{rent}}(\mathbf{x}), \\ \text{Retain current housing portfolio:} & V_j^{\text{stay}}(\mathbf{x}), \\ \text{Invest:} & V_j^{\text{invest}}(\mathbf{x}) - \xi + (\mathbf{1}_{[h=0]} \times -\infty), \\ \text{Adj. OO house size/mortgage:} & V_j^{\text{adjust}}(\mathbf{x}), \\ \text{Refi. INV mortgage:} & V_j^{\text{refi}}(\mathbf{x}), \\ \text{Disinvest:} & V_j^{\text{disinvest}}(\mathbf{x}) \end{array} \right\} dG(\xi). \tag{1.7}$$

be the envelope over these options, integrating over the iid utility cost of investing, drawn from an exponential distribution with mean λ:

$$G(\xi) \overset{iid}{\sim} 1 - \exp\left(-\frac{\xi}{\lambda}\right). \tag{1.8}$$

Note that the term $(\mathbf{1}_{[h=0]} \times -\infty)$ in the value function simply implies that renters cannot buy an investment property.

A household who chooses to rent solves

$$\begin{aligned} & V_j^{\text{rent}}(\mathbf{x}) = \max_{c,a',s} u(c,s) + \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \\ & \text{subject to:} \qquad\qquad (1.9) \\ & c + p_r s + a' = y_j + (1+r)a + (1-\kappa_s-\delta)p_h(h+i) - (1+r_h)m_h - (1+r_i)m_i \\ & a \geq 0 \end{aligned}$$

A household who chooses to retain in their current housing portfolio and make any required mortgage repayments solves:

$$
\begin{aligned}
& V_j^{\text{stay}}(\mathbf{x}) = \max_{c,a'} u(c,h) + \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \\
& \text{subject to:} \\
& c + \delta(h+i) + \bar{\pi}_h + \bar{\pi}_i + a' = y + (1+r)a + (1-\gamma)p_r i \\
& m_l' = (1+r_l)m_l - \bar{\pi}_l, \quad l \in \{h, i\} \\
& s = h \\
& a \geq 0
\end{aligned}
\tag{1.10}
$$

A homeowner who chooses to buy an investment property solves:

$$
\begin{aligned}
& V_j^{\text{invest}}(\mathbf{x}) = \max_{c,a',i',m_i'} u(c,h) + \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \\
& \text{subject to:} \\
& c + (1+\tau)p_h i' + \delta p_h h + \bar{\pi}_h + \kappa_m + a' = y_j + (1+r)a + (1-\gamma)p_r i' + m_i', \\
& m_i' \leq \theta_i p_h i' \\
& \bar{\pi}_i \leq \theta_y p_h i' \\
& i' = \underline{i} \\
& s = h \\
& a \geq 0
\end{aligned}
\tag{1.11}
$$

A homeowner who chooses to adjust their owner-occupied house size or refinance their owner-occupied mortgage solves

$$
\begin{aligned}
&V_j^{\text{adjust}}(\mathbf{x}) = \max_{c,a',h',m_h'} u(c,h') + \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \\
&\text{subject to:} \qquad (1.12) \\
&c + \delta p_h(h+i) + \bar{\pi}_i + a' = y_j + (1+r)a + (1-\gamma)p_r i + \mathbf{1}_{h' \neq h} p_h[(1-\kappa_s)h - h']... \\
&\qquad - \kappa_m - (1+r_h)m_h + m_h', \\
&m_h' \leq \theta_h p_h h' \\
&\bar{\pi}_h \leq \theta_y p_h h' \\
&s = h' \\
&a \geq 0
\end{aligned}
$$

An investor who chooses to refinance their investor mortgage solves

$$
\begin{aligned}
&V_j^{\text{refi}}(\mathbf{x}) = \max_{c,a',m_i'} u(c,h) + \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \\
&\text{subject to:} \qquad (1.13) \\
&c + \delta p_h(h+i) + a' + \bar{\pi}_h + \kappa_m = y_j + (1+r)a + (1-\gamma)p_r i - (1+r_i)m_i + m_i', \\
&m_i' \leq \theta_i p_h i \\
&\bar{\pi}_i \leq \theta_y p_h i \\
&s = h \\
&a \geq 0
\end{aligned}
$$

Finally, an investor who chooses to sell their investment property and possibly adjust their owner-occupied house size and mortgage solves[7]

$$V_j^{\text{disinvest}}(\mathbf{x}) = \max_{c,a',h',m_h'} u(c,h') + \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')]$$

subject to: (1.14)

$$c + \delta p_h h + a' = y_j + (1+r)a + (1-\kappa_s)p_h i + \mathbf{1}_{h' \neq h} p_h[(1-\kappa_s)h - h' - \kappa_m] - (1+r_h)m_h + m_h',$$

$$m_h' \leq \theta_h p_h h'$$

$$\bar{\pi}_h \leq \theta_y p_h h'$$

$$s = h'$$

$$a \geq 0$$

Decision rule for investing. Homeowners only invest if the gain from investing, after incurring the stochastic utility cost, exceeds the gain from the next best alternative:

$$V_j^{\text{invest}}(\mathbf{x}) - \xi > \max_{k \in \mathcal{K}} \{V_j^k(\mathbf{s}_O)\}, \quad \mathcal{K} = \{\text{rent}, \text{stay}, \text{adjust}, \text{refi}, \text{disinvest}\}. \tag{1.15}$$

Thus, the structure of the discrete choice problem leads to a cutoff rule for purchasing an investment property, such that owner-occupiers only invest if they draw a utility cost that is less than

$$\xi_j^*(\mathbf{x}) = \max\left\{V_j^{\text{invest}}(\mathbf{x}) - \max_{k \in \mathcal{K}}\{V_j^k(\mathbf{x})\}, 0\right\}. \tag{1.16}$$

Accordingly, the probability that an owner-occupier with individual state $\mathbf{x}$ invests is given by $G(\xi^*(\mathbf{x}))$, and the expected value function can be written as:

$$V_j(\mathbf{x}) = -\int_0^{\xi_j^*(\mathbf{x})} \xi dG(\xi) + G(\xi_j^*(\mathbf{x}))V_j^{\text{invest}}(\mathbf{x}) + [1 - G(\xi_j^*(\mathbf{x}))] \max_{k \in \mathcal{K}}\{V_j^k(\mathbf{x})\}. \tag{1.17}$$

[7] When solving the model on the computer I do not allow households to sell their investment property and refinance their owner-occupied mortgage in the same period to save on the number of optimization problems to solve. Nonetheless, households can sell their investment property and upsize/downsize their owner-occupied property in the same period, and originate a new owner-occupied mortgage.

1.2.3. Rental sector

Rental services are produced by household investors and a rental services firm. Investors can costlessly transform their investment property of size i' into i' units of rental services. If an investor chooses to sell their investment property it effectively destroys the i units of rental services associated with the property, thereby reducing the supply of rental housing and reducing demand for owner-occupied housing at the same time.

The firm operates a linear technology which converts q units of the consumption good into one unit of rental services (and vice versa). The firm's optimality condition for rental services production is:

$$p_r = q \tag{1.18}$$

since the marginal cost of producing one unit of rental services is q.

1.2.4. Housing supply

To close the model I assume a supply curve for owner-occupied and investor housing of the form:

$$p_h = \left(H/\bar{H}\right)^{1/\phi}. \tag{1.19}$$

ϕ is the elasticity of housing supply, H is total supply of owner-occupied and investor housing, and $\bar{H}$ is the stock of owner-occupied and investor housing in the baseline stationary equilibrium.

1.2.5. Stationary equilibrium

Let $X = \mathcal{A} \times 0 \cup \mathcal{H} \times \mathcal{M}_h \times \{0, \underline{i}\} \times \mathcal{M}_i \times \mathcal{Z}$ be the idiosyncratic state space for an age-j household.

Rental market clearing. The equilibrium rental rate p_r is determined by the rental firm's optimality condition (1.18) and this market automatically clears because the firm is willing to supply any amount of rental housing at this rate.

Housing market clearing. The house price p_h is determined by the aggregate demand for for owner-occupied and investor housing and the aggregate housing supply given by equation (1.19). The housing market clearing condition is:

$$\sum_{j=1}^{J}\sum_{X}(h'_j(\mathbf{x}) + i'_j(\mathbf{x}))\mu_j(\mathbf{x}) = \bar{H}p_h^{\phi} \tag{1.20}$$

where the LHS is demand for owner-occupied and investor housing and the RHS is the aggregate housing stock. In the baseline calibrated steady state I normalize the house price: $p_h = 1$.

Definition. A *stationary recursive competitive equilibrium* consists of: a collection of value functions, $\{V_j(\mathbf{x}), V_j^{\text{rent}}(\mathbf{x}), V_j^{\text{adjust}}(\mathbf{x}), V_j^{\text{invest}}(\mathbf{x}), V_j^{\text{refi}}, V_j^{\text{stay}}, V_j^{\text{disinvest}}(\mathbf{x})\}$ and associated decision rules $\{c_j(\mathbf{x}), s_j(\mathbf{x}), h'_j(\mathbf{x}), m'_{h,j}(\mathbf{x}), i'_j(\mathbf{x}), m'_{i,j}(\mathbf{x}), a'_j(\mathbf{x})\}$ for each j and $\mathbf{x} \in X$; prices (p_r, p_h); and a stationary distribution households over idiosyncratic states, $\mu_j(\mathbf{x})$ for each j and $\mathbf{x} \in X$ such that:

1. The value functions and decision rules solve the household's problems.

2. The rental firm's optimality condition (1.18) holds.

3. The owner-occupied and investment housing market clearing condition (1.20) holds.

4. The distribution of households over idiosyncratic states μ_j is invariant and has the law of motion

$$\mu_{j+1}(\mathbf{x}') = \sum_{X} Q_j(\mathbf{x}, \mathbf{x}')\mu_j(\mathbf{x}) \tag{1.21}$$

   where Q_j is a transition function that defines the probability that an age j household transits from its current state $\mathbf{x}$ to the set $\mathbf{x}'$ at age $j+1$, and is induced by the household's decision rules and the exogenous process for income.

1.3. Parameterization

I assign most of the model's parameters based on external evidence or standard values used in the literature. I then compute the remaining six parameters to minimize the distance between a set of moments from the model's steady state and their values in the data. I normalize the per-unit house price to be 1 in the baseline steady state ($p_h = 1$).

1.3.1. Assigned parameters

Below I describe how I chose the assigned parameter values, which are listed in Panel A of Table 1.1.

Demographics and preferences. The model period is two years. Households enter the economy at age 21, retire at age 65 ($J^{ret} = 23$), and die on their 81st birthday ($J = 30$). I set $\sigma = 2$ to give an intertemporal elasticity of substitution of 0.5, which is standard in the literature.

Income. I take the parameters that govern the idiosyncratic income process (1.3) from Kaplan, Mitman, and Violante (2020), who set the annualized persistence parameter $\rho = 0.97$ and the standard deviation of shocks $\sigma_\epsilon = 0.2$. The initial idiosyncratic income shock is drawn from normal distribution with mean zero and standard deviation 0.42, again following Kaplan, Mitman, and Violante (2020). This parameterization implies that income inequality (measured by the the variance of log income) rises over the life-cycle, consistent with empirical evidence in Heathcote, Perri, and Violante (2010).[8] I set the deterministic age-profile of earnings $\{\chi_j\}$ using PSID data for 1970–2017, following a similar approach to most recent papers that calibrate a life-cycle model. First, I apply the sample selection criteria from Heathcote, Perri, and Violante (2010).[9] I then regress log annual real wage earnings of household heads on a quartic in age. The age-profile value χ_j is equal to the fitted value from this regression for age $2 \times (j - 1) + 22$. I normalize the level of earnings in the model so that median annual earnings during working life in the model is equal to 1. The replacement rate of income in retirement is $\zeta = 0.5$, taken from Kaplan, Mitman, and Violante (2020).

Interest rates and housing. I set the risk-free rate $r = 0.03$ based on the 30-year

[8] At age 21, the standard deviation of log income is 0.42 (as mentioned in the text), while it eventually converges to $\sigma_\epsilon / \sqrt{1 - \rho^2} = 0.82$.

[9] I keep households in the main SRC sample with male heads aged 22–64. I drop observations where the head's labor income was missing or non-positive, or their hourly wage was less than half the Federal minimum wage in that year. I also drop observations where the head was out of the labor force.

Treasury constant maturity rate less the annual rate of CPI inflation, averaged over 1978–2019. Similarly, I set the owner-occupier mortgage rate $r_h = 0.044$ based on the average 30-year fixed mortgage rate from Freddie Mac's Primary Mortgage Market Survey less the annual rate of CPI inflation, averaged over 1978–2019. To set the investor mortgage rate r_i I use Freddie Mac's Single-Family Loan-Level Dataset. These data contain loan-level information on mortgages that were purchased or guaranteed by Freddie Mac, starting in 1999Q1. I limit the sample to 30-year fixed-rate purchase mortgages, and compute quarterly time series of the mean owner-occupier mortgage rate and the mean investor mortgage rate for the period 1999–2019. The average difference between the mean investor rate and the mean owner-occupier rate was 51 basis points over this period, so I set $r_i = 0.049$. I set the LTV limit on owner-occupier mortgage to $\theta_h = 0.85$ based on evidence from Greenwald (2018). I set the investor LTV limit to be equal to the owner-occupier LTV limit in the baseline economy, $\theta_i = 0.85$. The PTI limit is set to $\theta_y = 0.45$ in line with Freddie Mac's underwriting guidelines (see Hu (2021)). I set the mortgage origination cost to \$3 000, following Karlman, Kinnerud, and Kragh-Sorensen (2021). The selling cost κ_s of 7 per cent of the house value, and the depreciation rate δ of 1.5 per cent are taken from Kaplan, Mitman, and Violante (2020). I set the housing supply elasticity to $\phi = 2.5$, which is slightly above the long-run elasticity estimated by Aastveit, Albuquerque, and Anundsen (2020) for the 2012–2016 period (they estimate a long-run elasticity of 2.2). I set the smallest owner-occupier house size (h_2) equal to the 25th percentile owner-occupied house value from the 2019 SCF (\$130 000). I then somewhat arbitrarily set $h_3 = 1.75h_2$ and $h_4 = 1.75h_3$. I set the smallest rental property size (h_1) to be roughly half the size of the smallest owner-occupied house. Finally, I set the investment property size $\underline{i} = \$150\ 000$ to equal the median investment property value from the 2019 SCF.

Initial distribution of assets and income. I loosely follow Kaplan and Violante's (2014) procedure for initializing the initial income/asset distribution. Let $\{z_i\}_{i=1}^{5}$ be the discretized idiosyncratic income grid that I use to solve the model numerically (with $z_i > z_{i-1}$). I allocate age $j = 1$ households across the 5 income states such that the initial standard deviation of idiosyncratic income is 0.42 by integrating the area under the normal density function using a Tauchen-type approach. This procedure yields a discrete probability mass function, which is rougly given by $p(z_2) = p(z_4) = 0.16$,

$p(z_3) = 0.68$ and $p(z_1) = p(z_5) = 0$. I use these probabilities to split the sample of households in the 2019 SCF with heads aged 21–29 into three groups based on their labor income: the bottom 16 per cent, the middle 68 per cent, and the top 16 per cent. Within each income group, I initialize a fraction of agents with zero assets to match the fraction in the data, and the rest are endowed with liquid assets equal to median net worth conditional on having positive net worth in the data.

1.3.2. Fitted parameters

I calibrate the remaining six parameters listed in Panel B of Table 1.1 to minimize the sum of squared per cent deviations of six steady state moments from their empirical counterparts in the 2019 SCF. The targeted moments, along with the fitted and empirical values, are listed in Table 1.2. I follow Hu (2021) and exclude households whose net worth is above the 95th percentile when computing the empirical moments in the SCF because housing is a less important savings vehicle for these households.

The computed parameters are jointly identified, but nonetheless I outline which moments do most of the work in pinning down each parameter value. I compute an annualized discount factor $\beta = 0.90$ to match the ratio of median net-worth to median labor income of 1.18. The preference weight for housing in the utility function $\alpha = 0.85$ is computed to match the home ownership rate of 0.65. The strength of the bequest motive $B = 16.98$ is computed to match that households older than 65 have 1.93 times more wealth than younger households. The mean utility cost of investing $\lambda = 0.96$ is computed to match the investor rate of 0.13, and the investor monitoring cost $\gamma = 0.04$ is computed to match the fraction of investors with an outstanding investor mortgage of 0.37. Finally, I compute the rental firm's marginal cost to be $q = 0.07$ (which is equivalent to the annual rental rate of housing in equilibrium) to match the home ownership rate of under-35s of 0.36. Table 1.2 shows that the model matches the targeted moments reasonably well, except the home ownership rate is a little too high.

Table 1.1: Parameter Values

Parameter	Description	Value
	A. Assigned	
J	Length of life (years)	60
J^{ret}	Working life (years)	44
σ	Relative risk aversion	2
ρ	Autocorrelation of earnings	0.97
σ_ϵ	SD of earnings shocks	0.2
ζ	Replacement rate in retirement	0.5
δ	Depreciation rate	0.015
r	Risk-free rate	0.03
r_h	Owner-occupier mortgage rate	0.044
r_i	Investor mortgage rate	0.049
θ_h	Owner-occupier LTV limit	0.85
θ_i	Investor LTV limit	0.85
θ_y	PTI limit	0.45
κ_m	Mortgage origination cost ($ ‘000)	3
κ_s	Transaction cost of selling house	0.07
$\widetilde{\mathcal{H}}$	Rental housing grid ($ ‘000)	$\{61, 130, 228\}$
$\mathcal{H}$	Owner-occupied housing grid ($ ‘000)	$\{130, 228, 398\}$
$\underline{i}$	Investment property size ($ ‘000)	150
ϕ	Housing supply elasticity	2.5
	B. Calibrated	
β	Discount factor	0.90
α	Nondurable consumption weight in utility	0.85
B	Strength of bequest motive	16.98
λ	Mean utility cost of investing	0.96
γ	Investor monitoring cost	0.04
q	Rental firm marginal cost	0.07

Notes: The model period is two years. All values for which the time period is relevant (interest rates, discount factor, depreciation, rental firm marginal cost, earnings process parameters) are annualized.

Table 1.2: Moments Targeted in Calibration

Targeted moment	Data	Model
Median net-worth / median labor income	1.18	1.17
Home ownership rate	0.65	0.69
Mean net-worth, ages 65+ / mean net-worth, ages <65	1.93	1.92
Investor rate	0.13	0.13
Fraction of investors with an investor mortgage	0.37	0.37
Home ownership rate, ages < 35	0.36	0.37

Notes: Data moments are from the 2019 SCF, excluding households above the 95th percentile of wealth. Model moments are computed from the stationary distribution.

1.4. Testing the Model

In this section I use a numerical example to illustrate the underlying mechanisms that drive household behavior in the model.[10] I then evaluate how well the model matches various non-targeted moments, focusing on the characteristics of investors.

1.4.1. Household behavior in the model

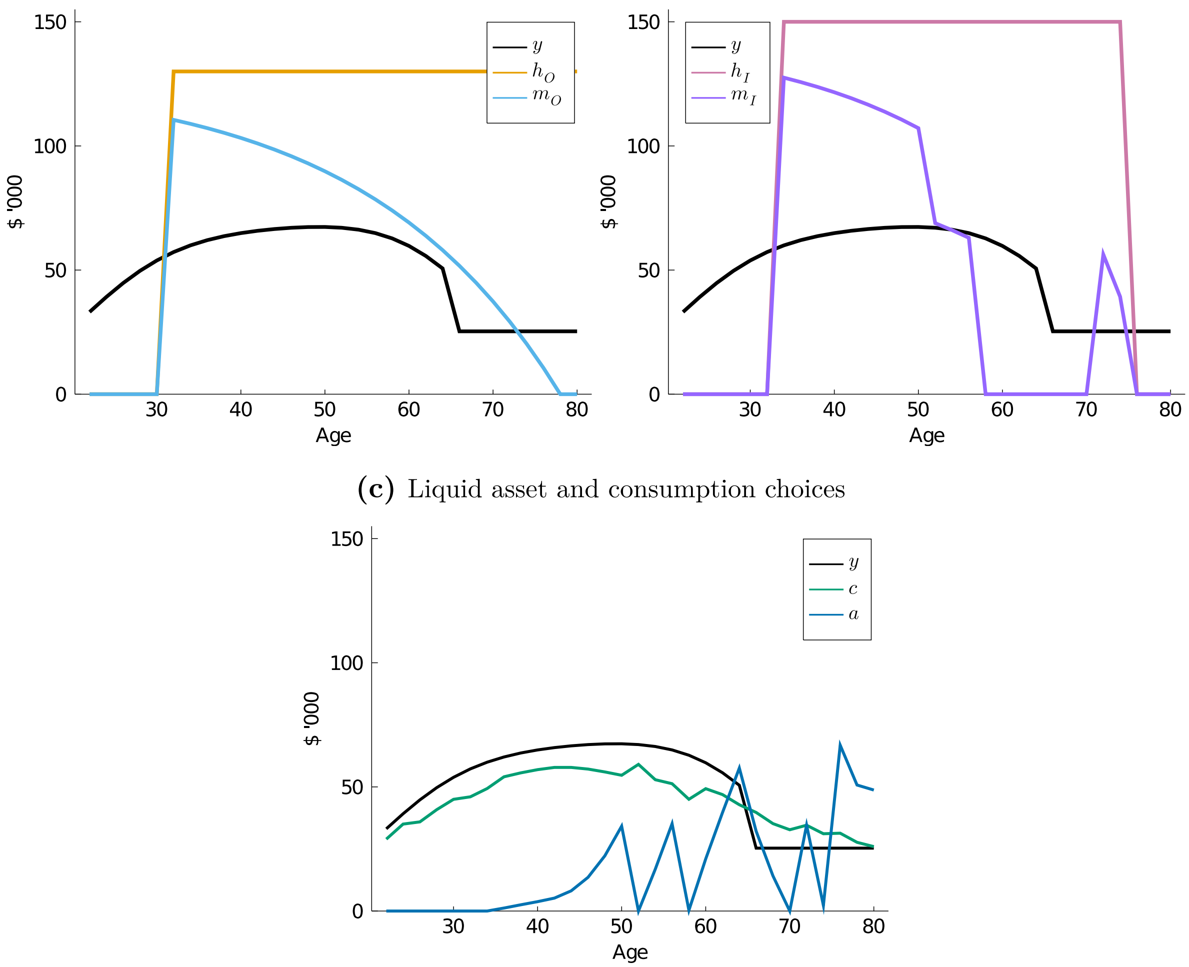
Figure 1.1 shows housing, mortgage, and consumption decisions for a household who starts life with no assets and recieves an idiosyncratic income shock (z_j) equal to zero in all periods of her working life. To highlight investment decisions, I assume that there is no utility cost of investing.[11] The household begins life by renting, buys a house at age 30, and pays off its owner-occupier mortgage over their remaining life (Panel (a)). In the period after buying its home, the household purchases an investment property (Panel (b)). Since there is no utility cost of investing in this example, the household invests very early in life so that it can take advantage of the relatively high return on investment property for a long period (see below). The household pays down its investor mortgage debt more rapidly than its owner-occupier mortgage, because the interest rate on the investor mortgage is higher. Panel (c) shows that the household builds up liquid assets in order to pay off large chunks of its investor mortgage during her fifties. After repaying its investor mortgage in her late fifties, the household starts accumulating

[10] My discussion of household behavior in the model draws on the discussion in Section 4.1 of Kaplan and Violante (2014).

[11] In other words, I assume $\lambda \approx 0$. All other parameters are at their calibrated values from Table 1.1.

liquid assets to fund consumption in retirement. Towards the end of her life the agent extracts equity in her investment property to smooth consumption, first by cash-out refinancing her investor mortgage and then by selling (Panel (b)).

Figure 1.1: Example Household Behavior in the Model



(a) Owner-occupied housing/mortgage choices

(b) Investment housing/mortgage choices

(c) Liquid asset and consumption choices

User cost of housing and investment returns. The household behavior depicted in Figure 1.1 is ultimately driven by asset returns in the model. Table 1.3 shows the user cost of owning a house and the one-period return on investment property, abstracting from debt financing and transaction costs. The user cost of owning is lower than the calibrated rental rate, which is the main incentive for owning a home in the model.

The return on investment property is substantially higher than the return on the one-period bond, which encourages households to invest. However, the indivisibiltiy of the investment property with $\underline{i} >> 0$ and the utility cost imply that investing is out-of-reach for most owner-occupiers in the model.

Table 1.3: User Costs of Housing and Investment Returns
Per cent, annual

User cost of owning (LTV = 0)	4.2
User cost of owning (LTV = 0.85)	5.3
Rental rate (p_r)	6.8
Investment return	5.3
Risk-free rate (r)	3.0

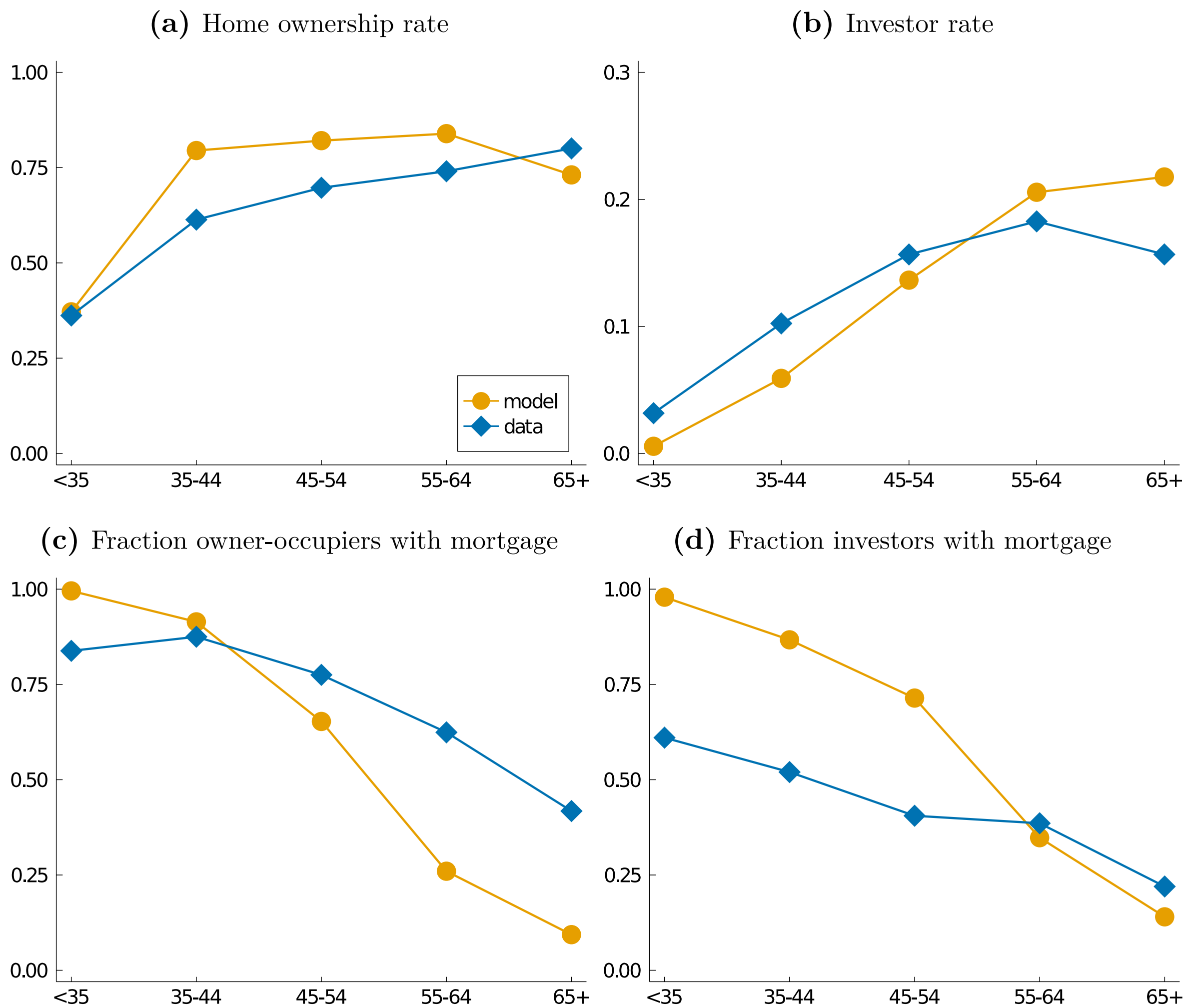
Notes: User cost of owning and rental rate are a per cent of the house price. The user cost of owning reported here ignores transaction costs. The investment return is the annualized one-period return abstracting from debt financing and transaction costs.

1.4.2. Model vs. data

Life-cycle statistics. Figure 1.2 shows the life-cycle profiles of home ownership, investment ownership, and outstanding mortgage debt in the model and the 2019 SCF. The model does a decent job of matching the rise in home ownership and investment ownership over the life-cycle. However, there are too many middle-aged home owners and too many old investors in the model, compared to the data. The model also generates a decline in the fraction of owner-occupiers and investors with outstanding mortgage debt over the life-cycle, which broadly matches the pattern in the data. However, in the model the fraction of older owner-occupiers with outstanding debt is too low and the fraction of younger investors with outstanding debt is too high. But note that younger households make up only a very small share of investors – in the model and the data – as discussed below.

Characteristics of investors. Since this paper tries to get at how tighter regulation of investment property purchases may affect the characteristics of investors, the baseline model should do a decent job of matching those characteristics in the data. Figure 1.3

Figure 1.2: Life-cycle Statistics



shows the distributions of investors by age and income quintile in the model at the 2019 SCF. In the model and data investment ownership is skewed towards older and higher-income households. Figure 1.4 shows that the model also does a good job of matching the decline in LTV for investor mortgagors over the life-cycle.

Figure 1.3: Distributions of Investors

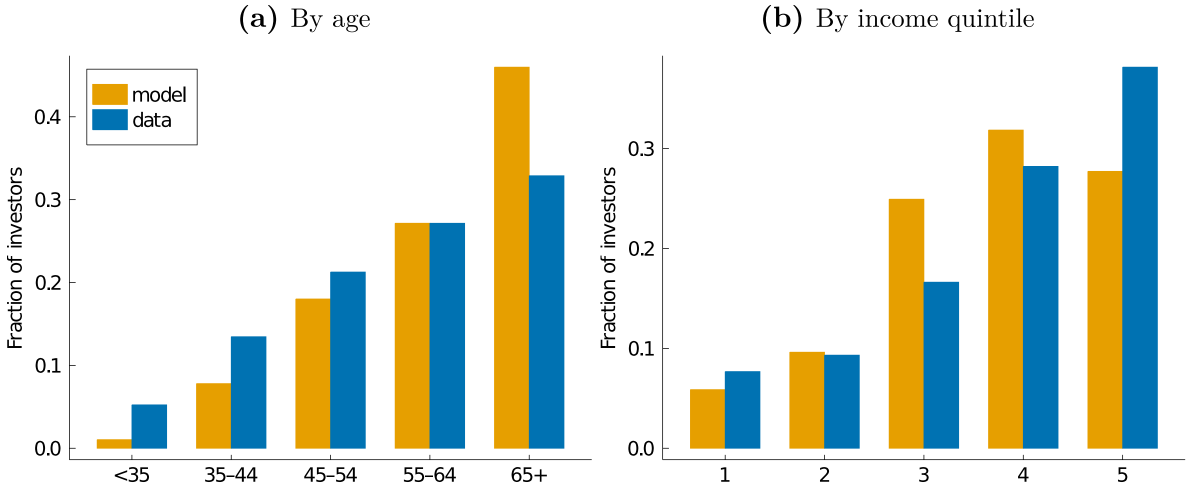
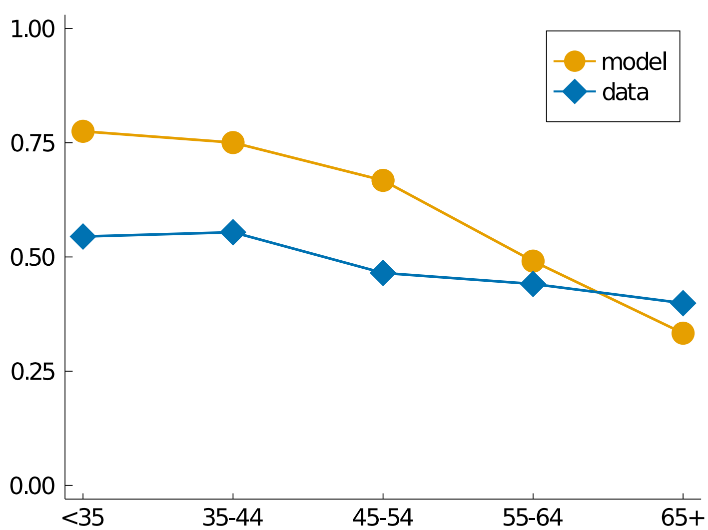


Figure 1.4: Mean Investor LTV by Age



1.5. Impact of Tighter Regulation on Investor Characteristics

I now study how tighter restrictions on investment property purchases affect the characteristics of investors in the model's steady state. I consider three fairly large and permanent policy changes, summarized in Table 1.4: (1) a reduction in the LTV limit on investor mortgages from 0.85 to 0.75; (2) an increase in the investor mortgage rate from 4.9 per cent to 5.4 per cent; and (3) a transaction tax of 5 per cent on investment property purchases (there is no tax in the baseline economy). To highlight the direct effects of tightening restrictions, in this section I assume that the house price does not respond to the policy changes.

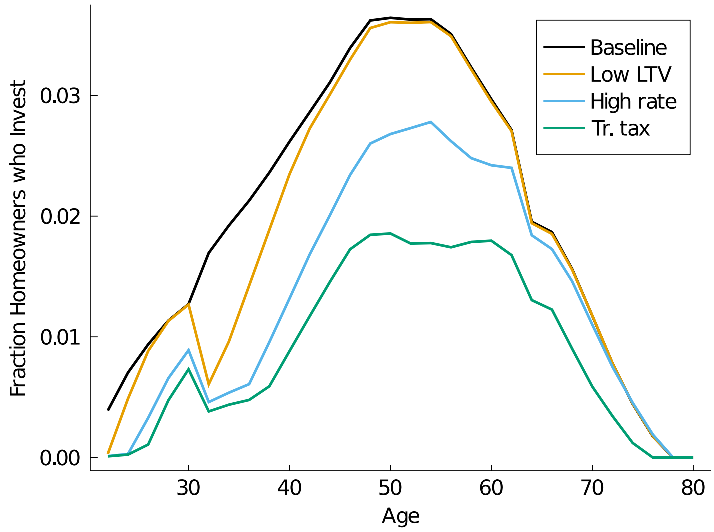
Table 1.4: Parameterization of Permanent Policy Changes

	θ_i	r_i (%)	τ
Baseline	0.85	4.9	0
Low LTV	**0.75**	4.9	0
High rate	0.85	**5.4**	0
Transaction tax	0.85	4.9	**0.05**

Figure 1.5 plots the fraction of owner-occupier households at each age who invest (the investment hazard) in the baseline and three counterfactual economies with tighter regulation. There are a few takeaways. First, under tighter regulation, owner-occupiers are less likely to invest at all ages than they are in the baseline economy. In other words, tighter regulation reduces investment demand, as expected. Second, lowering the LTV has a much smaller impact on the investment hazard compared to the higher mortgage rate and transaction tax. For ages above 50, the investment hazard in the low LTV economy essentially overlaps with the baseline hazard. The relatively muted impact of the low LTV policy is one of the main quantitative findings of this paper, and will be echoed in the results presented in the remainder of the paper. Finally, in all cases the probability of investing peaks at around 50–55 years old, consistent with the peak of the age-profile of earnings.

Panels A and B of Table 1.5 report the average age and balance sheet composition of investors in the period that they invest (new investors), and of all owners of investment property across policies. Unsurprisingly, when tighter regulation is in place, investors

Figure 1.5: Investment Hazard



– both in the period that they invest and overall – are, on average, older, have higher incomes, and are more wealthy, compared to the baseline economy. That being said, lowering the LTV has little impact on the financial holdings of new investors, compared to the higher mortgage rate and transaction tax. For example, the average net worth of new investors is around $100 \times (255/240 - 1) = 6$ per cent higher than baseline in the low LTV economy, compared to $100 \times (342/240 - 1) = 43$ per cent higher in the transaction tax economy. Tighter regulation also reduces the indebtedness of households who choose to invest, and the level of investor mortgage debt they take on. For example, under the transaction tax policy 35 per cent of new investors have an outstanding owner-occupier mortgage, compared to 54 per cent of new investors in baseline. The higher mortgage rate and transaction tax reduce the average investor's LTVs on their main home and their investment property by about half. Lowering the LTV also lowers the indebtedness of the average investor, but to a much lesser extent than the other policies.

Tighter regulation shifts the distribution of investors towards older households (Figure 1.6). Under the higher mortgage rate and transaction tax policies, the share of investors aged 65+ is around 9 percentage points higher than baseline. Similarly, tighter regulation shifts the distribution of investors towards higher-income households (Figure 1.7). Under the higher mortgage rate and transaction tax policies, the share of working-age investors in the highest income quintile is around 10 and 15 percent-

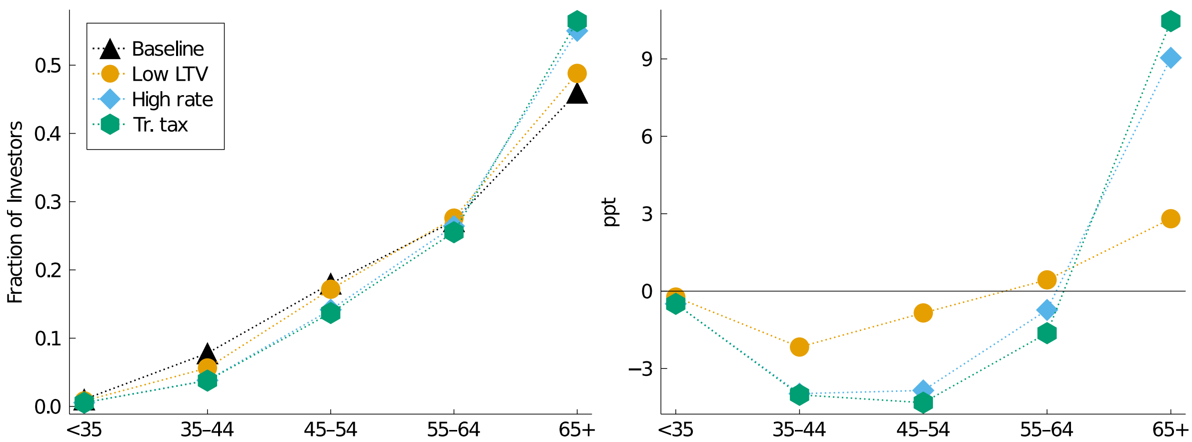
Table 1.5: Characteristics of Investors Across Policies

	Baseline	Low LTV	High rate	Tr. tax
A. New investors$^{(a)}$				
Mean age	49	50	52	51
Mean income ($ '000)	95	98	109	118
Mean liq. assets ($ '000)	90	97	124	137
Mean home value ($ '000)	209	213	228	243
Mean net worth ($ '000)	240	255	310	342
Frac. with owner-occ. mortgage	0.54	0.51	0.40	0.35
Mean LTV on main home	0.36	0.33	0.25	0.21
B. All investors				
Mean age	61	62	64	64
Mean income ($ '000)	92	96	106	114
Mean liq. assets ($ '000)	60	65	76	85
Mean home value ($ '000)	204	208	223	236
Mean net worth ($ '000)	347	366	413	440
Frac. with owner-occ. mortgage	0.41	0.36	0.25	0.18
Frac. with investor mortgage	0.37	0.33	0.19	0.17
Mean LTV on main home	0.23	0.20	0.13	0.10
Mean LTV on investment	0.21	0.18	0.10	0.10

Notes: The reported statistics are computed from the stationary distribution of the model, assuming a fixed house price across policies. The statistics for new investors correspond to the period in which a household invests, so the balance sheet items do not reflect investment property holdings.

Figure 1.6: Distribution of Investors by Age

(a) Levels **(b)** Difference from Baseline



age points higher than baseline, respectively. While lowering the LTV has the same qualitative effect as the other policies, quantiatitvely, it produces little change in the distribution of investors by age or income.

Figure 1.7: Distribution of Investors by Income Quintile

(a) Levels **(b)** Difference from Baseline

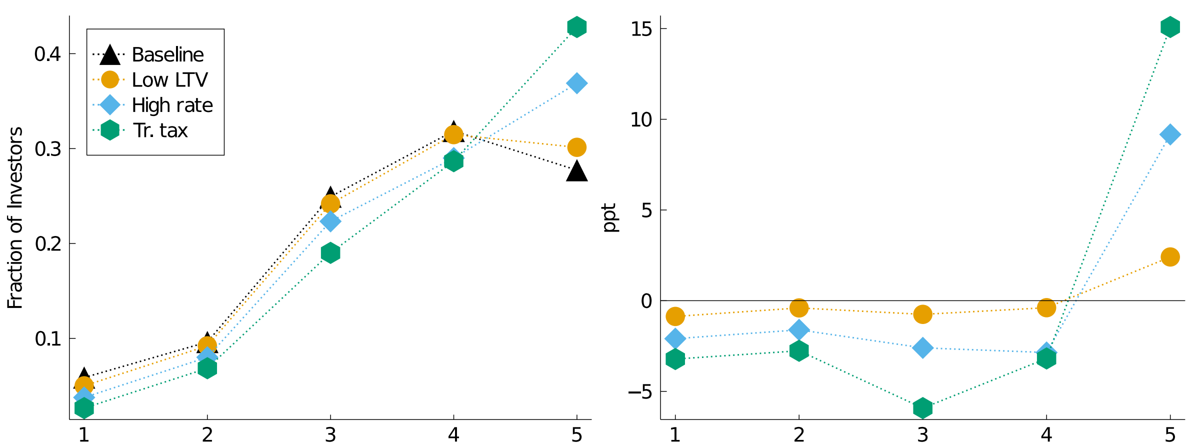
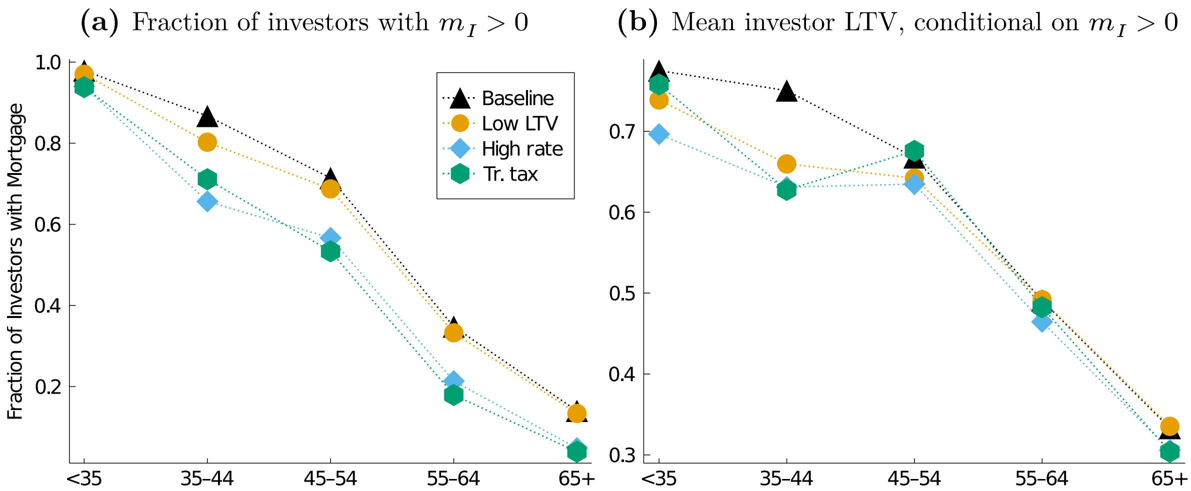


Figure 1.8 plots two measures of investor leverage by age. Panel (a) shows the fraction of investors with an investor mortgage by age (the extensive margin of debt); and panel (b) shows the average LTV on investment property by age of the investor, conditional

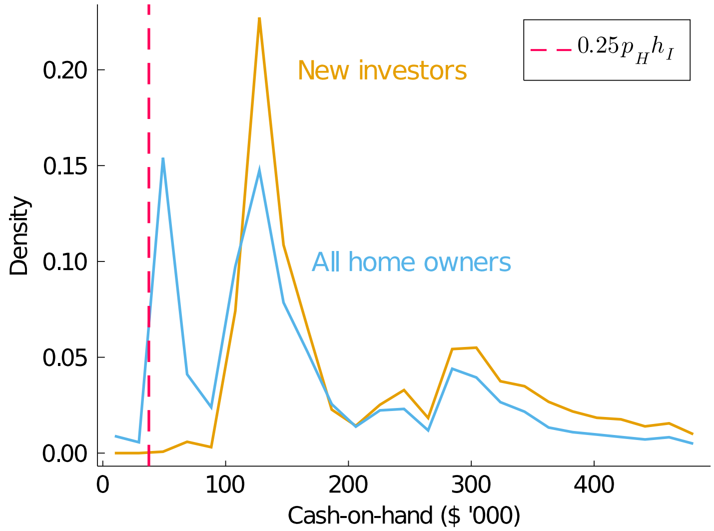
Figure 1.8: Investor Leverage by Age



on having an investor mortgage (the intensive margin of debt). The key takeaway is that the higher mortgage rate and transaction tax mainly reduce investor indebtedness via the extensive margin. Under these policies, new investors are richer compared to baseline, on average, so they are more likely to be cash buyers. In contrast, the leverage of investors with an outstanding investor mortgage is quite similar across policies.

Why does permanently lowering the investor LTV limit have little effect on the characteristics of investors? The reason is straightforward: most new investors are not constrained by the larger downpayment requirement. Figure 1.9 plots the distribution of cash-on-hand (defined as the sum of income and liquid assets brought into the period) for new investors and all home owners in the baseline economy. All new investors have cash-on-hand in excess of minimum 25 per cent investor mortgage downpayment required under the lower LTV limit. Accordingly, the lower LTV limit has little effect on who invests.

Figure 1.9: Baseline Cash-on-Hand Distribution



1.6. Equilibrium Consequences of Tighter Investor Regulation

I next evaluate the possible equilibrium impact of the permanent tightening of investor restrictions. Consistent with the partial equilbrium results above, I find that the higher mortgage rate and transaction tax have larger effects on the house price, home ownership and debt levels than lowering the LTV limit. However, only the transaction tax lowers the house price enough to meaningfully raise the home ownership rate, which is driven by higher ownership among young mid-income households.

1.6.1. Equilibrium concept and constant rent assumption

I focus on comparing stationary equilibria of the model, where the house price is allowed to vary across equilibria but rents are fixed. I relegate the formal definition of equilibrium to the appendix, but give a description here. In the baseline stationary equilibrium I fix $p_h = 1$. Given the house price and model parameters, I solve the household's problem. The aggregate housing stock in the baseline equilibrium is then simply given by the overall demand for owner-occupier and investor housing.[12] When comparing stationary

[12]In other words, housing supply is perfectly elastic in the initial equilibrium.

equilibria, the aggregate housing stock is fixed at this baseline level, with the house price adjusting so that the market clears.[13] Importantly, I do not include demand for rental units in the housing market clearing condition, which determines the house price, and assume that the rental firm's marginal cost q, which controls the rental rate rate p_r, remains fixed at its calibrated level in the baseline steady state.[14] This assumption implies that tighter regulation of investors will affect aggregate housing demand, as less households invest, and lead to a lower house price, and price-to-rent ratio, which raises home ownership.

The assumption of constant rents is stark, but greatly simplifies the analysis since it means that I do not have to solve for an equilibrium rental rate. I also suspect that endogenizing rents would not materially affect my quantitative results because the price-to-rent *ratio* largely determines households' housing tenure and investment decisions in the model. In a setting where the rental rate adjusts to clear the rental market, tighter regulation of investors would raise rents (due to the reduction in the supply of rental properties).[15] In this setting, the house price would still need to fall so that the housing market clears, but would fall by less than in my model with constant rents (since the reduction in investor demand due to tighter regulation would be partly offset by higher rental income). Thus, with tighter regulation in place, the house price and rental rate would *both* be higher in a setting with endogenous rents, compared to a model with constant rents, suggesting that the price-to-rent ratio could end up being quite similar across the two settings. As Guren, Krishnamurthy, and McQuade (2021) note, in the data, changes in the price-to-rent ratio largely reflect changes in house prices, not rents, suggesting that my constant rent assumption may not be too far from the mark.

[13] While the aggregate housing stock is fixed across equilibria, its composition between owner-occupier and investor housing is allowed to vary.

[14] Garriga and Hedlund (2020) and Guren, Krishnamurthy, and McQuade (2021) also assume that rents are fixed but house prices vary in their equilibrium models of the housing market.

[15] A common approach in the literature is to assume that a user-cost equation pins down the rental rate for a given house price (for example, see Kaplan, Mitman, and Violante (2020) and Karlman, Kinnerud, and Kragh-Sorensen (2021)). This assumption gets around the issue of having to jointly solve for an equilibrium rental rate and house price to clear two markets, but implies a positive correlation between the steady state house price and rental rate. Accordingly, modelling the rental rate in this way would be inappropriate for my analysis because a reduction in investor demand would be expected to lower prices and raise rents.

Table 1.6: **Aggregate Effects of Tighter Investor Regulations**

	Baseline	Low LTV	High rate	Transaction tax
House price	1.000	0.998	0.992	0.989
Home ownership rate	0.691	0.691	0.693	0.711
Investor rate	0.126	0.117	0.094	0.069
M/Y	0.661	0.642	0.613	0.625
M_I/Y	0.061	0.048	0.026	0.020
M_O/Y	0.600	0.594	0.587	0.605
LTV	0.327	0.317	0.302	0.300

1.6.2. Results

Table 1.6 shows the aggregate effects of tighter investor regulations under my equilibrium assumptions of a fixed aggregate housing stock and fixed rental rate. As explained above, with tighter regulation in place, the investor rate declines, the house price falls, and home ownership increases. The higher mortgage rate and transaction tax raise the home ownership rate by around 0.2 and 2 percentage points, respectively. Interestingly, despite a lower house price, the level of outstanding owner-occupier debt is slightly higher than baseline under these two policies. All three policies reduce the level of outstanding investor debt in the economy, with the low LTV policy reducing investor debt by around 20 per cent compared to baseline, and the high rate and transaction tax more than halving the level of investor debt. Consistent with the partial equilibrium analysis in Section 5, lowering the LTV has little effect on the investor rate, and hence the house price and home ownership.

The increase in aggregate home ownership under the transaction tax is almost entirely driven by higher home ownership among younger households, whose tenure decisions are most sensitive to changes in the price-to-rent ratio (Figure 1.10). The transaction tax raises the home ownership rate of households aged under 35 by around 6 percentage points. This increase in home ownership among under 35s is concentrated in the middle income quintile (Figure 1.11).

Finally, the increase in home ownership among under 35s results in a shift in the distribution of total mortgage debt outsanding in the economy towards these younger mortgagors (Figure 1.12). The increase in debt taken out by younger first-home buyers

Figure 1.10: Home Ownership Rates by Age

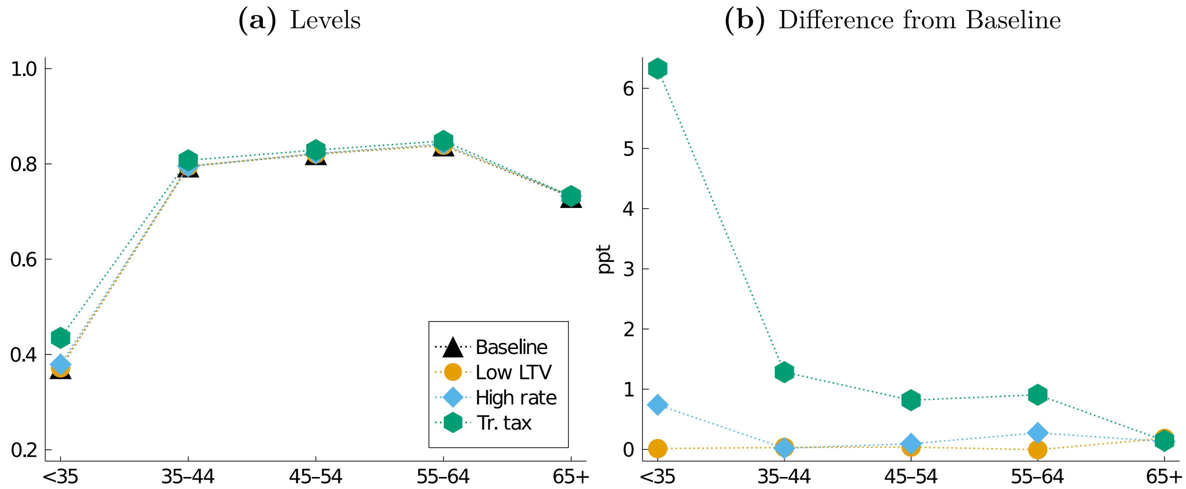
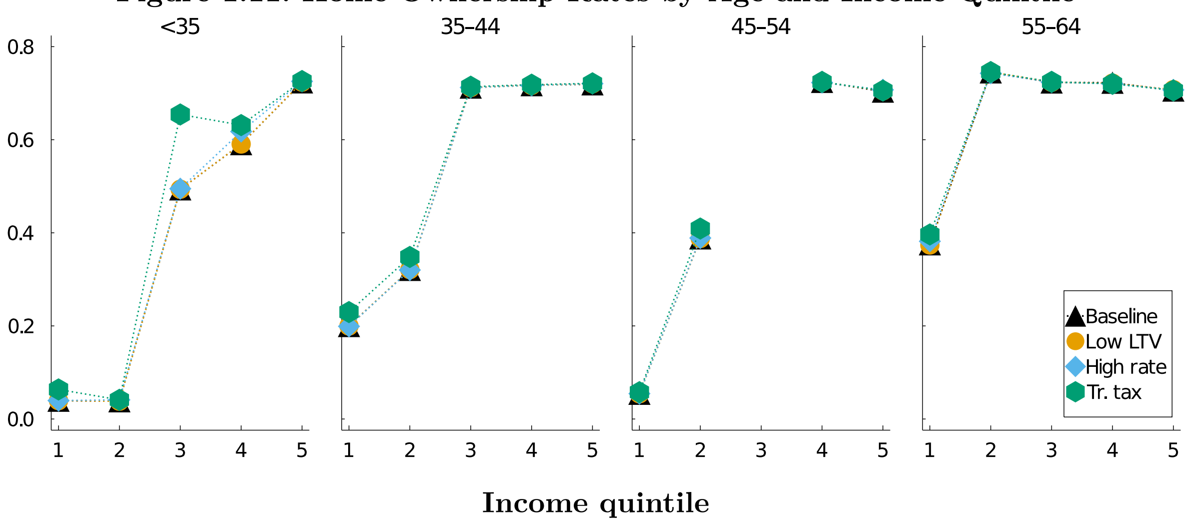


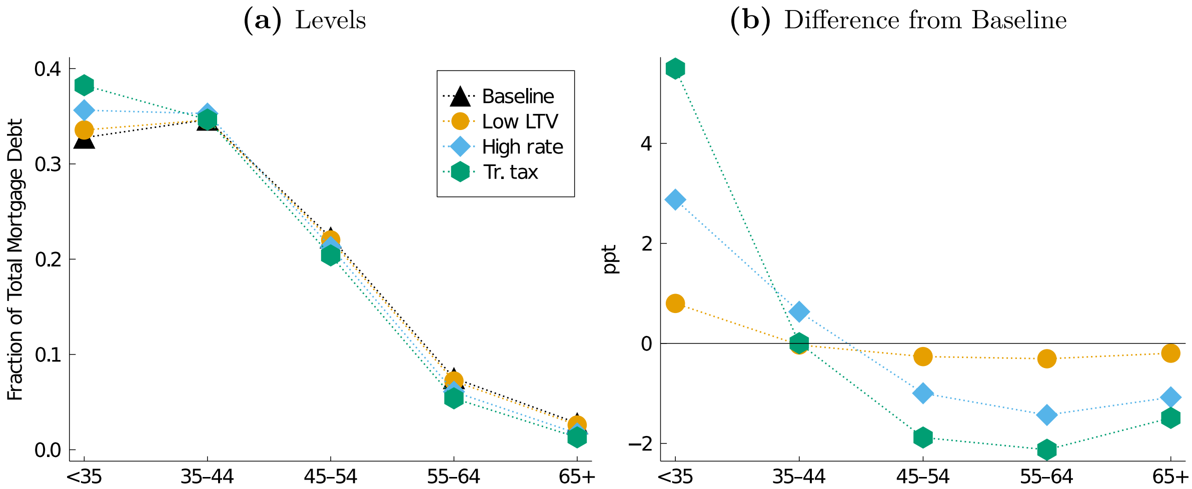
Figure 1.11: Home Ownership Rates by Age and Income Quintile



Note: In my calibrated income process it turns out that there is no overlap between the third income quintile and the 45–54 age group, hence the missing observations in this cell.

explains why the overall level of owner-occupier debt is slightly higher than baseline in the transaction tax economies, despite a lower house price.

Figure 1.12: Distribution of Total Mortgage Debt by Age



1.7. Conclusions

I extend a standard incomplete markets life-cycle model to include housing investors and investor mortgages to study tightened regulation of investment property purchases. The model suggests that raising investor mortgage rates or imposing a transaction tax on investment purchases can substantially reduce demand for investment property. By making it more costly to invest, these two policies shift the distribution of investors towards older, higher-income, and wealthier households. Furthermore, if a reduction in investor demand lowers the price-to-rent ratio, as I assume in the equilibrium analysis, then tighter regulation of investor purchases can lead to higher home ownership. The question is whether this possible redistribution of the housing stock from investors to owner-occupiers, as a result of tighter regulation, is quantitatively important. The model suggests that it is in the case of the transaction tax, which raises the overall home ownership rate by 2 percentange points, reflecting higher home ownership among young mid-income households. In contrast, I find that lowering the LTV limit on investor mortgages has little effect on investment demand and the characteristics of investors because most investors are not constrained by the higher downpayment requirement. Accordingly, in the model a permanently lower investor LTV limit also has little effect on home ownership in equilibrium.

My analysis suggests a couple of ideas for future research. Building on a recent empirical literature documents the increase in investor activity over the mid-2000s housing boom, a dynamic analysis could look at whether tighter regulation of investors would have been effective as a boom-mitigation tool.[16] Taking this notion further, one could envisage a model where households have heterogenous house price beliefs and the most optimisitic invest. It seems possible that by reigning-in the optimists in such an environment tighter regulation of investors could have larger effects on house prices than in a model without heterogenous beliefs, like the one in this paper. Finally, incorporating endogenous default would open the door to studying how effective these policies would be at lowering aggregate default rates, given that investors are more likely to default than owner-occupiers.

[16]For example, Haughwout, Lee, Tracy, and Klaauw (2011) and Bhutta (2015) use credit report data to show that borrowing by investors was a key driver of mortgage credit growth over 1999–-2007. Chinco and Mayer (2016), Gao, Sockin, and Xiong (2019), García (2019) and Mian and Sufi (2021) use geographically disaggregated data to show that the increase in investor activity contributed to the increase in house prices over this period.

Chapter 2

Stuck at Home: Housing Demand During the COVID-19 Pandemic

William Gamber, James Graham and Anirudh Yadav

The COVID-19 pandemic induced an increase in both the amount of time that households spend at home and the share of expenditures allocated to at-home consumption. These changes coincided with a period of rapidly rising house prices. We interpret these facts as the result of stay-at-home shocks that increase demand for goods consumed at home as well as the homes that those goods are consumed in. We first test the hypothesis empirically using US cross-county panel data and instrumental variables regressions. We find that counties where households spent more time at home experienced faster increases in house prices. We then study various pandemic shocks using a heterogeneous agent model with general equilibrium in housing markets. Stay-at-home shocks explain around half of the increase in model house prices in 2020. Lower mortgage rates explain around one third of the price rise, while unemployment shocks and fiscal stimulus have relatively small effects on house prices. We find that young households and first-time home buyers account for much of the increase in housing demand during the pandemic, but they are largely crowded out of the housing market by the equilibrium rise in house prices.

2.1. Introduction

Why have US house prices grown so rapidly during the COVID-19 pandemic? Dramatic increases in uncertainty about health, the macroeconomy, and social circumstances might have predicted a sharp downturn in housing markets.[17] But house prices increased by around 10 percent in real terms in 2020, and rose by 15 percent in the year to July 2021 (see Figure 2.1). Housing demand is likely to have been affected by a range of pandemic-related factors. While unemployment increased, real borrowing costs declined and the US government provided substantial fiscal stimulus.[18] Household activities and consumption patterns also changed dramatically. In particular, households spent much more of their time and money at home. In this paper, we argue that the greater utilization of housing was associated with a significant increase in the demand for and valuation of houses. In particular, we study the extent to which stay-at-home shocks explain the rise in house prices during the pandemic.

Our paper presents both empirical evidence and quantitative modelling analysis that show that the shift towards at-home activity was associated with a significant increase in house prices. First, we document large and persistent shifts towards household time spent at home and expenditures on at-home consumption during the pandemic. We then provide cross-sectional evidence that counties with larger increases in time spent at home also experienced faster house price growth. Second, we build a heterogeneous agent model with general equilibrium in housing markets to study the quantitative importance of stay-at-home shocks during the pandemic. In the model, households consume goods away-from-home, goods at-home, and housing services. We model a stay-at-home shock as a change in consumption preferences that is consistent with the observed shift towards at-home consumption during the pandemic. Since at-home goods and housing services are consumed together, the shock also raises the demand for housing and increases house prices in equilibrium. In a series of dynamic pandemic experiments, we find that stay-at-home shocks account for nearly half of the overall rise in house prices during 2020.

[17] For example, the Mortgage Bankers Association cited macroeconomic uncertainty as the main reason for a sharp tightening of mortgage credit in March and April 2020. See https://www.mba.org/2020-press-releases/may/mortgage-credit-availability-decreased-in-april.

[18] On the variety of fiscal policies enacted and their various effects see, for example, Carroll et al. (2020), Devereux et al. (2020), Faria-e-Castro (2021), and Lacey, Massad, and Utz (2021).

We begin by studying changes in consumption patterns and time-use during the pandemic. Using household-level micro-data from the Consumer Expenditure Survey (CEX), we show that at-home consumption expenditure rose significantly in 2020. The share of food expenditure on food consumed at home rose from around 65 percent to around 70 percent during 2020. We construct a measure of non-durable goods and services consumption, and we show that the away-from-home share of non-durables fell by 4 percent, while the at-home consumption and housing services shares rose by around 2 percent each.[19] These changes in consumption patterns are also reflected in changes in the time that households spent at home and away from home. Drawing on measures of household mobility from Google Mobility Reports, we show that households spent around 10 percent more time at home on average during the pandemic in 2020.

We then provide cross-sectional regression evidence that more time spent at home is associated with greater housing demand. Using monthly county-level data from 2020, we regress real house price growth on time spent at home as well as the number of visits to retail and recreational locations. In addition to controlling for a range of potentially confounding factors, we also make use of a plausibly exogenous instrument for changes in household mobility. We construct a shift-share instrument by combining the county-level share of jobs that can be performed at home (Dingel and Neiman, 2020) with state-level measures of pandemic intensity (Hale et al., 2021). Both our OLS and 2SLS results suggest a strong positive relationship between household mobility and house price growth during the pandemic.

Next, we build a structural model of the housing market to rationalize our empirical evidence and quantitatively assess the overall contribution of stay-at-home and other macroeconomic shocks to house price growth during the pandemic. Our model features heterogeneous households that consume goods away from home, goods at home, as well as housing services. We assume that at-home goods and housing services are consumed as part of a home bundle, while away-from-home goods are imperfect substitutes for this bundle. We model stay-at-home shocks during the pandemic as a shift in preferences towards consumption of the home bundle, which in-turn causes an increase in demand

[19]While food expenditures reported in the CEX are explicitly categorized into at-home and away-from-home consumption, other expenditures are not. We show that the changes in our measures of non-durable expenditure shares are robust to different assumptions about which goods and services are consumed away-from-home or at-home. See Section 2.2.2 and Appendix B.1 for details.

for both at-home goods consumption as well housing services.[20] Housing may either be rented or purchased with the help of mortgage financing. Households are subject to both idiosyncratic income shocks and age-dependent employment shocks. Homeowners are also limited in how much they can borrow, which affects their ability to smooth consumption over time. We calibrate the model to match pre-pandemic statistics on unemployment, income, homeownership, wealth, and consumption expenditure shares.

We model the pandemic as a collection of four shocks that hit the economy in 2020 and 2021 and study the dynamics of housing demand over this period. In addition to the preference shocks that induce households to consume more at home, we include a negative shock to mortgage interest rates, a spike in unemployment, and large fiscal transfers in the form of stimulus checks and expanded unemployment benefits. Our calibrated pandemic shocks are sufficient for our model to match the excess rate of house price growth observed in 2020. We use the model to decompose the increase in house prices into contributions from each of the shocks, and to shed light on the underlying sources of the rise in housing demand. The model suggests that stay-at-home shocks to preferences explain nearly half of the overall increase in house prices in 2020. Declining mortgage interest rates explain a little over a third of the house price increase, while unemployment shocks and fiscal stimulus have relatively small effects on house prices. We show that much of the increase in housing demand is driven by first-time home buyers, with some additional effect due to more existing homeowners upsizing and fewer existing homeowners downsizing. Finally, our model suggests that most of the underlying increase in housing demand comes from young households that would like to become homeowners. However, the general equilibrium rise in house prices crowds out many of these would-be buyers, which results in an overall decline in homeownership rates for the young during the pandemic. Overall, we find that the forces leading households to spend more of their time and money at home account for the bulk of the increase in housing demand observed during the pandemic.

Related literature. A growing literature explores the impact of COVID-19 on real estate markets. On the empirical side, several papers document that within cities housing demand shifted away from urban cores toward lower-density suburban areas during the

[20]This aggregate preference shock is consistent with a view of the pandemic in which households stay home to avoid falling ill to the virus, even in the absence of government directions to do so (see, for example, Chetty et al., 2020).

pandemic (Guglielminetti et al., 2021; Gupta et al., 2021; Liu and Su, 2021; Ramani and Bloom, 2021). Both Gupta et al. (2021) and Liu and Su (2021) show that house prices and rents grew faster in locations further from city centers. In addition, these changes in relative prices were larger in cities that had a higher fraction of jobs with which employees can work from home (WFH). Delventhal, Kwon, and Parkhomenko (2020) and Davis, Ghent, and Gregory (2021) use spatial equilibrium models of internal city structure and worker location choice to study the increase in WFH during the pandemic. Consistent with the intra-city empirical evidence, these models generate declining demand for inner-city housing relative to the rising demand for houses further from the city center.

Our paper also contributes to an understanding of the importance of stay-at-home shocks in driving housing market dynamics during the pandemic. However, we make two points of departure from the urban and real estate literature cited above. First, we do not model the impact of stay-at-home shocks on housing demand as explicitly arising from an increase in WFH. Rather, we model the effect of stay-at-home shocks through the complementarity between at-home consumption and housing services. Our motivation for exploring this channel is the large and persistent shift towards the consumption of goods and services at home during the pandemic, which we document in Section 2.2. This novel housing demand channel rationalizes our empirical finding that locations where households spent more time at home and less time at retail and recreation establishments experienced faster house price growth. Second, we study the aggregate effects of pandemic shocks on housing demand, rather than the reallocation of housing demand across space within a given market. Our focus on aggregate dynamics is motivated by the fact that the increase in house prices has been broad-based across US regions, and has occurred against the backdrop of other important aggregate shocks such as rising unemployment, falling real mortgage rates, and generous fiscal support. We use our quantitative model of the housing market to disentangle the effect of stay-at-home shocks on housing demand from the effects of these other aggregate factors.

The most closely related study to our own is in Diamond, Landvoigt, and Sánchez (2021). They model the endogenous effect of a decline in consumption of "in-person" goods on household incomes, and the subsequent spillover to the housing market. They show that absent government fiscal policies to support household incomes and temporarily delay mortgage foreclosures, aggregate income and consumption would have fallen, house prices would have declined, and mortgage defaults would have increased. Diamond, Landvoigt, and Sánchez (2021) model the COVID-19 shock as a shift in preferences away from "in-person" goods, which is similar to our choice to model the shock as a shift in preferences from away-from-home consumption and toward at-home consumption. The primary difference between the two papers is that we model housing services as complementary to at-home consumption which generates strong co-movement between the rise in demand for consuming at home and the consumption of housing services. Other smaller differences are that we abstract from mortgage default, the financial sector, and general equilibrium in goods markets, and Diamond, Landvoigt, and Sánchez (2021) adopt a two-agent spender-saver model while we employ a life-cycle heterogeneous agent model.

Our paper also relates to the much larger literature that uses quantitative macroeconomic models to study the effects of COVID-19 and the associated government policy responses. As in our model, the previous literature variously studies the effect of unemployment shocks (Carroll et al., 2020; Fang, Nie, and Xie, 2020), sectoral demand or supply shocks (Danieli and Olmstead-Rumsey, 2021; Faria-e-Castro, 2021; Graham and Ozbilgin, 2021; Guerrieri et al., 2021), and fiscal policies regarding unemployment insurance and transfer payments (Bayer et al., 2020; Carroll et al., 2020; Fang, Nie, and Xie, 2020; Faria-e-Castro, 2021; Kaplan, Moll, and Violante, 2020; Mitman and Rabinovich, 2020). While several of these papers build heterogeneous agent models to understand the role of the wealth distribution in the pandemic (for example, Carroll et al., 2020; Kaplan, Moll, and Violante, 2020; Nakajima, 2020), we specifically focus on the effects of pandemic shocks in a heterogeneous agent model with housing. We then study a novel sectoral demand (i.e. stay-at-home) shock which shifts consumption towards at-home goods while simultaneously increasing the demand for housing services. Our primary contribution is to show that these stay-at-home shocks account for nearly half of the overall increase in housing demand during the pandemic.

Finally, our quantitative analysis builds on a large and growing literature that embeds illiquid housing assets and mortgage finance decisions in incomplete markets models to study the interaction between aggregate fluctuations and the housing market (see, for example, Garriga and Hedlund, 2020; Guren, Krishnamurthy, and McQuade, 2021; Iacoviello and Pavan, 2013; Kaplan, Mitman, and Violante, 2020; Kinnerud, 2021). We extend the standard environment typically studied in these models by assuming households have preferences over a composite of away-from-home and at-home non-durable consumption goods, as well as housing services. Additionally, we incorporate life-cycle unemployment fluctuations, which do not typically feature in the existing literature. These additional features allow us to study the effects of changes in the composition of consumption, shocks to unemployment, and fiscal stimulus measures during the pandemic on outcomes in the housing market.

2.2. Motivating Evidence

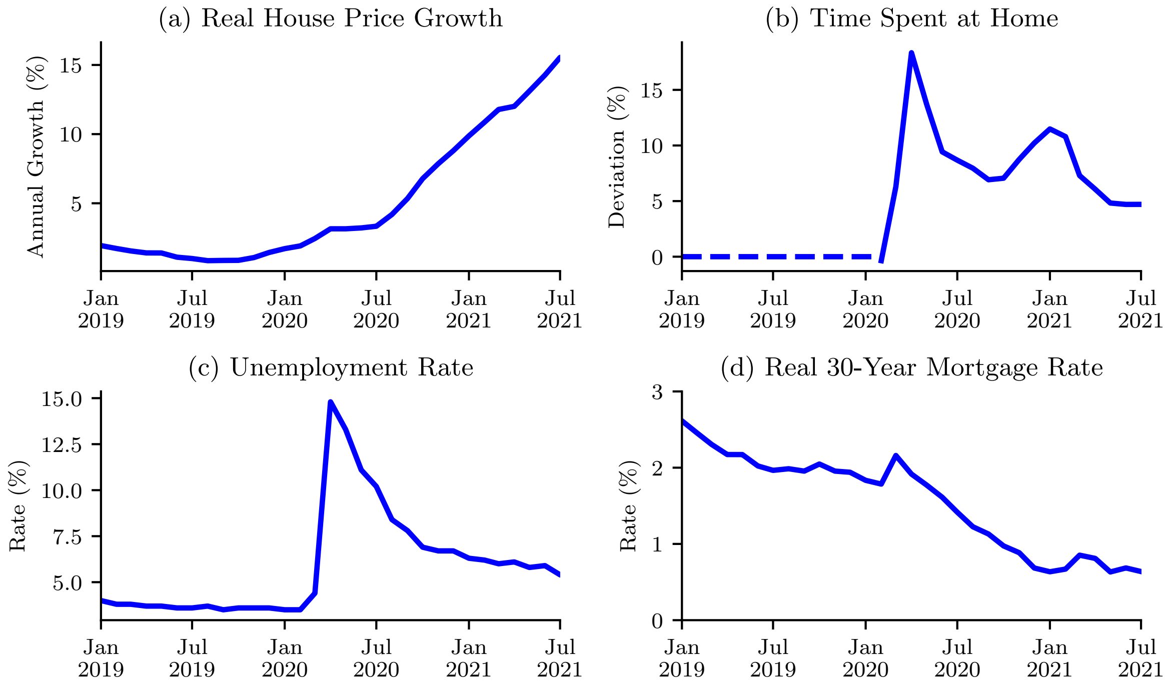
In this section, we document two related patterns in the data over the course of the pandemic. First, there was a significant acceleration of house price growth in the US. Second, households spent significantly more time at home and shifted expenditures towards at-home consumption of goods and services. We then provide cross-sectional evidence that more time spent at home is associated with faster house price growth.

We then study the relationship between house prices and time use in a county-month panel. To address concerns about endogeneity, we construct a shift-share instrument for time spent at home by interacting a county-level measure of the share of employment that could be carried out at home before the pandemic (Dingel and Neiman, 2020) with time-varying state-level measures of pandemic intensity. Our two-stage least squares estimates imply that counties with larger increases in time spent at home experienced significantly larger increases in house prices.

2.2.1. Aggregate trends during the pandemic

Figure 2.1 depicts the evolution of four key macroeconomic aggregates before and during the pandemic. Panel (a) shows the annual growth rate of the S&P/Case-Shiller national house price index adjusted for CPI inflation. Real house price growth accelerated sharply during 2020. While the growth rate in the year to July 2019 was just 2 percent, prices grew by 5 percent from July 2019 to July 2020 and by 15 percent from July 2020 to July 2021. Note that the S&P/Case-Shiller index is a repeat sales price index, so the changes in prices reported in panel (a) are adjusted for any differences in the composition of houses sold over the course of the pandemic. Panels (b)–(d) depict the evolution of macroeconomic aggregates that are likely to be related to house prices over

Figure 2.1: Evolution of Macroeconomic Aggregates During the Pandemic



this period. Panel (b) shows changes in the time that households spent at home, from Google Mobility Reports data.[21] Early in the pandemic, time spent at home increased by more than 15 percent. Households continued to spend more time at home throughout 2020 and 2021, and as at July 2021 this measure remained 5 percent above its pre-pandemic level. Panel (c) documents the exceptionally sharp increase in unemployment during 2020. The unemployment rate quickly increased to nearly 15 percent, and then gradually declined to 5.4 percent by July 2021. Finally, panel (d) shows that real 30-year fixed mortgage interest rates declined by a little over 1 percentage point from 2019 to 2021.[22]

[21] Google uses anonymized GPS information gathered from personal cell phones to track where households have spent time over the course of the pandemic. Changes in various measures of household mobility are computed by comparing to baseline mobility measured during the five-week period from January 3 to February 6, 2020. For more information see: https://www.google.com/covid19/mobility/.

[22] To compute real interest rates at the 30-year horizon, we use expected 30-year inflation rates by combining information from nominal 30-year Treasury constant maturity securities and inflation-indexed 30-year Treasury constant maturity securities.

2.2.2. The rise in at-home consumption

While much more time was spent at home during the pandemic, households also shifted their consumption expenditure towards at-home goods and services. To measure the magnitude of this shift, we study household consumption patterns reported in the Consumer Expenditure Survey (CEX), a monthly survey of U.S. household expenditures. In each survey, the CEX questions a rotating panel of households about their consumption over the previous quarter across a number of detailed categories. Additionally, the survey reports a range of demographic information about the panelists, including whether they own or rent their home.

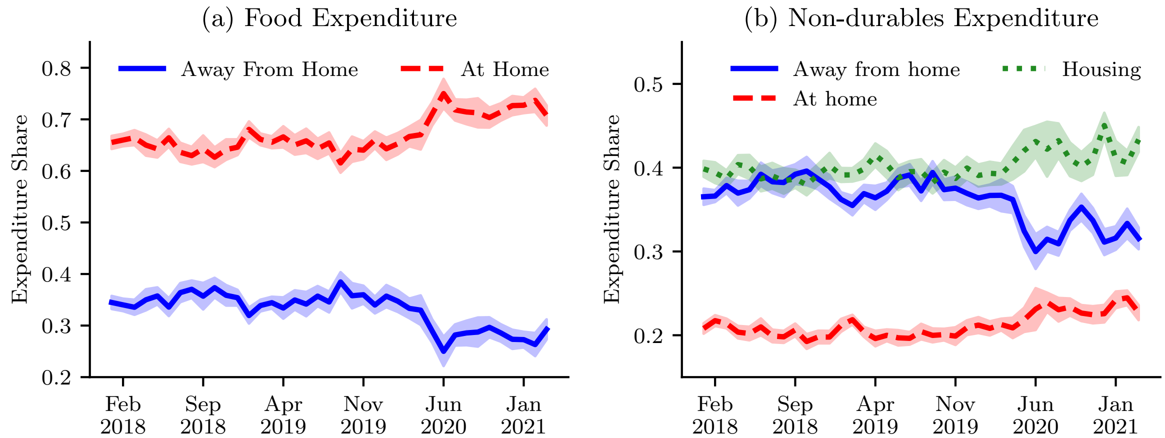
We construct two measures of expenditure on non-durable goods and services consumed at home and away from home. First, we use the CEX categories for food consumed at home and food consumed away from home. Although this measure is limited to food expenditures only, it has the benefit of being explicitly separated into consumption at home and away from home.[23] Second, we construct a measure of non-durable consumption expenditure that includes food, apparel, personal care, non-durable transportation, non-durable entertainment, housing services, alcohol, tobacco, education, and health.[24] This measure is similar to the one used by Aguiar and Hurst (2013), but expanded to include education and healthcare spending. We then divide the non-durable consumption categories into those that are plausibly consumed at home and away from home. In our baseline definition, we assume that consumption at home consists of food at home, apparel, non-durable entertainment, and personal care. We assume that consumption away from home includes food away from home, alcohol, tobacco, transportation, health, education, and fees and admissions. In Appendix B.1 we show that all of our results are robust to alternative definitions of consumption at home and away from home. We then separate housing services into its own category of consumption. Finally, all of our statistics are computed using the core weights provided by the Consumer Expenditure Survey.

Figure 2.2 shows median household consumption expenditure shares prior to and

[23]Using the CEX Blundell, Pistaferri, and Preston (2008) show that food consumption is a good predictor of overall non-durable consumption.

[24]Our measure excludes some components of expenditure in the CEX, including automobile purchases, home maintenance and services, mortgage interest payments, insurance, reading, cash contributions to people or organizations outside the household, and some other small categories.

Figure 2.2: Median Consumption Expenditure Shares



Notes: Median consumption expenditure shares for (a) food only, and (b) non-durables and housing services. Shaded regions show 95% confidence intervals for the median expenditure shares, computed via bootstrapping. In panel (b) spending on alcohol, tobacco, transportation, health, education, and fees and admissions is allocated to spending away from home. Household weights used to compute median shares, with weights provided by the CEX.

during the pandemic. Both of our measures of consumption show that households shifted expenditure towards consumption at home, and out of categories consumed away from home. Panel (a) shows that while the expenditure share on food at home had been stable at around 65 percent in the years prior to the pandemic, it increased by 5 percentage points in 2020. Panel (b) shows the shares of non-durables expenditure allocated to the at home, away from home, and housing services categories. The three non-durable consumption shares had also been relatively stable prior to the pandemic at 20 percent, 38 percent, and 39 percent, respectively. From 2019 to 2020, the at-home share rose by 1.9 percentage points, the housing services share rose by 2.0 percentage points, while the away-from-home share of consumption fell by 3.9 percentage points.

In Appendix B.1 we show that these results are robust to alternative definitions of away-from-home and at-home consumption. In Figure B.1 spending on health, education, alcohol, and tobacco are allocated to consumption at home. In that case, the median non-durables share spent at home rises by 2.7 percentage points and the share spent away from home falls by 4.3 percentage points in 2020. Since these changes in consumption shares are similar to those reported in Figure 2.2, it must be that the shifts in consumption are largely associated with a few key categories, such as food, fees and admissions (which includes recreation items, such as film and concert tickets), and transport. Figure B.2 reports aggregate consumption shares, which exhibit very similar patterns to the median consumption shares.

Finally, Figure B.3 in Appendix B.1 shows consumption shares separately for homeowners and renters using our baseline definition of at-home and away-from-home consumption. Although the levels of the expenditures shares are different for homeowners and renters, we find little difference between the changes in their respective consumption shares during the pandemic. For homeowners, the at-home consumption share rises by 2 percentage points, the away-from-home share falls by 4 percentage points, and the housing services share rises by 2.1 percentage points. For renters, the at-home consumption share rises by 1.6 percentage points, the away-from-home share falls by 4 percentage points, and the housing services share rises by 2.3 percentage points. This result suggests changes in consumption shares are not driven by differences in the evolution of housing costs for owners and renters during the pandemic.

2.2.3. Time at home and house prices

In this section we investigate whether more time spent at home during the pandemic was associated with changes in demand for housing, as observed in house price growth. We use cross-sectional variation in county-level data and find that locations with greater increases in time spent at home or larger decreases in visits to retail or recreation establishments also experienced larger increases in house prices. That is, more time and money spent at home appears to be associated with larger increases in housing demand.

Our data on household mobility come from the Google Mobility Reports data. We use two measures of household mobility at the county-level: time spent at home, and the number of visits to retail and recreation locations.[25] The first of these directly measures the extent to which households are spending more time at home during the pandemic. The second of these measures visits to restaurants, cafes, shopping centers, theme parks, museums, libraries, and movie theaters. The Google Mobility Reports data provides changes in household mobility relative to average mobility during a baseline period of January 3 to February 5, 2020. While the data are reported at a daily frequency, we

[25] See https://www.google.com/covid19/mobility/data_documentation.html?hl=en for an explanation of the various measures of household mobility.

use county-level averages at a monthly frequency.

The Google Mobility Reports data are informative about the composition of consumption across at-home and away-from-home goods. Our first measure, time spent at home, is likely to be associated with both home production and home consumption. While time spent consuming at home is likely to be correlated with the amount of home consumption, time spent working from home is also likely to be associated with eating, exercising, and consuming entertainment at home.[26] Our second measure – visits to retail and recreation locations – is directly related to consumption outside of the home.

Our data on house prices are from the Zillow Home Value Index, provided by the real estate company Zillow.[27] We observe county-level house price data at the monthly frequency from January 2019 to August 2021. In order to remove seasonality in the data we compute annual house price growth rates. Finally, we construct real house price growth by deflating the nominal data by annual changes in the CPI.

Figure 2.3 illustrates the unconditional relationship between household mobility and house price growth in 2020. The red dots represent percentile bins of the household mobility distribution with average house price growth reported for each bin. Panel (a) shows that counties with a larger increase in the amount of time spent at home experienced faster house price growth. Panel (b) shows that counties with a larger decrease in the number of visitors to retail and recreational locations also experienced faster house price growth. Note that there is some non-monotonicity in the tails of the mobility distribution, with counties facing especially large changes in mobility experiencing somewhat lower house price growth. Overall, however, the data is consistent with common movements in time spent at home and housing demand.

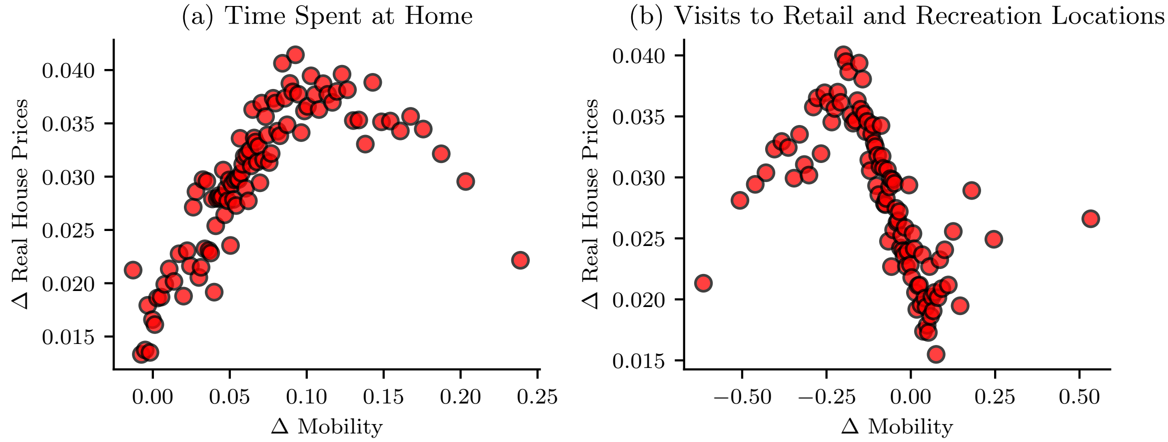
2.2.4. Two stage least squares estimates

We now present a more formal econometric analysis of the relationship between time spent at home and house price growth. Our empirical strategy is to estimate panel data

[26] Many of these "out-of-the-home" expenses are work-related. As noted in Aguiar and Hurst (2013), work-related expenses, like food away from home and transportation, decline significantly in retirement.

[27] Like the Case-Shiller index, the Zillow Home Value Index accounts for changes in the composition of houses sold at different times by measuring changes in the prices of a fixed set of houses over time. See https://www.zillow.com/research/zhvi-methodology-2019-deep-26226/ for details.

Figure 2.3: Changes in mobility and house prices



Notes: Binned scatter plots of changes in household mobility against annual real house price growth. Panel (a) sorts on percentiles of changes in average duration at own place of residence. Panel (b) sorts on percentiles of changes in average duration away from home. Changes in household mobility throughout 2020 are calculated relative to the 5-week period of 3 January to 6 February 2020. The latter is from the Google mobility dataset, which uses anonymized and aggregated GPS data from personal cellphones.

regressions of the following form:

$$\Delta \log P_{c,t} = \beta \Delta \text{Mobility}_{c,t} + \gamma X_{c,t} + \alpha_s + \alpha_{t \leq June2020} + \epsilon_{c,t} \tag{2.1}$$

where $\Delta \log P_{c,t}$ is the real annual growth rate of house prices in county c at time t, $\Delta\text{Mobility}_{c,t}$ is the change in household mobility relative to the pre-pandemic period, $X_{c,t}$ is a vector of control variables, α_s are state-level fixed effects, and $\alpha_{t \leq June2020}$ is a dummy variable for observations in the first half of 2020. We are interested in the parameter β, which measures the response of house prices to changes in time spent at home.

The data used to estimate Equation (2.1) come from several sources. As above, house price data are from Zillow and household mobility data comes from Google Mobility Reports where the two measures are time spent at home and number of visits to retail and recreation locations. We then use several different data sources to produce control variables. We use: annual county-level employment growth data from the BLS Local Area Unemployment statistics; county-level population estimates for 2019 from the American

Census; local per-capita adjusted gross income from the 2018 IRS Statistics of Income; and the share of total land unavailable for building on as a proxy for county-level housing supply elasticity from Lutz and Sand (2019).[28] Our state-level fixed effects control for potential differences in the way in which state governments responded to the pandemic, for example, via more or less stringent lockdowns. Our dummy variable $\alpha_{t \leq June2020}$ indicating the months in the first half of 2020 controls for the significant disruptions in real estate markets that occurred in the early months of the pandemic. This captures the non-monotonic relationship between mobility and prices illustrated in Figure 2.3, which is mostly due to data in the early months of 2020.

While our control variables help to account for likely confounding factors, the cross-sectional variation in house prices may be correlated with other unobserved variables that also affect mobility. For example, counties with more severe outbreaks or lockdowns may have had larger declines in income that suppressed house prices. Since bigger outbreaks and stricter lockdowns would be associated with more time spent at home but also lower house prices through the income channel, we would expect OLS estimates of β from Equation 2.1 to be biased towards zero.

We address this endogeneity problem by estimating Equation (2.1) via two-stage-least-squares using a shift-share style instrument for household mobility.[29] To construct our instrument, we interact the local share of employment that can feasibly be carried out at home with a time-varying measure of the intensity of the pandemic. The first (share) component of the instrument is taken from Dingel and Neiman (2020) who estimate occupation- and industry-level proxies for the share of jobs that can be conducted at home. These jobs are often referred to as "working from home" (WFH) jobs. To produce county-level WFH shares, we combine industry-level shares from Dingel and Neiman (2020) with county-level shares of total employment in each industry from the 2019 County Business Patterns survey.[30] The second (shift) component of the instrument uses a time-varying state-level measure of pandemic intensity. We use state-

[28]Lutz and Sand (2019) estimate land availability in the same way as Saiz (2010) but provide more geographically disaggregated measures than the MSA-level measures reported by Saiz (2010).

[29]For recent discussions of shift-share instruments see Goldsmith-Pinkham, Sorkin, and Swift (2020).

[30]Dingel and Neiman (2020) classify nearly 1000 US occupations as either able or unable to WFH. They then aggregate this classification in various ways, including at the level of two- and three-digit NAICS codes. While Dingel and Neiman (2020) provide MSA-level data, they do not provide data for more disaggregated levels of geography. We combine WFH and County Business Patterns data at the two-digit NAICS code level to produce a county-level measure.

level observations on the confirmed number of COVID-19 deaths from data collated by authors at Oxford University (Hale et al., 2021).[31]

Our shift-share instrument is likely to be a good predictor of household mobility. Conditional on the same intensity of pandemic shock within a state, counties with more WFH workers are likely to experience a larger increase in time spent at home and less time spent away from home. The exogeneity of our instrument relies on the shares of WFH employment being independent of other shocks to house prices during the pandemic, conditional on controls.[32] While ability to work from home is pre-determined since most jobs were chosen prior to the onset of the pandemic, Dingel and Neiman (2020) note that remote work is positively correlated with income across occupations, industries, and locations. Additionally, remote workers were less likely to to become unemployed than those whose jobs required them to work *in situ* (Dey et al., 2020). For this reason, we control for both the level of income and changes in employment over the course of the pandemic. We also include state-level fixed effects, which ensures that we are comparing counties within states facing the same level of pandemic intensity. Finally, since the time series variation in the instrument is the same across counties within a state we cluster standard errors at the state level.

Table 2.1 reports our OLS and 2SLS estimates of Equation (2.1). Columns (1) and (2) report our OLS results. Column (1) suggests that a 10 percent increase in time spent at home during 2020 is associated with 1.25 percent faster annual house price growth. Column (2) suggests that a 10 percent decrease in the number of visits to retail and recreation locations is associated with 0.11 percent faster house price growth. Columns (3) and (4) report our 2SLS estimates using the shift-share instrument for household mobility. We find that a 10 percent increase in time spent at home is associated with 4.57 percent faster house price growth. Additionally, a 10 percent larger decline in the number of visits to retail and recreation locations is associated with a 1.28 percent larger increase in house prices.

Table 2.1 shows that our 2SLS estimates are statistically significantly larger in absolute value than our OLS estimates. These differences are consistent with unobserved

[31] We also consider alternative instruments constructed using the confirmed number of COVID-19 cases and the stringency of lockdowns. Our results are similar across these different instruments. See discussion below.

[32] This is the exogeneity assumption for shift-share instruments discussed in Goldsmith-Pinkham, Sorkin, and Swift (2020).

pandemic shocks that generate larger declines in household mobility in counties that also faced weaker housing demand. For example, areas with more severe COVID-19 outbreaks that forced people to stay home are also likely to have suffered larger declines in local income, which tends to reduce demand for housing.

Table 2.1: House Price Response to Changes in Local Mobility

	Real 12-month house price growth			
	(1)	(2)	(3)	(4)
Δ Time At Home	0.125***		0.457***	
	(0.015)		(0.116)	
Δ Visits to Retail, Recreation		−0.011**		−0.128***
		(0.005)		(0.036)
Δ Employment	0.027	−0.033**	0.220***	0.108***
	(0.017)	(0.013)	(0.064)	(0.040)
ln(Population)	0.008***	0.008***	0.006***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Income Per Capita)	−0.015***	−0.011***	−0.027***	−0.018***
	(0.004)	(0.004)	(0.005)	(0.005)
Land Unavailability	−0.014**	−0.015**	−0.009	−0.004
	(0.006)	(0.006)	(0.006)	(0.008)
$\mathbf{1}(t \leq$June 2020)	−0.007***	−0.007***	−0.009***	−0.009***
	(0.001)	(0.001)	(0.002)	(0.002)
Observations				
Total	13,890	13,890	13,890	13,890
Counties	1,442	1,442	1,442	1,442
Method	OLS	OLS	2SLS	2SLS
State Fixed Effects	Y	Y	Y	Y
State-Clustered Standard Errors	Y	Y	Y	Y
First Stage F-statistic	–	–	15.21	34.96
Adjusted R-squared	0.27	0.25	0.15	0.05

Notes: Columns (1) and (2) are OLS regressions, and Columns (3) and (4) are 2SLS regressions. The instrument for mobility is the interaction between the county-level share of workers most easily able to work from home with state-level confirmed COVID deaths over time. All specifications include county-level controls for employment growth rates, population, per-capita income, land unavailability, in addition to a dummy for months prior to July 2020, and state fixed effects. All standard errors and first-stage F-statistics clustered at the state level.

We also consider several robustness checks of our main empirical results. First, in Table B.2 in Appendix B.2, we re-estimate our 2SLS regressions using alternative versions of the shift-share instrument for mobility. Columns (1) and (2) restate the main results discussed in Table 2.1 above. Columns (3) and (4) construct an instrument using the interaction between the share of WFH employment with state-level confirmed

COVID-19 cases, rather than confirmed deaths. This instrument is weaker than our baseline instrument, as indicated by first-stage F-statistics below 10. Nevertheless, we find very similar effects (0.507 and -0.151, respectively) of changes in mobility on house prices as in our baseline estimates. Columns (5) and (6) construct an instrument using the interaction between the share of WFH employment with a state-level lockdown stringency index (see Hale et al., 2021). These estimates (0.127 and -0.052, respectively) also suggest that more time spent at home is associated with faster house price growth. However, these estimates are statistically significantly smaller than our baseline estimates. Finally, columns (7) and (8) construct an instrument using the interaction between county-level Republican vote shares in the 2016 presidential election with state-level COVID-19 deaths (MIT Election Data and Science Lab, 2018).[33] These estimates (0.827 and -0.286, respectively) are larger than but not statistically significantly different from our baseline results.

Second, in Table B.1 in Appendix B.2 we investigate whether our results are sensitive to other controls and samples. Column (1) repeats our baseline 2SLS results for the time spent at home variable. Column (2) includes an additional control for changes in time spent at the workplace, where we take the county-level average of deviations from the baseline period for the six months ending in March 2022. Our inclusion of this variable is an attempt to control for medium- to long-run changes in willingness to work from home. The estimated coefficient of 0.464 is not statistically different from our baseline estimate. In Column (3) we adjust the sample to include data from both 2020 and 2021. In this specification we also include a dummy variable for observations in the year 2021. The 2SLS estimate of 0.789 is larger than but not statistically significantly different from our baseline estimate. In Column (4) we only use data from the second half of 2020, by which time COVID-19 had spread throughout the US. This specification produces very similar results (0.541) to our baseline estimates. Finally, in Column (5) we again use data from 2020 but exclude data from New York and Washington, since these states were especially hard hit early in the pandemic when the shock was relatively new and potentially more disruptive. With an estimated coefficient of 0.581 we again find no statistically significant difference from our baseline estimates.

Third in Table B.3 in Appendix B.2 we consider whether rents respond to stay-at-

[33]Engle, Stromme, and Zhou (2020) document that counties with higher Republican vote shares had smaller reductions in household mobility during the pandemic.

home shocks in a similar way to house prices.[34] We might expect that the increase in demand for housing applies to both owned and rented houses. We find that the direction of the response of rents to stay-at-home shocks is similar to house prices, although the magnitude of the effects are much smaller. We find that a 10 percent increase in time spent at home is associated with a 0.1 to 0.9 percent increase in rents.

2.3. Quantitative Model

2.3.1. Household Environment

Demographics. Households live for a finite number of periods with their age indexed by $j \in [1, ..., J]$. Each household splits its life between working and retirement, with the final period of working life at age J_{ret} and retirement commencing the following period. Households face an age-dependent probability of death π_j each period, and can live up to a maximum age of J.

Preferences. Households maximize expected lifetime utility, which takes the form:

$$\mathbb{E}_0 \sum_{j=1}^{J} \beta^{j-1} \left[(1-\pi_j)u(c_{a,j}, c_{h,j}, s_j) + \pi_j \nu(w_j)\right]$$

where $u(\cdot)$ is the flow utility function, $\nu(\cdot)$ is a warm-glow bequest function, β is the discount factor, and π_j is the probability of death at age j. Flow utility is defined over non-durable consumption away from home c_a, non-durable consumption at home c_h, and consumption of housing services s. Bequests are defined over net wealth remaining at the time of death w.

Flow utility is the standard CRRA function over a CES aggregate of away-from-home consumption c_a and a home consumption bundle x_h:

$$u(c_a, c_h, s) = \frac{1}{1-\sigma}\left[\alpha c_a^{1-\vartheta} + (1-\alpha)x_h(c_h, s)^{1-\vartheta}\right]^{\frac{1-\sigma}{1-\vartheta}}$$

where α is the relative taste for consumption away from home, $1/\vartheta$ is the intratemporal

[34]Zillow provides data on rents by zip code, which we aggregate up to the county level.

elasticity of substitution between away-from-home consumption and the home bundle, and $1/\sigma$ is the intertemporal elasticity of substitution.[35] The home bundle x_h is a Cobb-Douglas combination of at-home consumption c_h and housing services s:

$$x_h = c_h^{\phi} s^{1-\phi}.$$

Our main pandemic experiment in Section 2.5 is a stay-at-home shock generated by a decline in the parameter α. Consistent with the data presented in Section 2.2.2, the stay-at-home shock shifts consumption from away-from-home goods towards the home bundle. In Appendix B.3.1 we present a simple static equilibrium model with the same preferences over consumption and show analytically that a stay-at-home shock results in greater housing demand and higher house prices.

Finally, households enjoy a warm-glow bequest motive over net wealth left behind if dying at age j:

$$\nu(w_j) = B \frac{w_j^{1-\sigma}}{1-\sigma}$$

where $B > 0$ captures the strength of the bequest motive, and net wealth w_j is defined as the sum of liquid assets and housing wealth.

Endowments. Households receive stochastic labor income while working and a constant pension when retired. When working, labor income is the combination of a deterministic life-cycle component χ_j and a stochastic component z_j. The stochastic component z_j follows a log-AR(1) process with persistence ρ_z and standard deviation of innovations ϵ_z. In addition, households may become unemployed during their working life. Unemployed households receive a fraction ω_u of their employed earnings potential. Employment status follows an age-dependent Markov chain with transition matrix Γ_j.

[35] In a multi-sector New Keynesian model, Guerrieri et al. (2021) show that sectoral supply shocks can have spillover effects on demand when the intertemporal elasticity of substitution is larger than the the intratemporal elasticity of substitution across goods. We do not model general equilibrium in goods markets in this paper, so the spillover channel is not active here.

Transitions into and out of employment at age j are given by

$$\Gamma_j = \begin{bmatrix} 1-d_j & d_j \\ f & 1-f \end{bmatrix}.$$

where unemployed households find a job with a constant probability f, but the job separation rate for employed households d_j depends on their age.[36] Our calibration in Section 2.4 generates declining job separation rates by age, which is consistent with the observed decline in unemployment rates over the life-cycle. Finally, in retirement households receive a constant pension equal to a fraction ω_{ret} of their earnings in the last year of working life.

Let y_j denote earnings at age j, and let $e \in \{0,1\}$ denote working status reflecting unemployment and employment, respectively. Then household earnings are

$$y_j = \begin{cases} \chi_j \cdot z_j & \text{if } j \le J_{ret}, \quad e = 1 \quad \text{(working-age, employed)} \\ \omega_u \cdot \chi_j \cdot z_j & \text{if } j \le J_{ret}, \quad e = 0 \quad \text{(working-age, unemployed)} \\ \omega_{ret} \cdot \chi_{J_{ret}} \cdot z_{J_{ret}} & \text{if } j > J_{ret} \quad \text{(retired)} \end{cases}$$

In our experiments described in Section 2.5, households may also receive government transfers, which stand in for stimulus checks and expanded unemployment benefits paid to households during the pandemic.

Housing. Housing services can be acquired by renting at the per-unit rental rate P_r or by owning property purchased at the per-unit house price P_h. Renters can costlessly adjust the size of their dwelling each period. In contrast, homeowners face a transaction cost F_h, proportional to the value of their house, whenever they wish to sell their property. Homeowners must also pay a maintenance cost δ each period, which is proportional to the value of their house. Rental units and owner-occupied houses are chosen from discrete sets $\mathcal{H}_r$ and $\mathcal{H}_o$, respectively.

Liquid assets. Households can save or borrow in a risk-free liquid asset a. When saving,

[36] Graham and Ozbilgin (2021) study the effects of pandemic lockdowns in a heterogeneous agent model with labor search and age- and industry-dependent employment status. Job separation rates endogenously respond to both pandemic shocks and government wage subsidies. In the current paper, we assume that job separation rates evolve exogenously. See Section 2.4.1 for details.

the return on assets is r. Homeowners can finance the purchase of houses by borrowing against the value of their property, which implies a negative liquid asset balance. This simple borrowing structure stands in for the more complex mortgages modelled in the literature.[37] Unsecured borrowing (i.e. by renters) is not allowed. Mortgage balances accrue interest at the rate r_m, where $r_m > r$ reflects a spread over the risk-free rate capturing unmodeled mortgage risk- and term-premia. Thus, the interest rate is a function of the household's asset position and is given by:

$$r(a) = \begin{cases} r & \text{if } a \geq 0 \\ r_m & \text{if } a < 0 \end{cases}$$

Borrowers pay an origination cost F_m proportional to the size of the mortgage when they take out a new purchase mortgage or when they refinance. We assume that refinancing occurs any time the borrower chooses to increase the mortgage balance without purchasing a new house. At origination, new mortgages a' are subject to a maximum loan-to-value (LTV) ratio constraint:

$$a' \geq -\theta_m P_h h'$$

where θ_m is the maximum LTV ratio, and $P_h h'$ is the value of the current house (either a new purchase, or an existing property). New mortgages are also subject to a payment-to-income (PTI) constraint, following Greenwald (2018):

$$r_m a' \geq -\theta_y y_j$$

where $r_m a'$ is the minimum required mortgage payment, and θ_y is the maximum PTI ratio.

Households begin life with no owned housing or mortgage debt. However, households may receive bequests in the form of a positive initial liquid asset balance. See Section 2.4 for details.

[37] We assume one-period mortgage debt for tractability, but recent papers have studied models with long-term mortgage contracts. See, for example, Boar, Gorea, and Midrigan (2021), Garriga, Kydland, and Šustek (2017), Kaplan, Mitman, and Violante (2020), and Karlman, Kinnerud, and Kragh-Sorensen (2021).

2.3.2. Household Decision Problems

Households enter a period at age j with the state vector $\mathbf{s} = (a, h, z, e)$, where a is liquid assets or debt, h is current owner-occupied housing (set to zero for renters), z is the persistent component of labor income, and e is employment status. A household chooses between renting, maintaining its current housing position, and adjusting its house size and/or mortgage debt. A household of age j with state $\mathbf{s}$ solves:

$$V_j(\mathbf{s}) = \max\left\{V_j^R(\mathbf{s}), V_j^N(\mathbf{s}), V_j^A(\mathbf{s})\right\}$$

where V_j^R is the value function of a renter, V_j^N is the value function of an owner that does not adjust its house size or increase its mortgage debt, and V_j^A is the value function of an owner that adjusts its house size and/or mortgage.

A household who chooses to rent solves:

$$\begin{aligned} V_j^R(\mathbf{s}) = & \max_{c_a, c_h, s, a'} u(c_a, c_h, s) + \beta \mathbb{E}\left[(1-\pi_{j+1})V_{j+1}(\mathbf{s}') + \pi_{j+1}\nu(w')\right] \\ & \text{s.t. } c_a + c_h + P_r s + a' = y_j + (1 + r(a))a + (1 - F_h)P_h h \\ & \quad s \in \mathcal{H}_r, \ a' \geq 0, \ h' = 0 \end{aligned}$$

The problem for a non-adjusting household is:

$$\begin{aligned} V_j^N(\mathbf{s}) = & \max_{c_a, c_h, a'} u(c_a, c_h, h) + \beta \mathbb{E}\left[(1-\pi_{j+1})V_{j+1}(\mathbf{s}') + \pi_{j+1}\nu(w')\right] \\ & \text{s.t. } c_a + c_h + \delta P_h h + a' = y_j + (1 + r(a))a \\ & \quad h' = h, \ a' \geq \min\{0, a\} \end{aligned}$$

where the constraint on the liquid asset choice indicates that homeowners with a mortgage cannot increase the size of their debt.

The problem for an adjusting household is:

$$
\begin{aligned}
V_j^A(\mathbf{s}) = & \max_{c_a, c_h, h', a'} u(c_a, c_h, h') + \beta \mathbb{E}\left[(1-\pi_{j+1})V_{j+1}(\mathbf{s}') + \pi_{j+1}\nu(w')\right] \\
\text{s.t. } & c_a + c_h + \delta P_h h' + a' + \psi(a, a', h, h') = y_j + (1 + r(a))a + \mathbf{1}_{h' \neq h}\left((1 - F_h)P_h h - P_h h'\right) \\
& h' \in \mathcal{H}_o \\
& a' \geq -\theta_m P_h h' \\
& r_m a' \geq -\theta_y y_j
\end{aligned}
$$

The function $\psi(a, a', h, h')$ represents the mortgage origination cost, which is incurred if the homeowner borrows when purchasing a new house, or if it remains in its current house but chooses to increase the size of its mortgage (i.e. refinances its mortgage):

$$
\psi(a, a', h, h') = \begin{cases} F_m|a'| & \text{if } \quad h' \neq h \;\; \& \;\; a' < 0 \\ F_m|a'| & \text{if } \quad h' = h \;\; \& \;\; a' < a < 0 \\ 0 & \text{otherwise.} \end{cases}
$$

The function $\mathbf{1}_{h' \neq h}$ is an indicator for new house purchases, and is equal to one whenever a household changes the size of their existing housing stock.

2.3.3. Equilibrium and Computational Details

We assume that a competitive rental firm trades housing units and rents them out to households at the market rental rate P_r. Accordingly, the supply of rental housing is perfectly elastic at the market rental rate, which is given by the user-cost relationship:

$$
P_r = (1 + \delta + \kappa)P_h - \frac{1}{1+r}\mathbb{E}[P_h'] \tag{2.2}
$$

where κ is an operating cost, proportional to the value of the rental firm's housing stock. The operating cost κ creates a wedge between the user cost of owning a house in the model and the cost of renting it, which provides households with an incentive to own. The stationary equilibrium of the model is defined below.[38]

[38] Note that since our primary focus is on the effect of the pandemic on housing markets, we do not solve for equilibrium in goods markets or with respect to government decisions. See Diamond, Landvoigt,

Definition. A stationary recursive competitive equilibrium is a set of value functions $\{V_j(\mathbf{s}), V_j^R(\mathbf{s}), V_j^N(\mathbf{s}), V_j^A(\mathbf{s})\}$ and decision rules $\{c_{a,j}(\mathbf{s}), c_{h,j}(\mathbf{s}), s_j(\mathbf{s}), h'_j(\mathbf{s}), a'_j(\mathbf{s})\}$ for all j; prices $\{P_h, P_r\}$; fixed housing supply $\bar{H}$; and a distribution of households over idiosyncratic states $\Phi_j(\mathbf{s})$ for all j such that:

1. Given prices, $\{V_j(\mathbf{s}), V_j^R(\mathbf{s}), V_j^N(\mathbf{s}), V_j^A(\mathbf{s})\}$ solve the household's problem, with associated decision rules $\{c_{a,j}(\mathbf{s}), c_{h,j}(\mathbf{s}), s_j(\mathbf{s}), h'_j(\mathbf{s}), a'_j(\mathbf{s})\}$ for all j.

2. Given $P_h = P'_h$, the rental price P_r is determined by the user-cost formula in Equation (2.2).

3. The total housing stock is equal to the total demand for owner-occupied housing and rental units:

$$\bar{H} = \sum_{j=1}^{J} \int_{\mathbf{s}} h'_j(\mathbf{s}) d\Phi_j(\mathbf{s}) + \sum_{j=1}^{J} \int_{\mathbf{s}} s_j(\mathbf{s}) d\Phi_j(\mathbf{s})$$

4. The distribution of households over idiosyncratic states is induced by the exogenous processes for income and unemployment and household decision rules.

We compute the stationary equilibrium numerically. In the initial steady state we normalize the house price $P_h = 1$. The rental rate is then given by the user-cost equation (2.2). Given the house price and rental rate, we then solve the household's problem via value function iteration and compute the stationary distribution using the histogram method of Young (2010). The rental market clears by assumption because the rental sector supplies any quantity of units at the market rental rate. We then infer the level of housing supply $\bar{H}$ from the market clearing condition in the equilibrium definition. In all of our dynamic model experiments we keep the aggregate housing stock fixed at $\bar{H}$. However, the composition of housing between owner-occupied and rental units is allowed to vary as demand conditions change.[39] All of our experiments are computed

and Sánchez (2021) for a more complete general equilibrium analysis.

[39] The assumption of a housing stock flexibly composed of different sizes of owner-occupied and rental units is common; see for example Kaplan, Mitman, and Violante (2020) and Karlman, Kinnerud, and Kragh-Sorensen (2021). Alternatively, we could fix the composition of house sizes and allow the relative price of each house size to adjust to clear separate housing markets. Landvoigt, Piazzesi, and Schneider (2015) provide an example of such a model. We abstract from this complication to maintain computational tractability.

as perfect-foresight transition paths, where we solve for the sequence of house prices $\{P_{h,t}\}_{t=1}^{t=T}$ such that the overall demand for housing equals the fixed housing stock in each period.

2.4. Calibration

2.4.1. External Parameters

Below we describe our choices for parameter values that are assigned directly or taken from other studies. These assigned parameters are listed in Table 3.1 Panel A.

Demographics and preferences. The model period is one year. Households enter the economy aged 25, retire after age 65 ($J_{ret} = 41$), and death occurs with certainty at age 80 ($J = 56$). The age-dependent death probabilities π_j are taken from male death probabilities reported in Social Security Administration Actuarial Tables. We set $\sigma = 2$ implying an intertemporal elasticity of substitution of 0.5, which is standard in the literature.

We set the intratemporal elasticity of substitution between away-from-home consumption and the home bundle to $1/\vartheta = 2$. There are no direct estimates of this particular elasticity. Piazzesi, Schneider, and Tuzel (2007) estimate an intratemporal elasticity of substitution between non-durable consumption and housing services of around 1.25 using aggregate data. Since the home bundle in our model includes non-durable at-home consumption goods it is likely to be more substitutable with away-from-home goods than total non-durables are with housing services (i.e. as in the estimates of Piazzesi, Schneider, and Tuzel, 2007). This suggests we should use an intratemporal elasticity larger than 1.25. Papers in the home production literature that estimate elasticities between the home and market sectors report values in the range of 1.7–2.5. For example, Benhabib, Rogerson, and Wright (1991) and McGrattan, Rogerson, and Wright (1997) estimate elasticities of substitution between home and market produced goods of around 2.5 and 1.75, respectively. Aguiar and Hurst (2007) and Nevo and Wong (2019) report estimated elasticities of substitution between time and market goods used in home production of 1.7–2.2. Although we do not explicitly model time use or home production, these estimates are instructive because there is likely a high correlation between home consumption of market goods (which we model) and home production.

Endowments. We take the parameters that govern the idiosyncratic income process from Kaplan, Mitman, and Violante (2020), who set the persistence of the log-AR(1) shocks $\rho_y = 0.97$ and the standard deviation of innovations $\sigma_y = 0.2$. The deterministic life-cycle profile of income χ_j follows a simple tent shape, following Ma and Zubairy (2021):

$$\chi_j = 1 + \xi \left(1 - \frac{\mid j - J_{peak} \mid}{J_{peak} - 1}\right) \ \forall \ j \leq J_{ret}$$

where J_{peak} is the peak age for earnings, and ξ captures the rise in earnings over the life-cycle. We set the peak earnings age to be 50 ($J_{peak} = 26$), and $\xi = 0.5$ so that, on average, labour income rises by 50 percent between entering the labor force and the peak earnings age. These parameters generate a reasonable approximation to the life-cycle profile of median household labor income in the 2019 SCF (see Figure 2.4(b)). The unemployment insurance replacement rate is set to $\omega_u = 0.5$ following Krueger, Mitman, and Perri (2016). Finally, we normalize median labor income of employed working-age households in the model to one.

In the first period of life households receive a bequest with probability π_b. Conditional on bequest, households receive a fraction ω_b of their initial period income. We calibrate these parameters using data on households aged 20 to 25 in the 2019 Survey of Consumer Finances. We set $\pi_b = .69$ based on the fraction of young households with positive net worth, and we set $\omega_b = 0.57$ based on the median net worth-to-income ratio for young households with positive net worth.

Interest rates, mortgages, transaction costs and depreciation. We set the risk-free interest rate to $r = 0.02$ and the mortgage interest rate $r_m = 0.04$. We set the LTV limit on mortgages $\theta_m = 0.9$ and the maximum PTI ratio $\theta_y = 0.5$ based on evidence from Greenwald (2018). The mortgage origination cost F_m is set to 0.5 percent of the mortgage balance at origination based on average origination fees and discount points for 30-year mortgages using the Freddie Mac Primary Mortgage Market Survey, accessed via FRED. The transaction cost for selling a house F_h is set to 6 percent of the house value, which is standard. The depreciation rate of owner-occupied housing is set to

Table 2.2: Parameter Values

Parameter	Description	Value
	A. Assigned	
J	Length of life (years)	56
J_{ret}	Working life (years)	41
J_{peak}	Life-cycle income, peak age	26
σ	Relative risk aversion	2
$1/\vartheta$	Elasticity of substitution	2
ξ	Life-cycle income growth	0.5
ρ_z	Autocorrelation of earnings	0.97
σ_z	Std. dev of earnings shocks	0.20
δ	Depreciation rate	0.03
r	Real risk-free rate	0.02
r_m	Mortgage interest rate	0.04
θ_m	LTV limit	0.9
θ_y	PTI limit	0.5
F_m	Mortgage origination cost	0.005
F_h	Transaction cost of selling house	0.06
π_b	Frac. newborns endowed with bequest	0.69
ω_b	Bequest/income ratio conditional on recieving bequest	0.57
ω_u	UI replacement rate	0.5
ω_{ret}	Retirement replacement rate	0.5
	B. Unemployment Process	
f	Job finding rate	0.98
ρ_d	Separation rate, persistence	0.85
μ_d	Separation rate, mean	0.03
$d_{j=1}$	Separation rate, age 25	0.05
$\pi_{u,j=1}$	Unemployment rate, age 25	0.05
	C. Calibrated	
β	Discount factor	0.84
α	Away-from-home consumption weight in utility	0.56
ϕ	Non-durable consumption weight in home-bundle	0.31
B	Strength of bequest motive	43.98
$\underline{h}$	Smallest owned house size	3.00
Δh	Housing grid spacing	0.60
κ	Rental firm operating cost	0.02

3 percent based on evidence from Harding, Rosenthal, and Sirmans (2007).

2.4.2. Fitted Parameters

Unemployment process. The parameters of the age-dependent Markov chain for employment Γ_j are calibrated to match the life-cycle profile of unemployment in the US.[40] We assume that the age-dependent job separation rates evolve according to an AR(1) process:

$$d_j = (1 - \rho_d)\mu_d + \rho_d d_{j-1}. \tag{2.3}$$

The job finding rate f is constant across ages. We then use simulated method of moments to calibrate five parameters: the job finding rate f, the long-run average separation rate μ_d, the persistence of separation rates across age ρ_d, the initial separation rate d_1, and the initial fraction of unemployed households $\pi_{u,1}$. Using data from the Current Population Survey from 2017 to 2019, we match average unemployment rates across workers in five-year age bins from 25 to 65.[41] Table 3.1 Panel B lists the estimated parameters. Figure 2.4(a) confirms that this simple process for employment transitions matches the pre-pandemic life-cycle profile of unemployment extremely well.

Preferences and housing. We calibrate the remaining parameters listed in Table 3.1 Panel C to minimize the sum of squared deviations of seven model moments from their empirical counterparts. Table 3.2 shows that the model matches the targeted moments reasonably well. These computed parameters are jointly identified by the targeted moments, but we outline which moments have the largest influence on each parameter below.

The annual discount factor is $\beta = 0.84$, which matches a median household net worth to income ratio of 2.0. The strength of the bequest motive is $B = 44.0$, which targets a ratio of 1.7 for the net worth of households older than 65 to those under 65. The relative taste for away-from-home consumption $\alpha = 0.56$ matches a median household expenditure share of around 37 percent (as shown in Figure 2.2(b)). Similarly, the share of at-home consumption in the home consumption bundle is set to $\phi = 0.31$, which

[40]Our calibration strategy follows Graham and Ozbilgin (2021), who calibrate an AR(1) process to generate separation rates for every age in the model while matching aggregated unemployment rates in 5-year age bins.
[41]By 2017, unemployment rates across age groups had converged to their pre-financial crisis levels.

helps match a median expenditure share of at-home consumption of 21 percent (also see Figure 2.2(b)). The rental firm's operating cost is $\kappa = 0.02$, which helps to match a homeownership rate of 44 percent for households under the age of 35. We assume that rental and owner-occupied house sizes are chosen from overlapping discrete sets with three sizes in each: $\mathcal{H}_r = \{h_1, h_2, h_3\}$ and $\mathcal{H}_o = \{h_3, h_4, h_5\}$. Two parameters control the distribution of house sizes: the minimum owner-occupied house size h_3 and the log-distance between consecutive sizes Δ_h.[42] We set the minimum owner-occupied house size to $h_3 = 3$ to target a homeownership rate of 67 percent. The log-distance parameter is $\Delta_h = 0.6$, which helps to match the difference between the house value-to-income ratios at 75th and 50th percentiles of the housing-to-income distribution.

Table 2.3: Moments Targeted in Calibration

Targeted moment	**Data**	**Model**
Median networth-to-income income	2.01	2.05
Mean net-worth, ages 65+ / mean net-worth, ages <65	1.73	1.65
Away-from-home expenditure share	0.39	0.38
At-home expenditure share	0.21	0.21
Home ownership rate	0.67	0.68
Home ownership rate, ages $<$ 35	0.44	0.43
House value-to-income, p75/p50	1.70	1.71

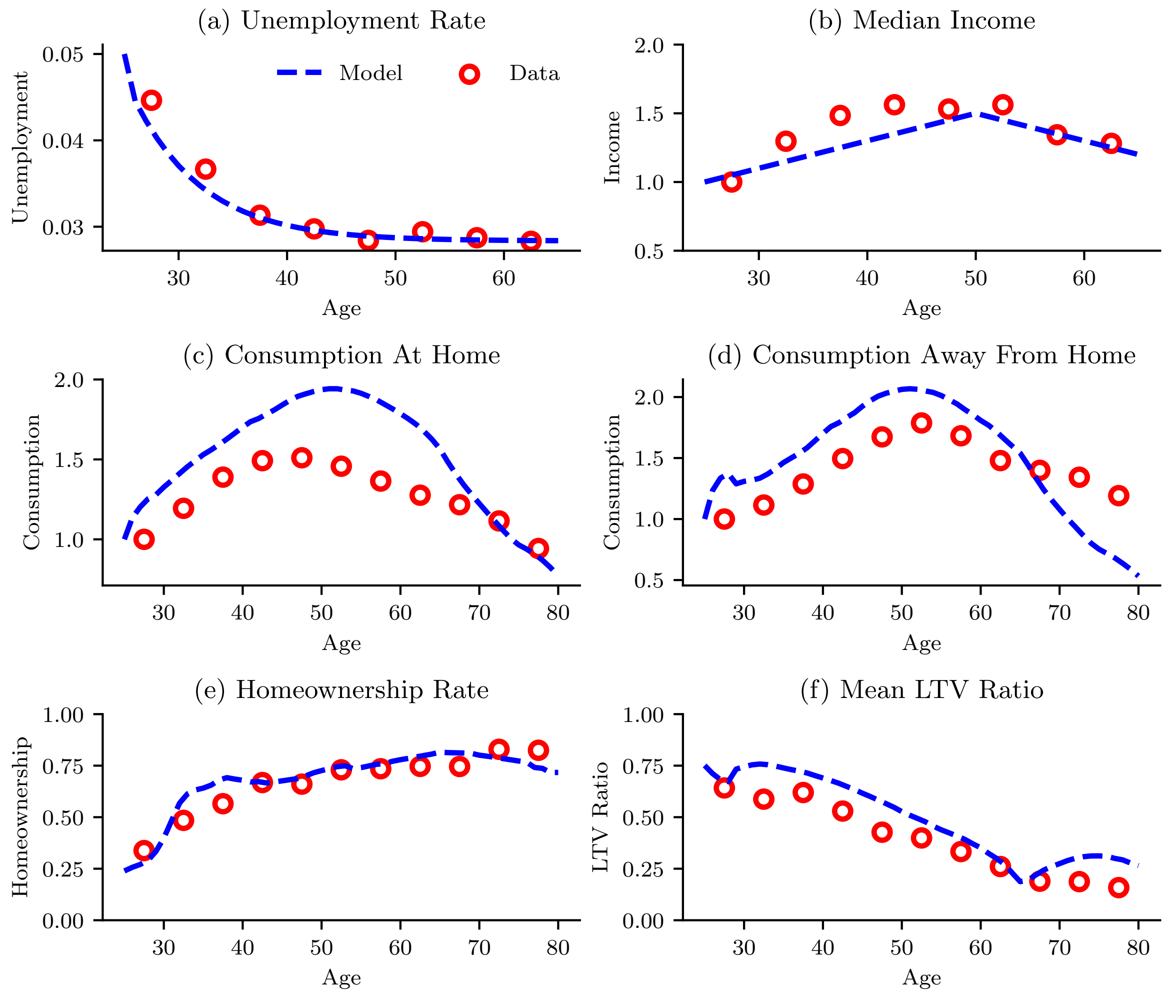
Notes: SCF data taken from the 2019 survey. Median consumption shares computed using sample averages in CEX data from 2017 to 2019. Unemployment rates computed using averages of monthly rates in CPS data from 2017-2019.

2.4.3. Model Fit

Figure 2.4 shows life-cycle profiles of unemployment, income, consumption, homeownership and mortgage leverage in the model and data. Since we calibrate the unemployment process in the model to match life-cycle unemployment data, it is unsurprising that the model provides a good fit to the data in Panel (a). Our parsimonious tent-shaped age-profile for labor income is broadly consistent with the profile of median household income in the SCF, as shown in Panel (b). Panels (c) and (d) show that the model also mimics the hump-shaped life-cycle profiles of both away-from-home and at-home consumption,

[42] The five house sizes are set as $h_i = \exp(\log(h_3) + (i-3) \times \Delta_h)$ for $i = 1, \cdots, 5$.

Figure 2.4: Model Fit to Life-Cycle Statistics



Notes: All statistics in the data computed for five-year age bins starting from age 25. Panels (b), (c), and (d) normalize both model and data to one at the first age. Panel (f) reports the average LTV ratio for all homeowners.

even though our calibration only targets median expenditure shares across households of all ages. Panel (e) shows that the model provides a good fit to the life-cycle profile of homeownership. Finally, Panel (f) shows that the model reproduces the life-cycle decline in average homeowner leverage very well, even though our calibration does not explicitly target any moments related to household debt.

Table 2.4: Parameters and Moments Calibrated for the Pandemic Experiment

Parameter	Value	Moment	Model	Data
α_{2020}	0.515	Δ Median At-Home Share of Non-Housing Exp., 2019-2020	0.057	0.057
α_{2021}	0.501	Δ Median At-Home Share of Non-Housing Exp., 2019-2021	0.074	0.073
$r_{m,2020}$	0.032	Δ 30-Year Mortgage Rate, 2019-2020	-0.008	-0.008
$r_{m,2021}$	0.026	Δ 30-Year Mortgage Rate, 2019-2021	-0.014	-0.014
$\varepsilon_{s,2019}$	0.085	Δ Unemployment Rate, 2019-2020	0.059	0.059
$\varepsilon_{f,2020}$	-0.280	Δ Unemployment Rate, 2019-2021	0.022	0.022
$T_{u,2020}$	0.218	Additional UI Per Person/Median Labor Income, 2020	0.218	0.218
$T_{u,2021}$	0.196	Additional UI Per Person/Median Labor Income, 2021	0.196	0.196
$T_{all,2020}$	0.035	Stimulus Checks Per Household/Median Labor Income, 2020	0.035	0.035
$T_{all,2021}$	0.058	Stimulus Checks Per Household/Median Labor Income, 2021	0.058	0.058
ρ_{α,r_m}	0.510	Excess Real House Price Growth, 2019-2020	0.072	0.074

Notes: Data statistics for 2020 are computed as means of monthly data from April 2020. Data statistics for 2021 are computed as means of monthly data up until August 2021. Real house price growth rates are computed using annual growth rates in December 2019 and 2020.

2.5. Pandemic Experiments in the Quantitative Model

We now study a series of experiments designed to understand the effect of the pandemic on the US housing market. We model the pandemic as four shocks that hit the economy in 2020 and 2021: (1) a stay-at-home shock characterized by a shift in preferences towards consumption at home, (2) a fall in real mortgage rates, (3) an increase in unemployment, and (4) government transfers in the form of stimulus checks and expanded unemployment benefits. We assume the economy is in steady state in 2019 and that all shocks are unexpected prior to the onset of the pandemic. However, the entire sequence of shocks becomes known to households in 2020. While all of the shocks are transitory, we assume that the stay-at-home shock and mortgage interest rate shock are somewhat persistent. We explain our assumptions about this persistence below in Section 2.5.1 and explore the robustness of our results to these assumptions in Section 2.5.4.

2.5.1. Calibration of the Pandemic Shocks

The size of each shock is chosen to match empirical observations from 2020 and 2021. Statistics from 2020 are computed as monthly averages starting from April to capture the onset of the pandemic. Table 2.4 reports the shock parameters and statistics used for calibration. First, there is a decline in the relative taste for away-from-home consumption α. We set the values of α to match the rise in the at-home consumption share of non-housing consumption in 2020 and 2021.[43] Second, the real mortgage interest rate r_m falls in line with the observed decline in real rates in 2020 and 2021.

Third, we implement a parsimonious set of unemployment shocks relative to the recent literature.[44] The unemployment shocks include a rise in the job separation rate for all age groups and a fall in the job finding rate f. We calibrate these shocks to match the rise in aggregate unemployment in 2020 and 2021 relative to 2019. Although steady state job separation rates vary by age, we assume that separations increase by the same amount ε_d for each age group. This means that the unemployment rate rises by a similar amount for all age groups. The separations shock ε_d occurs at the end of the 2019 period in order to affect unemployment rates in 2020. We then assume that the job separation rate f increases in 2020 so that higher unemployment rates carry over into 2021.

Fourth, we introduce flat-rate payments for unemployed workers and lump-sum transfers to all households in 2020 and 2021 to model the expanded unemployment insurance benefits and stimulus checks paid out under the CARES Act, COVID-related Tax Relief Act of 2020, and the American Rescue Plan Act.[45] Specifically, we assume that all households in the model receive stimulus payments of $2,400 in 2020 and $4,000 in 2021.[46] We assume unemployed households receive extra benefits of $12,000 in 2020 and $10,800 in 2021.[47]

[43] Scaling by non-housing consumption, rather than total consumption, means that the targeted consumption shares are not directly affected by endogenous changes in house prices and rents along the transition path.

[44] Fang, Nie, and Xie (2020) and Graham and Ozbilgin (2021) model search and matching models of the labor market during the pandemic and study exogenous and endogenous job separation rates, respectively. Carroll et al. (2020) model pandemic shocks by matching both the cross-sectional distribution of unemployment as well as heterogeneity in unemployment duration.

[45] Carroll et al. (2020) presents a detailed study of the consumption response to the CARES Act. They use a heterogeneous agents life-cycle model that matches estimated consumption responses to tax and benefit changes. Unlike the current paper, they do not model the housing market.

[46] We assume households in the model consist of two adults, so we give them two checks for each round of stimulus. The payment of $4,000 in 2021 reflects the $600 checks paid out in late December 2020 and the $1,400 checks paid out in March 2021. The three rounds of stimulus checks also included payments for children, which we do not model. We also ignore the income thresholds at which payments started being reduced. For details of the stimulus payments, see: https://home.treasury.gov/policy-issues/coronavirus/assistance-for-american-families-and-workers/economic-impact-payments.

[47] Federal Pandemic Unemployment Compensation, created under the CARES Act, provided an additional $600 per week to all UI recipients from late March to end-July 2020 (17 weeks), for a total of

We further assume that after the initial pandemic shocks in 2020 and 2021, the preference parameter α and the mortgage interest rate r_m slowly return to their steady state values following AR(1) processes with common persistence ρ_{α,r_m}. We set ρ_{α,r_m} so that the house price growth rate in 2020 in the model is equal to the excess annual growth rate of real house prices in December 2020 relative to December 2019. The persistence parameter affects the size of the house price boom in the model since the increase in housing demand is front-loaded with respect to the entire sequence of shocks. The longer that households expect to remain at home and the longer that real interest rates remain low, the more households are willing to pay for houses in 2020.

2.5.2. Aggregate Responses to the Pandemic Shocks

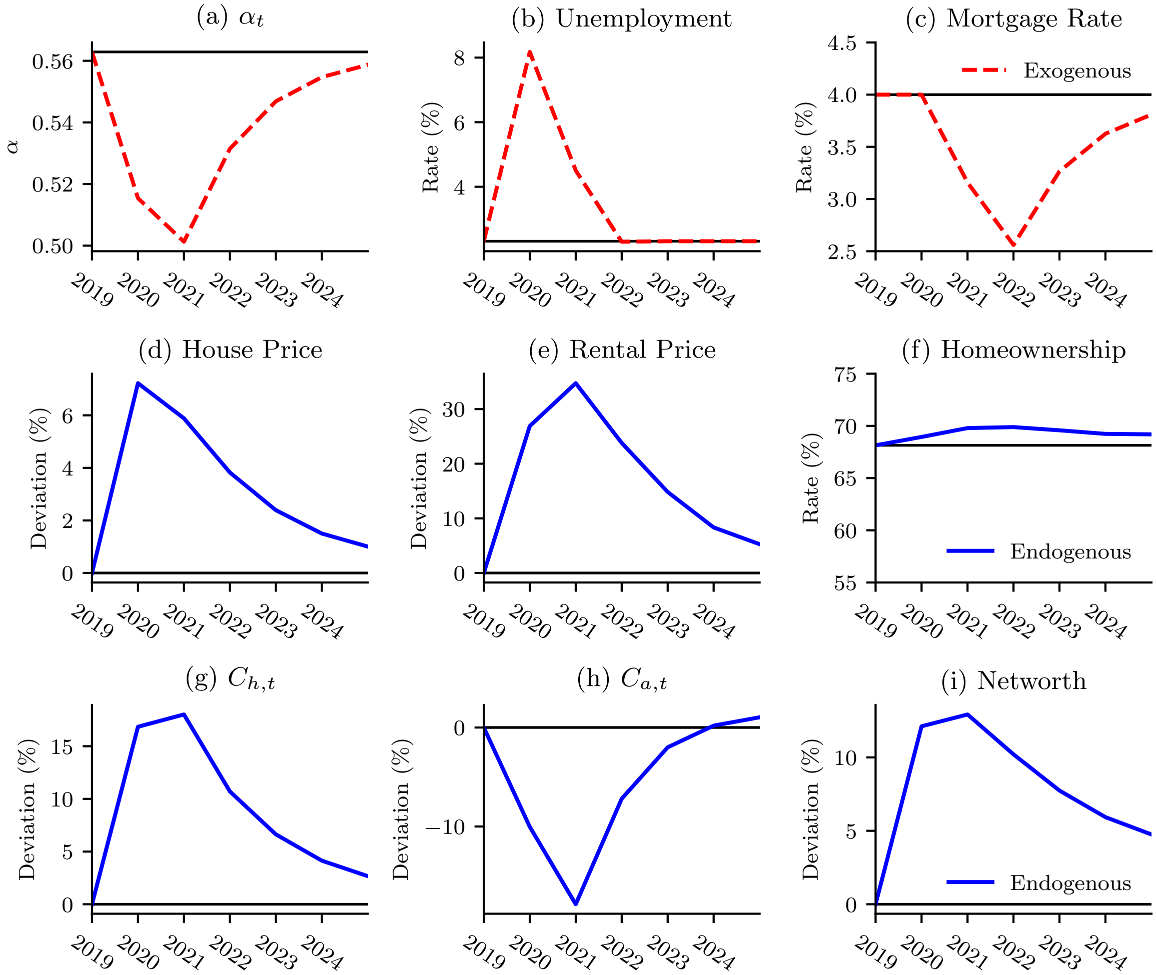
Figure 2.5 shows the responses of key macroeconomic aggregates in the model to the four pandemic shocks. Panels (a)–(c) show the exogenous paths of the preference parameter α, the unemployment rate, and the mortgage interest rate. Panels (d) and (e) show the endogenous response of the prices of owned and rental housing. Movements in house prices ensure that the overall housing market clears, while changes in rental rates are determined by the user-cost condition in Equation (2.2). House prices in the model rise by a little over 7 percent, consistent with observed excess house price growth in 2020 (see Table 2.4). Rental prices rise by significantly more than is observed in the data.[48] We discuss alternative assumptions about the rental market and rental rates in Section 2.5.4.

Panel (f) shows a small increase in the homeownership rate from 68 percent in 2019 to 70 percent by 2022. The homeownership rate slowly returns to its steady state value as the shocks dissipate. The higher ownership rate reflects the aggregate increase in housing demand in response to the preference shocks, lower mortgage rates, and stimulus measures. This increase in housing demand translates into higher house prices

$10,200. The Lost Wages Assistance program provided an additional $300 per week from August to September 2020 (6 weeks) for a total of $1,200. The American Rescue Plan Act gave UI recipients an additional $300 per week from late December 2020 to September 2021 (36 weeks) for a total of $10,800, which we allocate to households in 2021. For details on the additional UI payments see Boesch, Lim, and Nunn (2021) and Ganong et al. (2021).

[48] According to data from FRED, the annual growth rate of the CPI component for rent of the primary residence fell from 3.7 percent in 2019 to a low of 1.8 percent in 2021 (FRED code: CUSR0000SEHA).

Figure 2.5: Impulse Responses for Pandemic Experiment Shocks

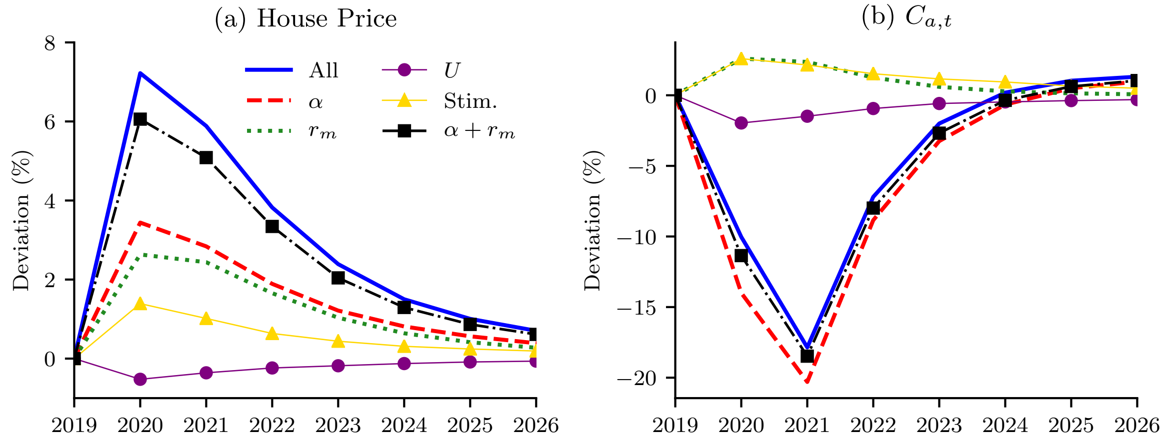


because housing supply is assumed fixed along the transition path.

Panel (i) shows that household net worth increases by over 10 percent in 2020 and remains elevated for several years. The rise in net worth in the model mostly reflects the rise in house prices, consistent with Financial Accounts data, which show that the increase in household wealth during the pandemic was largely driven by asset revaluations (Batty, Deeken, and Volz, 2021).

Finally, panels (g) and (h) show that consumption of at-home goods rises while consumption of away-from-home goods falls, in line with the significant shift in observed consumption expenditures documented in Figure 2.2. This change in the allocation of

Figure 2.6: Impulse Responses to Separate Pandemic Shocks



consumption expenditures is a direct result of the change in preferences associated with the stay-at-home shock.

Figure 2.6 illustrates a decomposition of the effect of each of the pandemic shocks on house prices and away-from-home consumption. We re-solve for the general equilibrium transition path of the economy in response to each shock separately, keeping all other exogenous variables fixed at their steady state values. We compare the effect of each shock to the model responses when the economy is hit by all four shocks, with the latter depicted in solid blue lines. The stay-at-home shock (dashed red lines) and the mortgage rate r_m shock (dotted green lines) have the largest effects on housing demand over the course of the pandemic. The stay-at-home shock alone explains 48 percent of the the increase in house prices, while the fall in mortgage rates accounts for 36 percent of the increase in house prices. Fiscal stimulus has a smaller effect on house prices, accounting for 19 percent of the price increase in 2020 (yellow lines with triangle markers). The unemployment shocks (purple lines with circle markers) also have a small effect on house prices; they cause prices to fall by 0.5 percent in 2020. It is worth noting that our model predicts that the large fiscal stimulus more than offsets the decline in housing demand caused by the spike in unemployment. The unemployment shocks have a small effect on housing demand for two reasons. First, the high steady state job finding rate implies that employment quickly recovers after the pandemic. Second, even in steady state, working households are insured by a relatively high replacement rate provided by unemployment insurance.[49]

Our model suggests that lower mortgage rates do not materially amplify the response of house prices to the stay-at-home shock. Figure 2.6(a) shows that when the economy is hit by the shift in household preferences and the mortgage rate shock simultaneously (black dashed line with square markers), the house price response is around 84 percent of the price increase in 2020. The sum of the price responses under each of the shocks separately is also around 84 percent of the total price increase. The lack of substantial amplification may seem surprising since falling mortgage rates loosen PTI constraints on mortgage borrowing, and so could potentially relax borrowing constraints at the same time as the stay-at-home shock increases housing demand. To understand why the interaction between lower mortgage rates and the stay-at-home shock does not have a quantitatively large effect in the model we compute the share of marginal house buyers for whom the PTI constraint dominates the LTV constraint, following Ma and Zubairy (2021). We define a marginal house buyer as a household whose value of purchasing a house is very close to the value of renting:

$$\frac{|V_j^O(a,h,y,e) - V_j^R(a,h,y,e)|}{|V_j^R(a,h,y,e)|} \leq 0.01$$

A marginal buyer is then PTI-dominant if the amount that can be borrowed at the maximum PTI constraint is less than the amount that can be borrowed at the maximum LTV constraint:

$$\frac{\theta_y y_j}{r_m} \leq \theta_m P_h \bar{h}$$

where $\bar{h}$ is the average house size chosen by households in steady state.

Table 2.5 reports the fraction of PTI-dominant marginal buyers in the steady state and in 2020 under selected pandemic shocks. Since the preference shock increases the demand for housing, more lower-income households want to purchase a house but these households are more likely to face a binding PTI constraint. However, the reduction in mortgage interest rates lowers the PTI ratio on new loans and so fewer marginal buyers are likely to run up against the PTI constraint. The combination of preference

[49] As Graves (2020) shows, the presence of unemployment insurance significantly dampens the aggregate demand effects of business cycle shocks in heterogeneous agent models.

Table 2.5: **Fraction of PTI Dominant Marginal House Buyers**

		Pandemic Shocks			
	Steady State	Preferences	Mortgage Rate	Preferences and Mortgage Rate	All Shocks
Frac. PTI-Dominant (%)	7.02	9.15	3.02	3.05	0.93

and mortgage shocks also results in fewer potentially PTI-constrained house buyers compared to steady state. When the economy is hit by all four pandemic shocks, the proportion of potentially PTI-constrained marginal buyers falls to just 0.9%, as the stimulus shocks also increase household income. Overall, however, the fraction of marginal buyers likely to be affected by changes in PTI is small at less than 10 percent in all experiments. Accordingly, the model generates very little amplification due to the interaction of a direct increase housing demand and looser borrowing constraints due to lower mortgage rates.[50]

2.5.3. Sources of Housing Demand Across Households

We now study the sources of the changes in housing demand during the pandemic across households. First, we consider changes in demand along the extensive margin. Table 2.6 reports the proportion of households that are renters, first-time buyers, upsizing, downsizing, refinancing their mortgage, or not adjusting their housing portfolio. The first row refers to the steady state of the model, while all other rows refer to the 2020 period following the pandemic shocks in the partial equilibrium of the model. That is, we compute changes following the shocks without the subsequent effects of endogenous house price and rental price changes. Overall, our model suggests that the increase in housing demand is largely driven by first-time home buyers. However, an increase in the proportion of homeowners who are upsizing and small declines in the number of households downsizing also contribute to higher housing demand. In steady state, 1.9 percent of households become new homeowners in a given year. In contrast, 3.3 percent, 3.8 percent, and 2.5 percent of households become first-time buyers under the preference shock, mortgage rate shock, and stimulus shock, respectively. When the economy is hit by all

[50] This lack of amplification is consistent with the model in Kaplan, Mitman, and Violante (2020), where a relaxation of borrowing constraints does not amplify the house price response to an increase in expected future housing demand.

Table 2.6: Proportion of Households by Housing Tenure, Partial Equilibrium

		Homeowners				
	Renters	First Time	Upsizing	Downsizing	Refinancing	Not Adjusting
Steady state	31.9	1.9	1.0	0.6	14.8	49.9
Preference shocks	30.1	3.3	1.6	0.4	15.0	50.9
Mortgage rate shocks	29.4	3.9	1.5	0.3	15.2	47.8
Unemployment shocks	32.3	1.8	0.9	0.8	17.3	45.7
Stimulus shocks	30.8	2.5	1.3	0.4	14.9	51.2
All Shocks	27.2	5.9	1.8	0.1	18.0	51.0

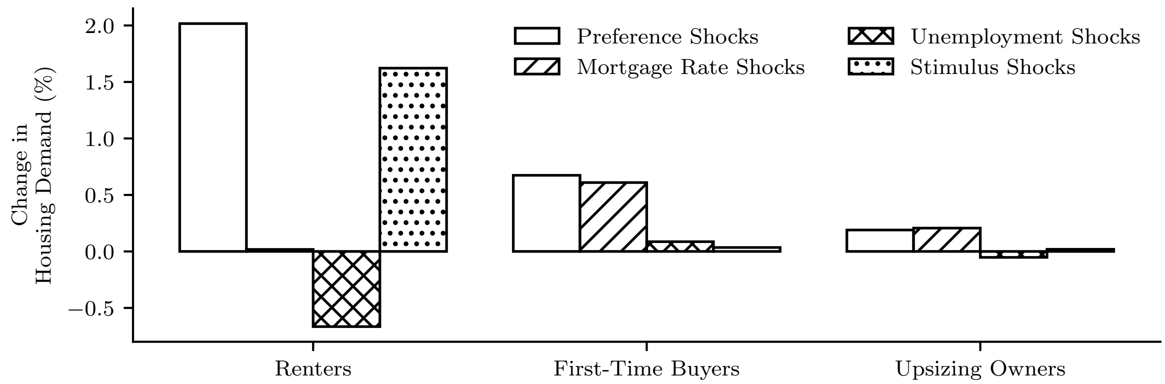
Notes: Fraction of households by type of housing decision, reported as a percent of all households. The first row computes fractions in steady state. All other rows compute fractions in the first period of the transition path following pandemic shocks under partial equilibrium (i.e. no price adjustment).

shocks simultaneously, the first-time buyer share nearly triples relative to steady state, to 6 percent of households. In steady state, one percent of households upsize their house in a given year. This number rises to 1.6 percent following the preference shocks, and to 1.5 percent following the decline in mortgage rates. The number of households downsizing their houses falls from 0.6 percent in steady state to 0.4 percent following the preference shocks, and to 0.3 percent following the mortgage rate shocks.

Second, we consider changes in housing demand along the intensive margin. Figure 2.7 shows the average house sizes chosen by renters, first time buyers, and those upsizing their housing following the pandemic shocks relative to steady state. Again, we make use of the partial equilibrium of the model so that price changes do not obscure the underlying sources of the changes in demand. As expected, preference shocks lead to increases in demand for house size for households of all tenure types. The effects are largest for renters, next largest for first-time home buyers, and smallest for upsizing homeowners. Decreases in the mortgage rate have no effect on renters since they cannot borrow. However, the mortgage rate shocks have similar effects to stay-at-home shocks among first-time buyers and upsizing owners. Unemployment shocks and stimulus shocks have large effects on renters, but very limited effects on home buyers. This is because renters tend to be younger and have lower incomes than homeowners and therefore are much more sensitive to changes in income.

Our results so far suggest that the shift to consumption at home and fall in mortgage rates account for the bulk of the changes in housing demand during the pandemic. However, the endogenous responses of housing and rental prices to the pandemic shocks also

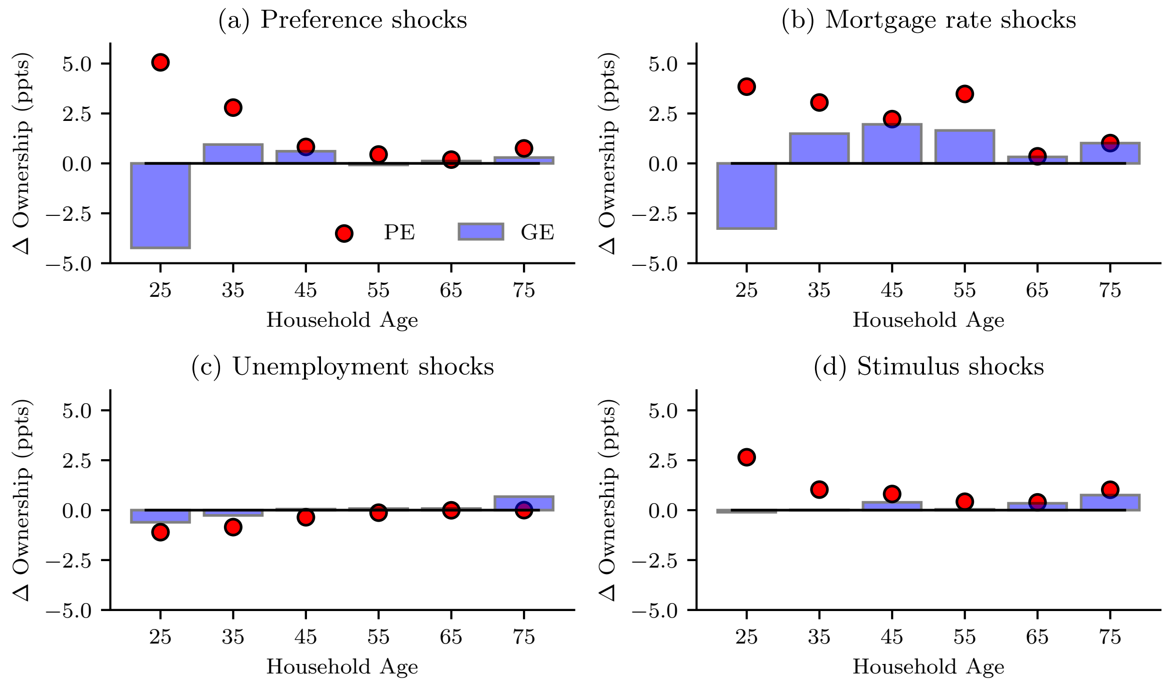
Figure 2.7: Changes in House Size by Housing Tenure, Partial Equilibrium



affect housing demand. These price changes can offset the initial effects of the pandemic shocks, and may have large implications for the equilibrium distribution of housing demand. Figure 2.8 shows changes in homeownership rates by age relative to steady state. We show the effects of each of the four shocks in general equilibrium (blue bars) and in partial equilibrium (red dots). The differences between partial equilibrium and general equilibrium effects of the pandemic illustrate how sensitive different households are to house price changes. Panel (a) shows the effect of the stay-at-home shocks alone. In partial equilibrium, young households experience a much larger increase in demand for homeownership than older households who are largely already homeowners. However, the large increase in house prices in general equilibrium more than offsets this effect so that the homeownership rate of households aged 25–35 declines. This crowding out of young households in general equilibrium is to the benefit of households aged 35–55, who enjoy a moderate increase in homeownership.

Panel (b) of Figure 2.8 shows that mortgage rate shocks result in a similar partial equilibrium increase in homeownership for households aged 25 to 65. However, again, general equilibrium house price increases crowd out young households so that homeownership declines for those aged 25 to 35. Panel (c) shows that unemployment shocks have a small negative effect on homeownership for young households, but have essentially no effect on older households. Panel (d) shows that the stimulus shocks have large partial equilibrium effects on the demand for homes among the youngest households. However, as with the other pandemic shocks, general equilibrium changes in house prices crowd out young home buyers whose homeownership rate is little changed on net.

Figure 2.8: Homeownership Changes In Partial Equilibrium and General Equilibrium



Figures B.4 and B.5 in Appendix B.3.3 reinforce the results of Figure 2.8. They illustrate the general equilibrium changes in house size choices of renters and owners in response to the pandemic shocks. Among homeowners in the first two years of the pandemic, there is a spike in demand for the largest house sizes and a fall in demand for smaller house sizes. For renters, there is a significant fall in demand for the largest rental units, and a compensating increase in demand for smaller rental units. These results reflect the fact that general equilibrium increases in house prices tend to squeeze housing demand of younger and poorer households. It is the older and wealthier households, who tend to buy larger and more expensive houses, that remain active in the housing market when house prices rise during the pandemic.

2.5.4. Robustness

We now explore the sensitivity of our model results to important assumptions about the structure of the rental market and the persistence of pandemic shocks.

First we consider the importance of our assumptions about the rental market. As shown in panel (e) of Figure 2.5, the aggregate rental price in the model is extremely sensitive to the pandemic shocks. This is both inconsistent with observed aggregate rental prices, but also with the small estimated response of rental rates in the empirical exercise of Section 2.2.3.[51] In the baseline model, the response of rents is entirely due to the user-cost Equation (2.2). In our experiments, house prices rise on impact and then fall back to steady state as the pandemic shocks dissipate. Higher rents then compensate the rental firm for the present discounted value of capital losses along the transition path.

In Appendix B.3.3 we explore the effect of alternative assumptions about the structure of the rental market. We first consider a model in which housing and rental markets are segmented and supplies of owner-occupied and rental housing are fixed along the transition path. In this version of the model, house prices adjust to clear the housing market and rental prices adjust to clear the rental market, independently of the user cost equation. Second, we consider a model in which rents are exogenously held fixed reflecting the possibility of long-term or sticky rental price contracts.[52] In this version of the model, the supply of rental housing is perfectly elastic at the steady state rental rate and house prices adjust to ensure that total housing demand (i.e. the sum of owner and renter demand) equals total housing supply. We solve these models using the same sequence of shocks as in the baseline analysis, but under the different assumptions about rental market structure. Figure B.6 reports the results. Under the assumption of segmented markets, rental prices rise by much less than in the baseline model and the homeownership rate is nearly constant. Under the assumption of exogenously fixed rental prices, rents are constant but the homeownership rate declines by 4 percentage points. Under both assumptions, equilibrium house prices and consumption patterns are essentially the same as they are in the baseline model. The main conclusion is that alternative assumptions about the structure of the rental market do not affect our conclusions about the aggregate increase in housing demand, but they do affect the allocation of housing demand across rental and owner-occupied properties.

Second, we consider the importance of our assumptions about the persistence of pan-

[51] See Table B.3 in Appendix B.2.

[52] For empirical evidence on the existence of sticky rental prices, see Aysoy, Aysoy, and Tumen (2014), Genesove (2003), and Suzuki, Asami, and Shimizu (2021). For a theoretical treatment, see Gallin and Verbrugge (2019).

demic shocks. As discussed in Section 2.5.1, we calibrate the persistence ρ_{α,r_m} of both the preference and mortgage interest rate shocks to target the overall increase in house prices observed in 2020. In Figure B.7 in Appendix B.3.3 we re-run our pandemic exercise under each of the following three assumptions: no persistence in preference shocks, no persistence in interest rate shocks, and no persistence in either preference or interest rate shocks. We use the same size of the shocks in 2020 and 2021 as in the baseline experiment (see Table 2.4), but adjust the persistence of preference and interest rate shocks in turn. Panel (a) of Figure B.7 shows that absent persistence in the shocks, house prices in 2020 and 2021 would be significantly lower. Removing persistence from only the preference shocks or the interest rate shocks reduces peak house prices from 7.2 percent above steady state in the baseline model to around 6 percent above steady state. Removing persistence from both shocks reduces peak house prices to around 5 percent above steady state. Thus, persistence in the shocks accounts for up to 30 percent of the overall increase in house prices during the pandemic period.

2.6. Conclusion

The pandemic forced households to spend more time and money at home, which appears to have had quantitatively important implications for housing market dynamics. We document a large and persistent increase in the share of household expenditure allocated to at-home consumption, and we show that more time spent at home was associated with faster house price growth during the pandemic. Our quantitative model suggests that around half of the increase in house prices over 2020 was due to these stay-at-home shocks, while lower mortgage rates accounted for around one-third of the increase. We find that young households and first-time home buyers drive the increase in underlying housing demand, but homeownership among young households declines during the pandemic due to the large equilibrium increase in house prices.

While our quantitative model provides a good fit to both pre-pandemic data and several important features of the pandemic, it remains limited in several respects. First, our model suffers from a similar problem facing most forward-looking models with asset prices: house price movements are front-loaded with respect to known future shocks. While house prices in our model jump in the first period of the pandemic before reverting to steady state, observed house price movements are more persistent. This shortcoming could potentially be overcome in a model with myopic households facing a sequence of unexpected shocks, with the addition of larger trading frictions, or with different household expectations formation. Second, to maintain computational tractability we combine households' liquid savings and mortgage debt into a single net asset position. This implies that our model is not able to match the large rise in personal savings during the pandemic. Some have suggested that the rise in household savings may have contributed to housing demand (see, for example, Bowman, 2021), possibly because it enabled households to make mortgage downpayments more easily than prior to the pandemic. We expect any additional boost to house price growth from this channel to be small compared to the effects of the shocks we model, especially since we account for the rise in household income from fiscal stimulus. However, future work could explore the "excess savings" channel by considering a model that separates liquid savings and mortgages, and directly restricts consumption opportunities early in the pandemic along the lines of Carroll et al. (2020). Finally, we do not explicitly model the effects of working from home. While changing consumption patterns are one way to rationalize an increase in housing demand, another is to consider the shift towards more time spent working from a home office, bedroom, or kitchen table. The sudden change in working patterns likely has more complex cross-sectional implications, since only some jobs can easily be carried out from home (Dingel and Neiman, 2020). We also leave this interesting issue for further research.

Chapter 3

Declining Interest Rates and Homeownership in Australia

Anirudh Yadav, Tom Cusbert and James Graham

How has the trend decline in interest rates, and the ensuing rise in house prices, affected homeownership rates by age and income in Australia? We study this question using a calibrated life-cycle model with equilibrium in housing markets. The model suggests lower rates and rising prices more than explain the decline in the under-40 homeownership rate and the decline in homeownership in the bottom income quintile since 1995. Lower mortgage deposit requirements could have supported homeownership among the young a bit as the economy transitioned to the new low interest rate equilibrium. We also find that the direct welfare costs to households of mortgage deposit requirements are much larger in the modern low-rate/high house price economy compared to the high-rate/low house price economy of the 1990s.

3.1. Introduction

From 1995 to 2018 the homeownership rate of under 40s in Australia declined by 15 percentage points from 60 to 45 per cent.[53] Among under 40s, the decline in homeownership was more pronounced for lower-income households. Over the same period, real interest

[53]Over the same period the aggregate homeownership rate declined by around 5 percentage points from 72 to 67 per cent.

rates declined by around 5 percentage points, and the average house price-to-income ratio increased by roughly 70 per cent from around 2.8 to 4.8. In this paper, we use a calibrated life-cycle model capable of linking these facts to answer two questions. First, how much of the fall in homeownership among the young and lower-income is due to the decline in real rates and the ensuing rise in house prices? Second, how have minimum mortgage deposit requirements impacted the response of homeownership rates to rising house prices resulting from lower interest rates?

In the model, households face idiosyncratic income risk and consume housing services via renting or owning their home. House purchases can be financed with long-term mortgages subject to loan-to-value (LTV) and payment-to-income (PTI) limits at origination. For our main experiment, we initialize the model with a real risk-free interest rate of 5 per cent, the level we estimate to have prevailed in the early 1990s, then gradually reduce it to 0.25 per cent, the level we estimate to have prevailed in the 2019. We implement the decline in interest rates via a sequence of 24 equally sized annual shocks (corresponding to the period 1996–2019), consistent with evidence that the decline in rates was unanticipated. In addition, we assume that households are myopic with respect to house prices: they expect the current period's house price — resulting from market clearing — to prevail forever.[54] Our benchmark model suggests that lower rates and rising house prices more than explain the decline in homeownership among the young and low-income. The house price-to-income ratio rises by around 70 per cent, roughly equal to the increase observed in the data, while the homeownership rate of under 40s declines by 38 percentage points, roughly two-and-a-half times the observed decline. In the model, as in the data, the decline in homeownership is most pronounced for young, lower-income households.

As rates decline and prices rise, required mortgage deposits increase, which may make it more difficult for young and lower-income households to buy a home. At the same time, lower returns on risk-free assets may make it more difficult to accumulate a deposit. To get at the quantitative importance of this deposit accumulation channel we repeat the main transition experiment but permanently increase the maximum LTV on mortgages by 10 percentage points from 85 to 95 per cent of housing values (reducing the minimum

[54]This informational assumption greatly reduces the computational cost of solving for the economy's transition path compared to the case where interest rates are repeatedly shocked but households have rational forward-looking expectations about future house prices.

deposit from 15 to 5 per cent of housing values) in the first period of the transition. Despite a slightly larger increase in house prices in the high LTV counterfactual, the homeownership rate of under 40s is higher than that predicted by the benchmark model throughout the transition. However, by 2019 the under-40 homeownership rate is only slighly above that in the benchmark model (24 vs. 20 per cent). The time series of homeownership rates of older households are little changed. Overall, these results suggest that while a higher LTV limit could have supported homeownership rates among the young a little bit as the economy transitioned to a low rate equilibrium, it would not have fully offset the effect of rising prices: the ownership rate of under 40s still declines by roughy 35 percentage points.

In a final experiment we compare the direct long-run welfare effects on households of increasing the LTV limit by 10 percentage points in the 1995 steady state, characterized by high interest rates and low house prices, to the welfare effects of the same policy change in a "modern" steady state, characterized by low interest rates and high house prices. The welfare effects on newborn households are much larger and positive in the low-rate/high-price economy. In the 1995 economy, the average newborn is slightly worse-off under the high LTV counterfactual due to higher house prices and rents. However, in the low-rate/high-price economy the welfare gain for the average newborn is around $1,200 (2021 AUD). The increase in average welfare in the low-rate/high-price economy is driven both by households who own their home under both the low LTV and high LTV regimes and a small proportion of households who are renters before the policy change but are able to buy a home under the high LTV counterfactual. Newborns who remain homeowners enjoy higher consumption under the high LTV regime because they put up a smaller mortgage deposit. The rent-to-own switchers are better-off because in the model the user cost of owning a home is lower than the rental rate.

Overall, our results suggest that the secluar decline in real rates and the ensuing run-up in house prices have had large negative effects on homeownership among young and low-income households. We find that higher LTV limits could have supported ownership rates along the transition, and that some households could benefit a lot from higher LTV limits in the current low-rate/high-price economy. However, a more levered household sector may come at the cost of additional aggregate financial stability risk, which we do not model.

Related Literature. The substantial decline in homeownership among younger and lower-income households since the 1980s in Australia has been well documented (Yates (2015), Daley, Coates, and Wiltshere (2018), RBA (2021)). There are similar trends in other advanced economies. The trend may be partly attributed to demographic and social factors, such as people starting work, forming long-term partnerships, and having children later in life (Baxter and McDonald (2005)). However, it is widely accepted that in a world with mortgage deposit constraints, household networth and the price of housing drive the transition from renting to owning (Gyourko (2002)). Wood, Watson, and Flatau (2006), using survey data from the late 1990s, find that that the deposit constraint is binding for around one-third of renters in Australia. Simon and Stone (2017) analyse first home buyer activity before and after the global financial crisis, and find that higher housing prices, rather than preference shifts or demographic changes, play a central role in explaining falling homeownership rates among younger households. Since discount rates have a direct link to the value of housing (and other financial assets), a natural hypothesis, which our work is the first to explore in a quantitative framework, is that falling interest rates have contributed to the decline in homeownership.

Many studies use calibrated models to study the determinants of homeownership over the lifecycle in static settings (see Davis and Van Nieuwerburgh (2015) for a comprehensive review). However, the quantiative literature studying long-run changes in homeownership rates, particularly across age groups, is relatively thin. Fisher and Gervais (2011) use a model with three life stages to study the decline in homeownership among young households in the US between 1980 and 2000. Their model suggests that the trend toward marrying later (which mechanically lowers young homeownership in their framework) and a rise in earnings risk accounts for the 3 percentage point decline in the homeownership rate of 25–44 year olds over this period. In contrast, we study a much larger decline in young homeownership, which suggests that factors other than latter marriage and earnings risk are at play. Chambers, Garriga, and Schlagenhauf (2009a) study the 5 percentage point rise in the US homeownership rate between 1994 and 2005. They find that the introduction of "combo loans", which allow borrowers to reduce their effective downpayment at the cost of slightly higher interest payments, can explain the increase in aggregate homeownership, which is driven by increased ownership among the young. In both Fisher and Gervais (2011) and Chambers, Garriga, and Schlagenhauf (2009a) the risk-free interest rate is endogenous, and both papers study time periods where the secular decline in rates was not evident.

3.2. Model

3.2.1. Household Environment

Demographics. Households live for a maximum of J years with their age indexed by j. The probability that an age-j household survives to the next year is ϕ_j.

Preferences. Households recieve utility from non-durable consumption c and consumption of housing services s. We assume a CRRA utility function over a Cobb Douglas aggregate of non-durables and housing services:

$$u(c,s) = \frac{(c^{\alpha} s^{1-\alpha})^{1-\sigma}}{1-\sigma}.$$

α measures taste for non-durable consumption relative to housing services, $1/\sigma$ is the intertemporal elasticity of substitution. Households also recieve utility from bequests that they leave behind when they die. The bequest motive takes the functional form:

$$\nu(w') = B\frac{(1+w')^{1-\sigma}}{1-\sigma}.$$

B controls the strength of the beqeust motive and the bequest w' is equal to the household's net worth left behind when they die.

Income. Household i of age j recieves income:

$$y_{i,j} = \chi_j z_{i,j}. \tag{3.1}$$

χ_j is a deterministic life-cycle component, common to all households, and $z_{i,j}$ is an idiosyncratic stochastic component. The stochastic component follows an AR(1) process in logs, with persistence ρ_z and standard deviation of innovations σ_z.

Liquid assets. Households can save in a risk-free liquid asset with a one-period real interest rate r. Borrowing in the liquid account is not allowed.

Housing. Housing services s can be obtained by renting at a unit price p_r or owning a house, with a per-unit purchase price p_h. A household who owns a house of size h recieves a service flow equal to the size of their house; i.e. $s = h$. Rental house sizes are chosen from a discrete set $\mathcal{S} = \{\underline{s}, ..., \bar{s}\}$. Similarly, owner-occupied house sizes are chosen from a discrete set $\mathcal{H} = \{\underline{h}, ..., \bar{h}\}$, which overlaps with the rental housing grid $\mathcal{S}$. We assume that the smallest house size available for purchase is larger than the smallest rental property; i.e. $\underline{h} > \underline{s}$. Homeowners pay a maintenence cost each period δ, which is proportional to the size of their house. Homeowners face transaction costs κ_b and κ_s when buying and selling their home, respectively; both transaction costs are proportional to the value of the property being bought/sold. In our parameterization of the model we calibrate the rental rate p_r to match the homeownership rate of under-40s in the initial steady state. As is common in quantitative housing models, this calibrated rental rate exceeds the user cost of owning a house in the model, which generates an incentive to own housing.[55]

Mortgages. Households can finance property purchases using long-term mortgages. We assume that the mortgage rate r_m is a constant spread λ_m above the risk-free rate: $r_m = r + \lambda_m$. Mortgages have a fixed origination cost κ_m. We assume that mortgages fully amortize over the remaining lifetime of the mortgagor, so that they must be repaid in full by the end of age J. The minimum repayment $\bar{\pi}$ faced by a mortgagor with an outstanding balance m is given by:

$$\bar{\pi} = \frac{r_m(1 + r_m)^N}{(1 + r_m)^N - 1} m \tag{3.2}$$

where $N = \min\{25, J-j+1\}$. When following this amortization schedule, a household's mortgage balance evolves according to:

$$m' = (1 + r_m)m - \bar{\pi}. \tag{3.3}$$

At origination borrowers face an LTV limit that restricts the maximum loan amount to

[55] Many modelers assume rental properties require higher maintenence expenses than owner-occupied houses, which generates a wedge between the rental rate and the user-cost of owning; see for example: Chambers, Garriga, and Schlagenhauf (2009a) and Karlman, Kinnerud, and Kragh-Sorensen (2021).

be a fraction θ_m of the house value:

$$m' \leq \theta_m p_h h'. \tag{3.4}$$

Borrowers also face a PTI limit at origination, which restricts mortgage balances to those where the minimum required repayment is less than or equal to a fraction θ_y of the mortgagor's income in the period of origination:

$$\bar{\pi} \leq \theta_y y. \tag{3.5}$$

Mortgagors may refinance by entering a new mortgage contract subject to the origination cost and the LTV and PTI constraints. If a mortgagor wants to make a repayment larger than $\bar{\pi}$ they have to refinance. Default is not permitted.

3.2.2. Household Decision Problems

Below we cast the household's problem recursively. An age-j household enters a period with an individual state vector $\mathbf{x} = (a, h, m, z)$, where a is liquid assets, h is owner-occupied housing (zero for renters), m is their outstanding mortgage balance and z is the current period's idiosyncratic component of income. Each period households make a discrete choice over whether to rent, stay in their current owner-occupied property and make a mortgage reapyment, buy a new house, or refinance their mortgage. An age-j household solves:

$$V_j(\mathbf{x}) = \max\{V_j^{\text{rent}}(\mathbf{x}), V_j^{\text{stay}}(\mathbf{x}), V_j^{\text{buy}}(\mathbf{x}), V_j^{\text{refi}}(\mathbf{x})\}. \tag{3.6}$$

A household who chooses to rent solves:

$$V_j^{\text{rent}}(\mathbf{x}) = \max_{c,a',s} u(c,s) + (1-\phi_j)\nu(w') + \phi_j \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \tag{3.7}$$

subject to:

$$c + p_r s + a' = y_j + (1+r)a + (1-\kappa_h)p_h h - \delta h - (1+r_m)m \tag{3.8}$$
$$w' = a'.$$

A household who chooses to stay in their current owner-occupied home and make a mortgage repayment (if they have outstanding debt) solves:

$$V_j^{\text{stay}}(\mathbf{x}) = \max_{c,a'} u(c,h) + (1-\phi_j)\nu(w') + \phi_j \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \tag{3.9}$$

subject to:

$$\begin{aligned} & c + \delta h + \bar{\pi} + a' = y + (1+r)a. \\ & m' = (1+r_m)m - \bar{\pi} \\ & w' = a' + p_h h - m'. \end{aligned} \tag{3.10}$$

A household who buys a new house solves:

$$V_j^{\text{buy}}(\mathbf{x}) = \max_{c,a',h',m'} u(c,h') + (1-\phi_j)\nu(w') + \phi_j \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \tag{3.11}$$

subject to:

$$c + (1+\kappa_b)p_h h' + \mathbf{1}_{m'>0}\kappa_m + a' = y_j + (1+r)a + (1-\kappa_h)p_h h - \delta h + m' - (1+r_m)m, \tag{3.12}$$

$$w' = a' + p_h h' - m',$$

and the LTV and PTI constraints (3.4,3.5). Finally, a household who refinances its mortgage solves:

$$V_j^{\text{refi}}(\mathbf{x}) = \max_{c,a',m'} u(c,h) + (1-\phi_j)\nu(w') + \phi_j \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \tag{3.13}$$

subject to:

$$\begin{aligned} & c + \delta h + \kappa_m + a' = y_j + (1+r)a + m' - (1+r_m)m, \\ & w' = a' + p_h h' - m', \end{aligned} \tag{3.14}$$

and the LTV and PTI constraints (3.4,3.5).

3.2.3. Rental Sector

The rental rate p_r is determined by the user-cost equation:

$$p_r = \frac{1}{1+r}\left(\delta + (r+\kappa_r)p_h - \mathbb{E}[\Delta p_h']\right). \tag{3.15}$$

The user-cost equation above is consistent with profit maximization by a competitive firm that owns housing and rents it out to households. The firm frictionlessly buys and sells housing, incurs the same maintenance expenses δ as households, an additional operating cost $\kappa_r > 0$, proportional to the value of housing it owns, and discounts profits at the risk-free real interest rate r. The operating cost κ_r creates a wedge between the user-cost of owning a home and the rental rate, which provides an incentive for households to own rather than rent.

3.2.4. Equilibrium

Our model represents a small open economy with the real risk-free rate r determined exogenously and the house price determined endogenously. In the initial steady state we normalize the house price p_h to be 1. The rental rate is then given by the user-cost equation C.19. Given the house price and rental rate, we solve the household's problem and compute the stationary distribution. The rental market clears by assumption because the the supply of rental units is perfectly elastic at the market rental rate. We then infer the level of housing supply $\bar{H}$ as the overall demand for housing services (i.e. rental housing demand plus owner-occupier housing demand).

Definition. A *stationary recursive competitive equilibrium* consists of: a collection of value functions $V_j(\mathbf{x})$; associated decision rules $\{c_j(\mathbf{x}), s_j(\mathbf{x}), h_j'(\mathbf{x}), m_j'(\mathbf{x}), a_j'(\mathbf{x})\}$; prices (p_h, p_r); an aggregate housing stock $\bar{H}$; and a distribution of households over idiosyncratic states μ_j for each j such that:

1. The value functions and decision rules solve the household's problems.

2. Given p_h the rental rate p_r is given by equation (C.19).

3. The aggregate housing stock is equal to the total demand for housing services:

$$\bar{H} = \sum_{j=1}^{J} \left(\int s_j(\mathbf{x}) d\mu_j(\mathbf{x}) \right)$$

4. The distribution of households over idiosyncratic states is induced by the exogenous process for income and household decision rules.

In the transition experiments the economy starts in the initial steady state where interest rates are high. We then feed in an annual sequence of unexpected (negative) shocks to the risk-free rate and mortgage rate (r, r_m), consistent with evidence that the decline in interest rates was unanticipated (Miles and Monro (2021)). Both rates decline by the same amount each period (i.e. the spread is kept constant). Households expect each shock to be permanent, so they are continually surprised by the new interest rate environment every period. The aggregate housing stock $\bar{H}$ is fixed at its level from the initial steady state, but the composition of the housing stock between owner-occupied and rental units is allowed to vary along the transition path as demand conditions change. The house price adjusts so that overall housing demand equals $\bar{H}$ each period, with the rental rate given by equation (C.19).

We also assume that households expect the equilibrium house price in every period to prevail forever.[56] That is, in period t, given a distriubtion of households over idiosyncratic states, households make their decisions assuming that (r, r_m, p_h, p_r) will prevail forever. In period $t+1$ households are surprised that interest rates (r, r_m) have declined; they are also surprised by the new house price p_h, which results from market clearing in period $t+1$. The information assumption about house prices may seem extreme but it significantly reduces the computational burden of solving the transition paths compared to the case where households are forward-looking with respect to house prices but are continually surprised by lower rates.[57]

[56]This informational assumption draws on the myopic transition experiment in Hubmer, Krusell, and Smith (2020).

[57]In the forward-looking case, we would essentially need to solve for $T = 24$ independent perfect foresight transition paths, where T is the number of years in the transition experiment, and stitch them togther.

Table 3.1: Parameter Values

Parameter	Description	Value
	A. Assigned	
σ	Relative risk aversion	2
ρ_z	Autocorrelation of earnings	0.94
σ_z	Std. dev of earnings shocks	0.18
δ	Depreciation rate	0.025
r	Initial real risk-free rate	0.05
λ_m	Mortgage spread	0.02
θ_m	LTV limit	0.85
θ_y	PTI limit	0.28
κ_m	Mortgage origination cost (2021 AUD)	1,000
κ_s	Transaction cost of buying	0.04
κ_s	Transaction cost of selling house	0.03
b_0	Frac. newborns endowed with bequest	0.7
A_0	Bequest/income ratio conditional on recieving bequest	1
	B. Calibrated	
β	Discount factor	0.92
α	Nondurable consumption weight in utility	0.72
B	Strength of bequest motive	10.01
$\underline{h}$	Smallest owned house size	3.07
κ_r	Rental firm operating cost	0.04

3.3. Parameterization

3.3.1. Model Parameters

We calibrate the model so that the steady state matches some key moments of the Australian economy in the early 1990s. We assign the values of some standard parameters based on external evidence then calibrate the remaining parameters to jointly match some key empirical moments.

Assigned Parameters

Demographics and Preferences. The model period is one year. Households enter the economy aged 25 and live up to a maximum age of 80 ($J = 56$). Age-specifc death probabilities $\{(1 - \phi_j)\}$ are taken from the 2003 ABS Life Tables. The coefficient of relative risk aversion σ is set to 2, which gives an intertemporal elasticity of substitution of 0.5.

Housing and Mortgages. We set the maximum LTV ratio θ_m to be 0.85 and the maximim PTI ratio θ_y to be 0.28. The maintenence cost δ is set to 0.025, which is roughly equal to the sum of depreciation and running costs (as a proportion of house values) from Fox and Tulip (2014). Transaction costs for buying and selling a house, κ_b and κ_s, are also from Fox and Tulip (2014), and set to 4 per cent and 3 per cent, respectively. We set the mortgage origination cost κ_m to be $1,000 (in 2021 dollars). The constant spread between the mortgage rate and the risk-free rate λ_m is set to 0.02.

Income Process and Assets of Newborns. We set the persistence of the idiosyncratic component of income ρ_z to 0.94, and the standard deviation of innovations σ_z to 0.18; both values are taken from Cho, Li, and Uren (2021). We compute the deterministic life-cycle income profile $\{\chi_j\}$ using HILDA data from 2001–2019, fitting a third-order polynomial to mean real household income by age. We assume that a fraction b_0 of newborn households in the model are endowed with a positive liquid asset balance, and the remainder are born with no assets. Newborns who are endowed with liquid assets recieve a balance equal to a fraction A_0 of their initial earnings. In this way we capture the positive relationship between wealth and earnings among young households. We assign b_0 and A_0 using data from the 2003–04 Survey of Income and Housing (SIH), which is the first wave of the SIH to include information on household wealth. We set b_0 to 0.7, which is equal to the fraction of households with heads aged 23–24 with positive net worth. We set A_0 to 1, which is equal to the median net worth to earnings ratio of households with heads aged 23–24, conditional on having positive net worth.

Interest Rates. We set r to be 5 per cent in the initial steady state, which represents the economy in the early 1990s. We compute $r = 0.05$ by subtracting the 10-year break-even inflation rate (dervied from nominal and inflation-indexed government bond yields) from the 10-year Australian government bond yield, and averaging the quarterly observations over 1990–1995. This value is robust to using nominal yields of bonds with 3- or 5-year maturities, and to using CPI inflation rather than the break-even rate to deflate the nominal yield. With a constant mortgage spread of $\lambda_m = 0.02$, the real mortgage rate r_m in the initial steady state is 7 per cent.

Fitted Parameters

The remaining five parameters $\{\beta, \alpha, B, \underline{h}, \kappa_r\}$ are jointly calibrated to minimize the distance between five moments from the model's steady state and their empirical counterparts. The resulting parameter values are listed in Panel B of Table **??**; the model-generated moments are listed alongside their empirical values in Table **??**. The parameters are jointly identified, but we point to the moments which are most relevant in pinning down each parameter. Unless otherwise stated, the emprical moments are computed from the 1994–95 wave of the SIH. The discount factor β is chosen to match a median LTV of homeowners of 0.19. The share of non-durables in utility α is chosen to match an aggregate housing value to income ratio of 2.85, derived from National Accounts data. The bequest motive parameter B affects wealth decumulation in old-age. To identify B we use the ratio of median net worth of 65–74 year olds to the median net worth of households aged 75+, equal to 1.2 in the 2003–04 SIH. The minimum house size $\underline{h}$ is chosen to match an aggregate homeownership rate of 0.73. The rental firm's operating cost κ_r controls the rent-price ratio in the initial steady state. In the model young households' tenure decisions are particularly senstive to the rent-price ratio. Accordingly, we pick κ_r to match a homeownership rate of under-40s of 0.60. The calibrated value for κ_r of 0.04 implies a rent-price ratio of 0.11 in the initial steady state.

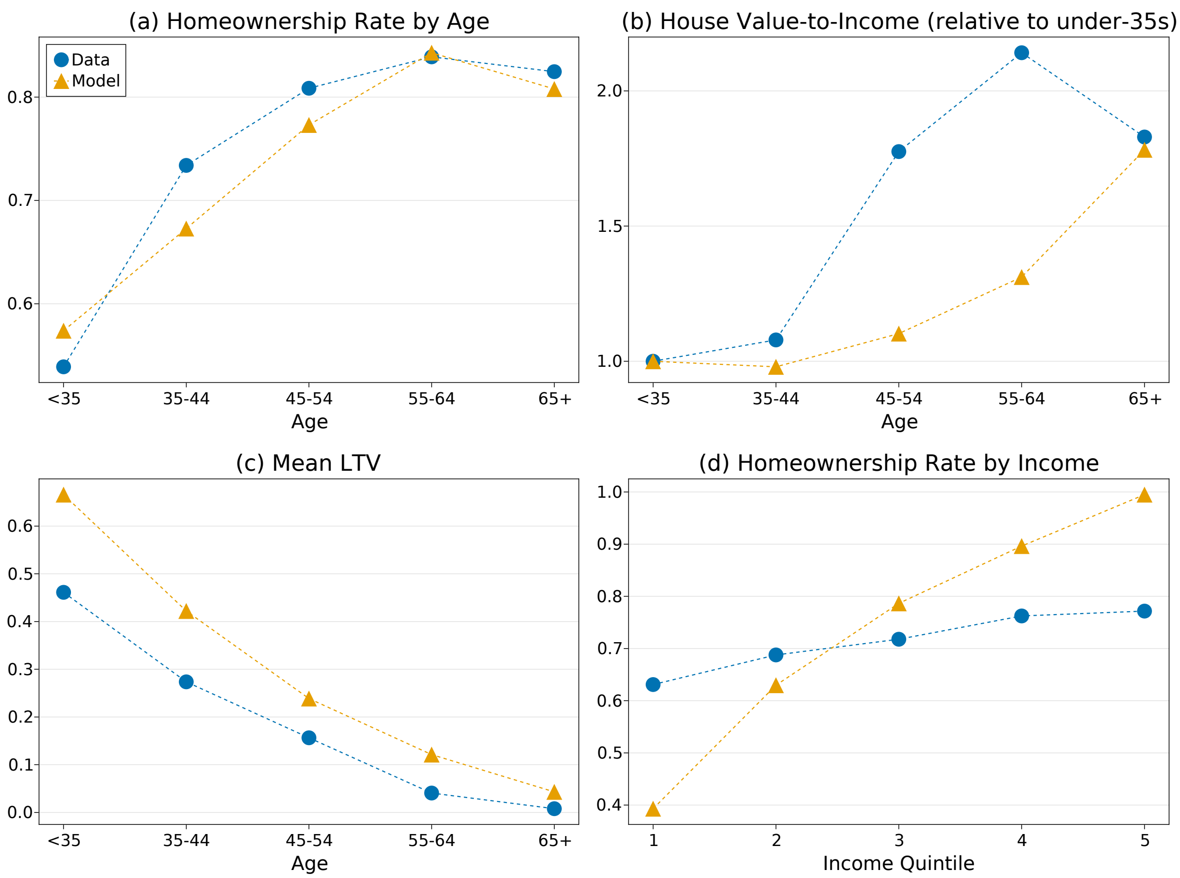
Table 3.2: Moments Targeted in Calibration

Targeted moment	**Data**	**Model**
Mean LTV	0.19	0.18
Agg. housing value / agg. income	2.85	2.82
Median net-worth ages 65–74/median net-worth ages 75+	1.21	1.20
Homeownership rate	0.73	0.74
Homeownership rate of under-40s	0.60	0.60

3.3.2. Model Steady State vs. Data

The model does a good job at matching the moments targeted in the calibration (Table 3.2). Importantly, the model matches the high homeownership rate of under-40s observed in 1994/5, which is a key statistic for our dynamic analysis below. Figure 3.1 shows untargeted profiles from the model's steady state compared to their empirical counterparts from the 1994/5 SIH. The model fits the age profile of homeownership and the mean LTV of owners well. However, the model implies that a relationship between income and homeownership that is much steeper than in the data, and also misses some of the rise in the house value-to-income ratio through middle age. Nonetheless, the model captures a rising profile of house value-to-income and a positive relationship bewtween income and ownership.

Figure 3.1: Steady State Profiles vs. Data



3.3.3. Interest Rate Decline

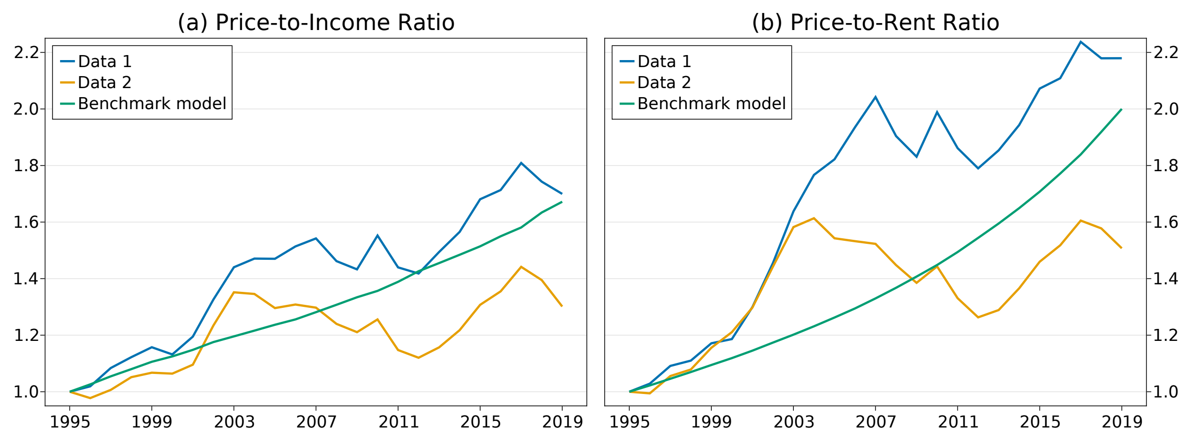
The economy starts in steady state in 1995 with a risk-free real rate of 5 per cent. We compute a real risk-free rate in 2019 of 0.25 per cent. We feed-in a linear decline in the risk-free rate from 5 to 0.25 per cent as an annual sequence of unanticipated shocks over a 24 year period (i.e. a decline of roughly 20 basis points each year).

3.4. Results

3.4.1. House Prices and Homeownership Rates Along the Transition Path

House Prices

Figure 3.2: House Prices: Model vs. Data



Notes: Data 1 in panel (a) divides the mean sales price for all dwellings from CoreLogic by annual household disposable income derived from National Accounts and Census data. Household disposable income is after tax and before the deduction of interest expenses. Data 2 in panel (a) divides CoreLogic's Home Value Index, which is a hedoinc price index, by annual household income. Data 1 in panel (b) divides CoreLogic's mean sales prices by the rent component of the CPI. Data 2 in panel (b) is the inverse of CoreLogic rental yield data from 2005 on, where rents and imputed prices are measured for the same properties. Prior to 2005, we splice with rents and prices data from the Real Estate Institute of Australia. All time series are indexed to be 1 in 1995.

Figure 3.2(a) shows the time series of the house price p_h generated by the benchmark model and two empirical measures of the house price-to-income ratio based on aggregate data.[58] The blue line measures house prices using CoreLogic data on the mean sales price for all dwellings, which makes no adjustment for changes in the composition of properties sold through time and changes in the quality of housing. The orange line measures house prices using CoreLogic's Home Value Index, a regression-based hedonic price index, which provides an estimate of pure price growth.[59] There is no compositional or quality change in the model so the hedonic measure is the empirical analog of the model's house price. Nonetheless, the mean-based measure may be a better gauge of housing affordability to the extent that it captures how easily an average household could purchase an average house. In the model, the price-to-income ratio increases by around 70 per cent over 1995–2019, while the mean-based and hedonic measures increased by around 70 and 30 per cent, respectively, over the same period. Thus, the model substantially overstates the pure house price change, but gets remarkably close to the change in the mean house price-to-income.

Figure 3.2(b) also compares model's time series of the price-to-rent ratio to two empirical measures. The blue line uses mean sales prices and the rent component of the CPI. The orange line uses CoreLogic data on a matched sample of properties, where rents and imputed prices are measured for the same properties. The CoreLogic series is available from 2005 on. Before 2005 we splice with REIA estimates of median rents and prices. The price-to-rent ratio doubles in the model. This increase is larger than the rise in the model house price since the rental rate falls by around 15 per cent in the model, which is similar to the fall in the rent-to-income ratio in the data (see Figure C.1).

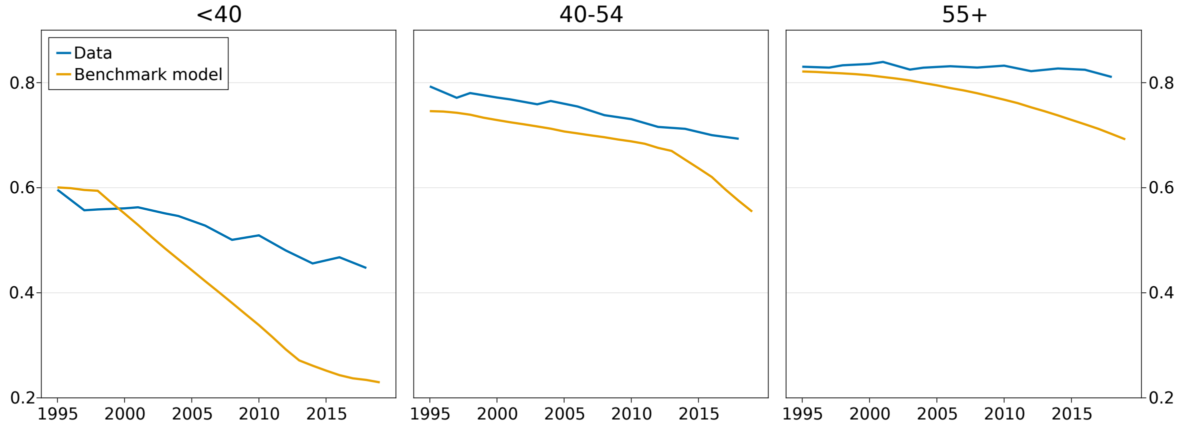
Homeownership Rates

Figure 3.3 shows the time series of homeownership rates by age group in the model vs. the data. The model matches the observed pattern of ownership rates falling by more for younger households compared to older households. Among under-40s the decline in homeownership over this period is more pronounced for lower-income households in the model and data (Figure 3.4). However, the model overstates the decline in homeowner-

[58] There is no aggregate income growth in the model so changes in the house price are equal to changes in the model's aggregate price-to-income ratio.

[59] The mean house price-to-income ratio displays lower average price growth over 1995–2019, implying that compositional and quality change has mattered empirically.

Figure 3.3: Homeownership Rates by Age

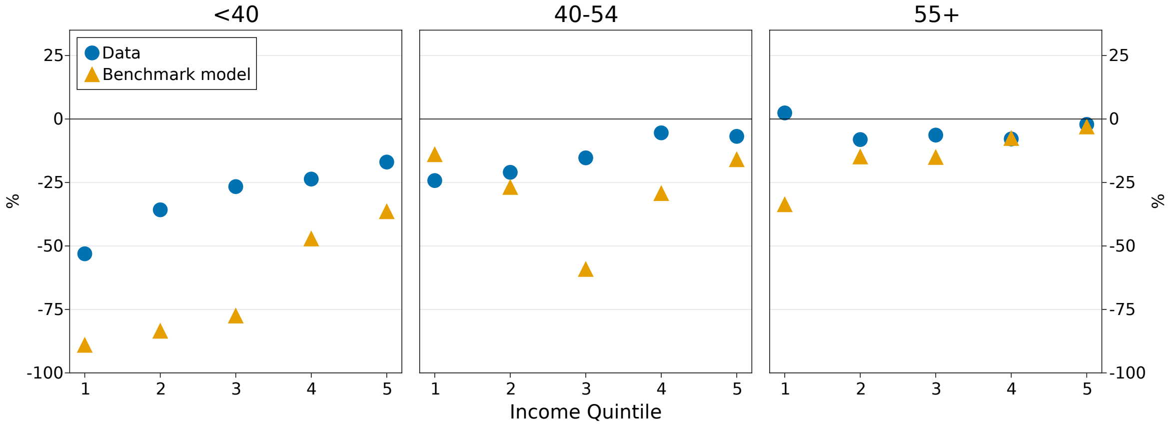


Notes: Data on homeownership rates are from the SIH, computed using household survey weights.

ship among the young: in the model the homeownership rate of under-40s declines by 30 percentage points from 60 to 30 per cent, compared to a 15 percentage point decline in the data. The model also generates a small decline in homeownership among households aged 55+, but in the data the ownership rate of these older households remained flat at around 80 per cent. Households in the model have a bequest motive, which ensures that some households die with positive wealth, as in the data. Nonetheless, as house prices rise along the transition some existing homeowners in the model choose to extract equity in old-age by selling their home and renting. In contrast, own-to-rent transitions among older households are very rare. There are of course other factors beyond a bequest motive that contribute to sticky homeownership in old-age, which our model ignores. For example, the Australian pension system gives preferential treatment to homeowners compared to renters and many older households may have strong ties to their family home.

There are several potential explanations for why homeownership among the young may have declined by less than our model suggests in response to lower rates and rising prices. Perhaps the most obvious explanation is that parental transfers for downpayment assistance may have increased as house prices have risen. In our model 70 per cent of newborns are endowed with a bequest equal to their initial income, but this share and the dollar amount of these initial bequests do not change over time. Ellis (2017) provides suggestive evidence that the share of first home buyers in Australia receiving help from

Figure 3.4: Change in Homeownership Rates by Age and Income, 1995–2019



Notes: Data on homeownership rates are from the SIH, computed using household survey weights.

family or friends to accumulate a mortgage deposit has been increasing over time, but remains fairly low (under 15 per cent) as of 2011–2015. For the US, Brandsaas (2021) reports that around 30 per cent of first home buyers received downpayment assistance from parents over 2009–2016, and that this share has increased over time. Furthhremore, Brandsaas (2021) builds a quantitative housing model with interactions between parents and children, and estimates that without parental transfers the homeownership rate of 25-44 year olds would be 15 percentage points lower. In future work, it would be possible to use our model to estimate the increased prevalance of parental transfers by computing how much the initial wealth of households would have to increase by so that the decline in homeownership of the young matches the decline in the data.

Another possibility is that the minimum owner-occupied house size $\underline{h}$ is fixed over time in our model and that it may, in some sense, be "too large" in the later periods of the transition. For example, Daley, Coates, and Wiltshere (2018) report that apartments have accounted for a larger share of building approvals since around 2000, and that apartment completions boomed in Australia's major cities after 2013. It seems highly likely that apartment sales were concentrated among younger households over this period. Thus, it is possible that our model does not pick-up the "emergence" of this new type of smaller dwelling, which may have supported ownership rates as prices rose. Other, more speculative, explanations why the model overstates the decline in homeownership among the young include: (i) government first home buyer subsidies;

(ii) expectations of strong house price and/or rent growth in the future. In the case of (i) Wood, Watson, and Flatau's (2006) microsimulation model suggests that first home buyer subsidies tend to bring forward purchases by households who would have bought a home at a later date in absense of the subsidy, rather than actually boosting overall homeownership. And in the case of (ii) strong house price growth expectations would increase house prices today, possibly making credit contraints more binding; so it is unclear on net how that would affect ownership rates. We leave incorporating these explanations into a quantitative framework for future work.

3.4.2. The Role of LTV Constraints

In this section we examine how the mortgage downpayment constraint has affected the response of homeownership rates to rising house prices caused by lower interest rates. To do so, we repeat the same transition experiment as above but we permanently increase the LTV limit on mortgages from 85 per cent to 95 per cent in the first period of the transition (1996). Figure 3.5 shows the house price paths generated by the benchmark model and the model with the higher LTV limit. The house price response is slightly larger under the higher LTV limit, with prices growing by 43 per cent over 1995–2019, compared to 37 per cent in the benchmark model.

Figure 3.5: House Prices in the High LTV Counterfactual

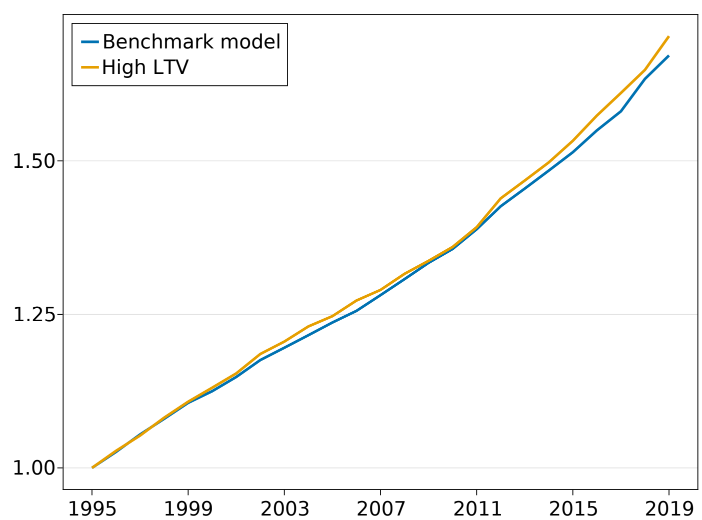
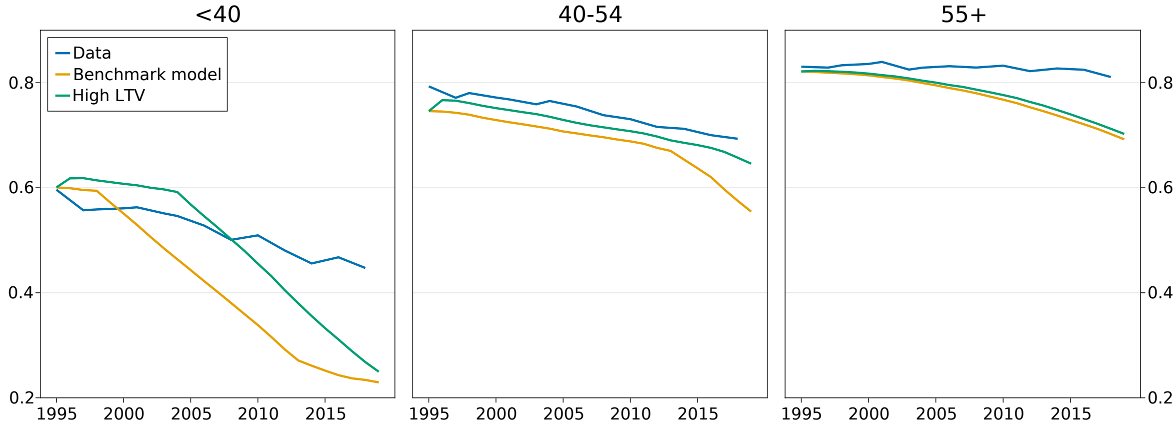


Figure 3.6: Homeownership Rates by Age in the High LTV Counterfactual



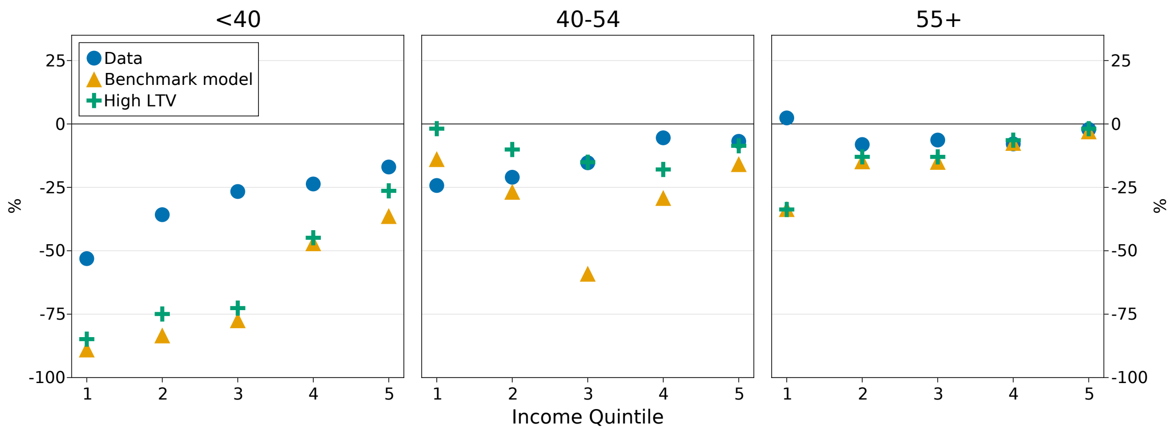
Notes: Data on homeownership rates are from the SIH, computed using household survey weights.

Despite the slightly larger house price response, the homeownership rate of under-40s remains well-above that implied by the benchmark model for most of the the transition (Figure 3.6). However, the under-40 homeownership rate is essentially the same by the end of the transition in 2019 in both versions of the model (25 per cent in the high LTV counterfactual vs. 23 per cent in the benchmark model) (also see Figure 3.7). The time series of homeownership rates of older households are little changed. Overall, the model suggests that a higher LTV limit could have supported homeownership rates of younger households a little bit as the economy transitioned to the low rate equilibrium despite causing slightly higher house prices.

Welfare effects of increasing the LTV limit in a high-rate vs. low-rate economy

In our final experiment we compare the direct welfare effects to households from increasing the LTV limit when the economy starts in a high interest rate, low house price steady state (representing the economy of the early 1990s) to the the welfare effects of the same policy change when the economy starts from a low rate, high price steady state (representing the modern economy). Starting from either the high-rate or low-rate steady state, we permanently increase the LTV limit from 85 to 95 per cent and re-solve for the new steady state (with a new house price and rental rate). We compute the welfare changes of newborn households as the change in the households' value, scaled

Figure 3.7: Change in Homeownership Rates by Age and Income in the High LTV Counterfactual, 1995–2019



Notes: Data on homeownership rates are from the SIH, computed using household survey weights.

by their marginal utility of nondurable consumption in the initial steady state:

$$\frac{\widetilde{V}(\mathbf{x}) - V(\mathbf{x})}{u'_c(c(\mathbf{x}), s(\mathbf{x}))}$$

where $\widetilde{V}$ is the household's value in the high LTV steady state and V is the household's value in the initial low LTV steady state. This calculation allows us to report welfare changes in 2021 AUD.[60] Table 3.4 summarizes the results of this experiment. House prices and rents increase very slightly in both the high-rate and low-rate economies. On average, newborn households in the high-rate economy are slightly worse-off when born into an alternate steady state with a higher LTV. In contrast, the average newborn in the low-rate economy is better-off under a higher LTV regime, with an average gain of $1,161 2021 AUD. This large average welfare gain in the low-rate economy reflects gains for households who own under both regimes, but have higher consumption under the high LTV regime because they put up a smaller mortgage deposit, and gains for the small proportion of households who switch from renting to owning. These switchers gain because the user cost of owning is lower than the rental rate in the model. Overall, we

[60]To convert model units into dollars we note that median household income was 54,000 2021 AUD in 1994 and scale units in the model accordingly. The same type of conversion is used by Boar, Gorea, and Midrigan (2021) to transalte welfare changes into dollar amounts.

Table 3.3: Long-Run House Price, Rent, and Welfare Changes of Newborns from Increasing the LTV Limit, By Initial Steady State

	$\%\Delta p_h$	$\%\Delta p_r$	Mean Welfare Change
High-rate economy ($r = 0.05$, $p_h = 1$)	0.50	0.39	-494
Low-rate economy ($r = 0.0025$, $p_h = 1.4$)	0.25	0.17	1,160

Notes: Welfare changes are computed as changes in the household's value scaled by their marginal utility of nondurable consumption, then translated into 2021 AUD. The mean welfare change is computed using household weights from the distribution of income/wealth of newborns, which is invariant in the model.

Table 3.4: Long-Run Welfare Changes of Newborns from Increasing the LTV Limit, By Initial Steady State and Tenure Transitions

	O2O	**R2O**	**R2R**
High-rate economy ($r = 0.05$, $p_h = 1$)	-639	6,961	-524
	[0.5]	[0.01]	[0.49]
Low-rate economy ($r = 0.0025$, $p_h = 1.4$)	4,161	15,341	25
	[0.17]	[0.03]	[0.8]

Notes: Welfare changes are computed as changes in the household's value scaled by their marginal utility of nondurable consumption, then translated into 2021 AUD. The mean welfare change is computed using household weights from the distribution of income/wealth of newborns, which is invariant in the model. "O2O" refers to own-to-own tenure transitions; "R2O" refers to rent-to-own; and "R2R" refers to rent-to-rent. The numbers in square brackets are the share of newborn households who make each tenure transition. In both cases no owners switch to renting as a result of the policy change, so this transition is excluded from the table.

conclude that the direct welfare gains to households from a higher LTV is much larger in a modern low-rate/high-price economy compared to the high-rate/low-price economy of the 1990s. However, we note that our experiment only sheds light on *direct* welfare effects on households from this type of policy change. A more levered household sector comes with possibly higher financial stability risk, which may impose indirect welfare costs on households if the aggregate economy is more suseptible to shocks.

3.5. Conclusion

Our model suggests that the trend decline in interest rates, and the ensuing rise in house prices, has played a large role in lowering homeownership among younger and lower-income households over 1995–2019. It also suggests that higher LTV limits could have supported ownership rates of the young a little bit, and that some households would gain a lot from a higher LTV limit in the current low interest rate, high house price economy.

A limitation of our model is that it does not incorporate income or population growth, and housing supply is fixed. A more comprehensive analysis could incorporate growth and an upward-sloping supply curve to study how these factors, along with the decline in interest rates, have interacted and contributed to changes in homeownership rates. Another limitation of our analysis is that it ignores potential financial stability risks that may arise from policies that ease mortgage constraints. Future work could extend our model to include mortgage default and aggregate risk to study the welfare effects of higher LTV polcies in an economy that experiences financial crises and other types of recessions.

Appendix A

Appendix for Chapter 1

A.1. Stationary Equilibrium As A System of Equations

A.1.1. Preliminaries

- Household age is indexed by $j = 1, ..., J$. They enter the period with individual state vector $\mathbf{x} = (a, h, m_h, i, m_i, z)$, where $a \in \mathcal{A}$ is liquid assets, $h \in 0 \cup \mathcal{H}$ is owner-occupied house size (zero for renters), $m_h \in \mathcal{M}_h$ is owner-occupied mortgage debt, $i \in \{0, \underline{i}\}$ is investment property size (zero for renters and non-investor owner-occupiers), $m_i \in \mathcal{M}_i$ is investor mortgage debt, and z is the current period's idiosyncratic income shock. Let $X = \mathcal{A} \times 0 \cup \mathcal{H} \times \mathcal{M}_h \times \{0, \underline{i}\} \times \mathcal{M}_i \times \mathcal{Z}$ be the idiosyncratic state space for an age-j household.

- To ease notation slightly, define a household's cash-on-hand b as:

$$b \equiv y + (1+r)a - (1+r_h)m_h - (1+r_i)m_i + (1-\delta-\kappa_s)p_h(h+i).$$

  Dependence of b on the individual state $\mathbf{x}$ is implict below.

- Also, for each type of mortgage $l \in \{h, i\}$ define the maximum mortgage balance at origination $\bar{M}_l$ as:

$$\bar{M}_h \equiv \min\left\{\theta_h p_h h', \theta_y y_j \left[\frac{(1+r_h)^N - 1}{r_h(1+r_h)^N}\right]\right\}, \quad \bar{M}_i \equiv \min\left\{\theta_i p_h i', \theta_y y_j \left[\frac{(1+r_i)^N - 1}{r_h(1+r_i)^N}\right]\right\},$$

where $N = J - j$. Dependence of $\bar{M}_l$ on choice of house size h', i', and the house price p_h is implicit below.

- Also, recall that the minimum mortgage repayment $\bar{\pi}_l$ payable by a mortgagor that does not adjust its house size or refinance its mortgage is

$$\bar{\pi}_l = \frac{r_l(1+r_l)^N}{(1+r_l)^N - 1} m_l \quad \forall l \in \{h, i\}$$

Dependence of $\bar{\pi}_l$ on the mortgage balance brought into the period m_l is implicit below.

A.1.2. Decision problems

Let $K = \{\text{rent}, \text{adjust}, \text{invest}, \text{stay}, \text{refi}, \text{disinvest}\}$ denote the mutually exclusive and exhaustive options available to a household each period. To save notation in the description of the household's decision problem below I omit the dependence of state and choice variables on age j. For each $k \in K$ the household's Bellman equation is:

$$V_j^k(\mathbf{x}) = \max_{c,a',s,h',m_h',i',m_i'} u(c,s) + \beta \mathbb{E}[V_{j+1}(\mathbf{x}')] \tag{A.1}$$

subjet to:

$$b + m_h' + m_i' = \begin{cases} c + a' + p_r s & \text{if } k = \text{rent} \\ c + a' + \kappa_m + \mathbf{1}_{h' \neq h} p_h h' + \mathbf{1}_{h'=h}(1-\kappa_s) p_h h + (1-\kappa_s) p_h i & \text{if } k = \text{adjust} \\ c + a' + \kappa_m + p_h i' + (1-\kappa_s) p_h h - (1-\gamma) p_r i' & \text{if } k = \text{invest} \\ c + a' + \kappa_m + (1-\kappa_s) p_h (h+i) & \text{if } k = \text{refi} \\ c + a' + (1-\kappa_s) p_h (h+i) & \text{if } k = \text{stay} \\ c + a' + \mathbf{1}_{h' \neq h}(p_h h' + \kappa_m) + \mathbf{1}_{h'=h}(1-\kappa_s) p_h h & \text{if } k = \text{disinvest} \end{cases} \tag{A.2}$$

and:

$$a' \geq 0 \qquad \forall k \tag{A.3}$$

$$\begin{aligned} &s = h' && \text{if } k \neq \text{rent} \\ &m'_l \geq 0 \quad \forall l \in \{h, i\} && \text{if} \quad k \neq \text{rent} \end{aligned} \tag{A.4}$$

$$m'_h \leq \bar{M}_h \qquad \text{if } k = \{\text{adjust}\} \tag{A.5}$$

$$m'_i \leq \bar{M}_i \qquad \text{if } k = \{\text{invest}, \text{refi}\} \tag{A.6}$$

$$\begin{aligned} &m'_h = (1 + r_h)m_h - \bar{\pi}_h && \text{if } k \in \{\text{inv.}, \text{refi}, \text{stay}\} \text{ or if } k = \text{disinv. } \& \ h' = h \\ &m'_i = (1 + r_i)m_i - \bar{\pi}_i && \text{if } k \in \{\text{stay}, \text{adjust}\} \\ &m'_l = 0 \quad \forall l \in \{h, i\} && \text{if } k = \text{rent} \\ &m'_i = 0 && \text{if } k = \text{disinvest} \\ &c > 0, s \in \mathcal{S}, h' \in 0 \cup \mathcal{H}, i' \in \{0, \underline{i}\} && \forall k \end{aligned}$$

I make the additional restriction that renters cannot buy and investment property: i.e. $V_j^{\text{invest}}(\mathbf{x}) = -\infty$ if $h = 0$. Let

$$V_j(\mathbf{x}) = \int_0^\infty \max\{V_j^{\text{rent}}(\mathbf{x}), V_j^{\text{adjust}}(\mathbf{x}), V_j^{\text{invest}}(\mathbf{x}) - \xi, V_j^{\text{stay}}(\mathbf{x}), V_j^{\text{refi}}(\mathbf{x}), V_j^{\text{disinvest}}(\mathbf{x})\} dG(\xi) \tag{A.7}$$

be the envelope over these options, integrating over the iid utility cost of investing, drawn from an exponential distribution with mean λ:

$$G(\xi) \overset{iid}{\sim} 1 - \exp\left(-\frac{\xi}{\lambda}\right). \tag{A.8}$$

The solution to the household's problem is given by $V_j(\mathbf{x})$ for each j and $\mathbf{x} \in X$ and associated policy functions:

$$\{c_j(\mathbf{x}), a'_j(\mathbf{x}), h'_j(\mathbf{x}), s_j(\mathbf{x}), m'_{h,j}(\mathbf{x}), m'_{i,j}(\mathbf{x}), i'_j(\mathbf{x})\}$$
$$\{g_j^{\text{rent}}(\mathbf{x}), g_j^{\text{adjust}}(\mathbf{x}), g_j^{\text{invest}}(\mathbf{x}), g_j^{\text{refi}}(\mathbf{x}), g_j^{\text{stay}}(\mathbf{x}), g_j^{\text{disinvest}}(\mathbf{x}), \xi_j^*(\mathbf{x})\}$$

where $g_j^k(\mathbf{x})$ is a dummy variable that denotes whether the discrete choice $k \in K$ is optimal and $\xi_j^*(\mathbf{x})$ is the critical value of ξ for investing, defined below.

A.1.3. Optimality conditions

Liquid assets

The Euler equation for liquid assets is

$$u_c(c, s) = \beta \mathbb{E}\left[\frac{\partial V_{j+1}}{\partial a'}\right] + \lambda_a \tag{A.9}$$

where $\lambda_a \geq 0$ is the Lagrange multiplier on the non-negativity constraint for liquid assets (A.3), and $u_c(\cdot)$ denotes the partial derivative of the utility function with respect to c. The associated complementary slackness condition is:

$$\lambda_a a' = 0 \tag{A.10}$$

Mortgages

The optimality condition for owner-occupied mortgage debt is

$$\begin{cases} m'_h = 0 & \text{if } g_j^{\text{rent}}(\mathbf{x}) = 1 \\ m'_h = (1 + r_h)m_h - \bar{\pi}_h & \text{if } g_j^{\text{stay}}(\mathbf{x}) + g_j^{\text{invest}}(\mathbf{x}) + g_j^{\text{refi}}(\mathbf{x}) + g_j^{\text{disinvest}}(\mathbf{x})\mathbf{1}_{(h'_j(\mathbf{x})=h)} = 1 \\ u_c(c, s) = -\beta \mathbb{E}\left[\frac{\partial V_{j+1}}{\partial m'_h}\right] - \lambda_{m,1} + \lambda_{m,2} & \text{otherwise} \end{cases} \tag{A.11}$$

where $\lambda_{m,1} \geq 0$ is the Lagrange multiplier on the nonegativity constraint for mortgages (A.4), and $\lambda_{m,2} \geq 0$ is the Lagrange multiplier on the borrowing limit (A.5). The associated complementary slackness conditions are:

$$\lambda_{m,1} m'_h = 0 \tag{A.12}$$

$$\lambda_{m,2}(m'_h - \bar{M}_h) = 0 \tag{A.13}$$

Similarly, the optimality condition for investor mortgage debt is

$$\begin{cases} m'_i = 0 & \text{if } g_j^{\text{rent}}(\mathbf{x}) + g_j^{\text{disinvest}}(\mathbf{x}) = 1 \\ m'_i = (1 + r_i)m_i - \bar{\pi}_i & \text{if } g_j^{\text{stay}}(\mathbf{x}) + g_j^{\text{adjust}}(\mathbf{x}) = 1 \\ u_c(c, s) = -\beta \mathbb{E}\left[\frac{\partial V_{j+1}}{\partial m'_i}\right] - \lambda_{m,3} + \lambda_{m,4} & \text{otherwise} \end{cases} \tag{A.14}$$

with $\lambda_{m,3} \geq 0$ and $\lambda_{m,4} \geq 0$ and slackness conditions:

$$\lambda_{m,1} m'_i = 0 \tag{A.15}$$

$$\lambda_{m,2}(m'_i - \bar{M}_i) = 0 \tag{A.16}$$

Rental and owner-occupied house size

House sizes are discrete. Accordingly, optimal housing services consumption s is given by the house size that maximizes the households value function, conditional on their other choices being optimal:

$$s = \begin{cases} \arg\max_{s \in \mathcal{S}} V_j^{\text{rent}}(\mathbf{x}; c, a', s) & \text{if } g_j^{\text{rent}}(\mathbf{x}) = 1 \\ \arg\max_{h' \in \mathcal{H}} V_j^{\text{adjust}}(\mathbf{x}; c, a', m'_h, h') & \text{if } g_j^{\text{adjust}}(\mathbf{x}) = 1 \\ \arg\max_{h' \in \mathcal{H}} V_j^{\text{disinvest}}(\mathbf{x}; c, a', m'_h, h') & \text{if } g_j^{\text{disinvest}}(\mathbf{x}) = 1 \\ h & \text{if } g_j^{\text{refi}}(\mathbf{x}) + g_j^{\text{stay}}(\mathbf{x}) = 1 \end{cases} \tag{A.17}$$

Optimal owner-occupied house size is:

$$h' = \begin{cases} 0 & \text{if if } g_j^{\text{rent}}(\mathbf{x}) = 1 \\ s & \text{otherwise} \end{cases} \tag{A.18}$$

Investing

Define $\tilde{K} \equiv K \backslash \{\text{invest}\}$. Homeowners only invest if the gain from investing, after incurring the stochastic utility cost, exceeds the gain from the next best alternative:

$$V_j^{\text{invest}}(\mathbf{x}) - \xi > \max_{k \in \tilde{K}} \{V_j^k(\mathbf{x})\}.$$

Thus, the cutoff for investing is:

$$\xi_j^*(\mathbf{x}) = \max \left\{ V_j^{\text{invest}}(\mathbf{x}) - \max_{k \in \tilde{K}} \{V_j^k(\mathbf{x})\}, 0 \right\}. \tag{A.19}$$

Homeowners who draw $\xi < \xi_j^*(\mathbf{x})$ invest, while homeowners who draw $\xi > \xi_j^*(\mathbf{x})$ do not:

$$g_j^{\text{invest}}(\mathbf{x}) = \begin{cases} 1 & \text{if } \xi < \xi_j^*(\mathbf{x}) \\ 0 & \text{otherwise} \end{cases} \tag{A.20}$$

And the optimality condition for investment property is:

$$i_j'(\mathbf{x}) = \begin{cases} \underline{i} & \text{if } g_j^{\text{invest}}(\mathbf{x}) + g_j^{\text{refi}}(\mathbf{x}) + g_j^{\text{stay}}(\mathbf{x}) = 1 \\ i & \text{if } g_j^{\text{adjust}}(\mathbf{x}) = 1 \\ 0 & \text{otherwise} \end{cases} \tag{A.21}$$

Discrete choice

For each $k \in \tilde{K}$:

$$g_j^k(\mathbf{x}) = \begin{cases} 1 & \text{if } V_j^k = \max_{l \in K} \{V_j^l\} \\ 1 & \text{if } V_j^k = \max_{l \in \tilde{K}} \{V_j^l\} \ \& \ \xi > \xi_j^*(\mathbf{x}) \\ 0 & \text{otherwise.} \end{cases} \tag{A.22}$$

A.1.4. System of equations

Let N_x be the number of grid points in the idiosyncratic state space for an age-j household. Let $\mu_j(\mathbf{x})$ denote the measure of households with individual state $\mathbf{x}$ at the start of age j.

Exogenous variables

- Income $y_j(\mathbf{x})$ for each j and $\mathbf{x} \in X$
- Initial distribution of households $\mu_1(\mathbf{x})$ for each $\mathbf{x} \in X$

Endogenous variables

- Values: $\{V_j(\mathbf{x}), V_j^{\text{rent}}(\mathbf{x}), V_j^{\text{adjust}}(\mathbf{x}), V_j^{\text{invest}}(\mathbf{x}), V_j^{\text{refi}}, V_j^{\text{stay}}, V_j^{\text{disinvest}}(\mathbf{x})\}$ for each j and $\mathbf{x} \in X$
- Policies:

$$\{c_j(\mathbf{x}), a'_j(\mathbf{x}), h'_j(\mathbf{x}), s_j(\mathbf{x}), m'_{h,j}(\mathbf{x}), m'_{i,j}(\mathbf{x}), i'_j(\mathbf{x})\}$$

$$\{g_j^{\text{rent}}(\mathbf{x}), g_j^{\text{adjust}}(\mathbf{x}), g_j^{\text{invest}}(\mathbf{x}), g_j^{\text{refi}}(\mathbf{x}), g_j^{\text{stay}}(\mathbf{x}), g_j^{\text{disinvest}}(\mathbf{x}), \xi_j^*(\mathbf{x})\}$$

  for each j and $\mathbf{x} \in X$
- Lagrange multipliers: $\{\lambda_{a,j}(\mathbf{x}), \lambda_{m,1,j}(\mathbf{x}), \lambda_{m,2,j}(\mathbf{x}), \lambda_{m,3,j}(\mathbf{x}), \lambda_{m,4,j}(\mathbf{x})\}$ for each j and $\mathbf{x} \in X$
- Prices: $\{p_h, p_r\}$
- Distribution of households $\mu_j(\mathbf{x})$ for each $j \in \{2, ..., J\}$ and $\mathbf{x} \in X$

Accordingly, there are $7JN_x + 14JN_x + 5JN_x + 2 + (J-1)N_x = (27J-1)N_x + 2$ variables to be determined in stationary equilibrium.

System of equations

- Intermediate value functions: equation (A.1) holds for each $k \in K$, j and $\mathbf{x} \in X$.
- Value function: equation (A.7) holds for each j and $\mathbf{x} \in X$
- Optimality condition for liquid assets: equation (A.9) holds for each j and $\mathbf{x} \in X$
- Optimality condition for owner-occupied mortgage debt equation (A.11) holds for each j and $\mathbf{x} \in X$
- Optimality condition for investor mortgage debt equation (A.14) holds for each j and $\mathbf{x} \in X$

- Complementary slackness conditions: equations (A.10), (A.12), (A.13), (A.15) and (A.16) hold for each j and $\mathbf{x} \in X$
- Optimality condition for housing services: equation (A.17) holds for each j and $\mathbf{x} \in X$
- Optimality condition for owner-occupied house size: equation (A.18) holds for each j and $\mathbf{x} \in X$
- Critical value for investment: equation (A.19) holds for each j and $\mathbf{x} \in X$
- Optimality condition for investment property: equation (A.21) holds for each j and $\mathbf{x} \in X$
- Optimal discrete choice: equation (A.22) holds for each $k \in \tilde{K}$, j and $\mathbf{x} \in X$ and (A.20) holds for j and $\mathbf{x} \in X$.
- Budget constraints: for each j and $\mathbf{x} \in \mathbb{X}$:

$$c_j(\mathbf{x}) = \begin{cases} b + m_h' + m_i' - a' - p_r s & \text{if } g^{\text{rent}} = 1 \\ b + m_h' + m_i' - a' - \kappa_m - \mathbf{1}_{h' \neq h} p_h h' - \mathbf{1}_{h'=h}(1-\kappa_s)p_h h + (1-\kappa_s)p_h i & \text{if } g^{\text{adjust}} = 1 \\ b + m_h' + m_i' + (1-\gamma)p_r i' - a' - \kappa_m - (1-\kappa_s)p_h h - p_h i' & \text{if } g^{\text{invest}} = 1 \\ b + m_h' + m_i' - a' - \kappa_m - (1-\kappa_s)p_h h & \text{if } g^{\text{refi}} = 1 \\ b + m_h' + m_i' - a' - (1-\kappa_s)p_h(h+i) & \text{if } g^{\text{stay}} = 1 \\ b + m_h' + m_i' - a' - \mathbf{1}_{h' \neq h}(p_h h' + \kappa_m) - \mathbf{1}_{h'=h}(1-\kappa_s)p_h h & \text{if } g^{\text{disinvest}} = 1 \end{cases} \tag{A.23}$$

In the above equation, a', h', m_h', i', m_i' and g^k for each $k \in K$ on the RHS should be interpreted as the optimal age-j decision rules at the point $\mathbf{x}$.

- Rental firm optimality:

$$p_r = q \tag{A.24}$$

- Housing market clearing:

$$\sum_{j=1}^{J}\sum_{X}(h'_j(\mathbf{x}) + i'_j(\mathbf{x}))\mu_j(\mathbf{x}) = \bar{H}p_h^{\phi} \tag{A.25}$$

- Law of motion for the distribution of households: for each $j \in \{1, ..., J-1\}$ and $\mathbf{x}' \in \mathbb{X}$:

$$\mu_{j+1}(\mathbf{x}') = \sum_{X} Q_j(\mathbf{x}, \mathbf{x}')\mu_j(\mathbf{x}) \tag{A.26}$$

  where Q_j is a transition function that defines the probability that an age j household transits from its current state $\mathbf{x}$ to the set $\mathbf{x}'$ at age $j+1$, and is induced by the household's decision rules and the exogenous process for income.

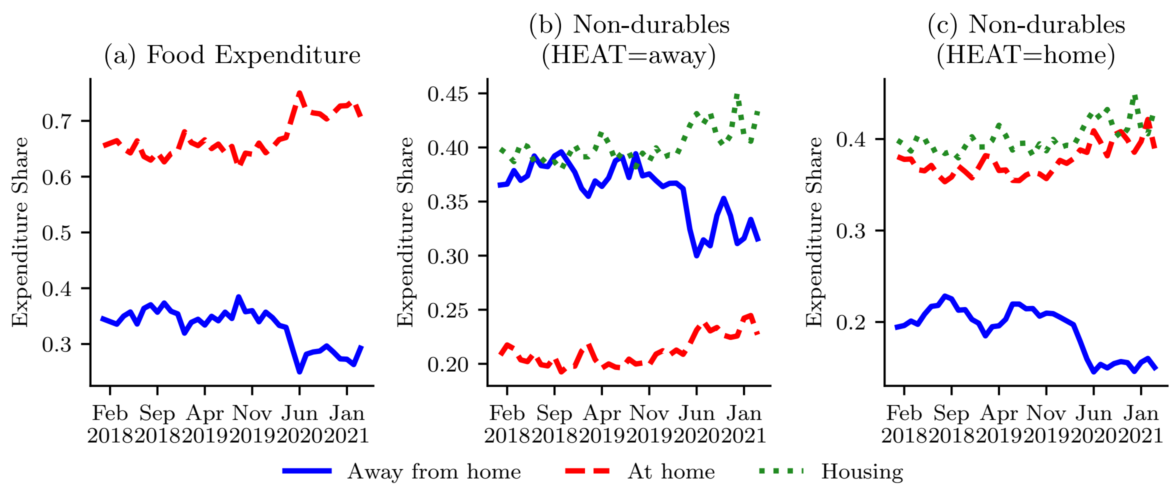
Accordingly, there are $6JN_x + JN_x + JN_x + JN_x + JN_x + 5JN_x + JN_x + JN_x + JN_x + JN_x + 6JN_x + JN_x + 2 + (J-1)N_x = (27J-1)N_x + 2$ equations in the system.

Appendix B

Appendix for Chapter 2

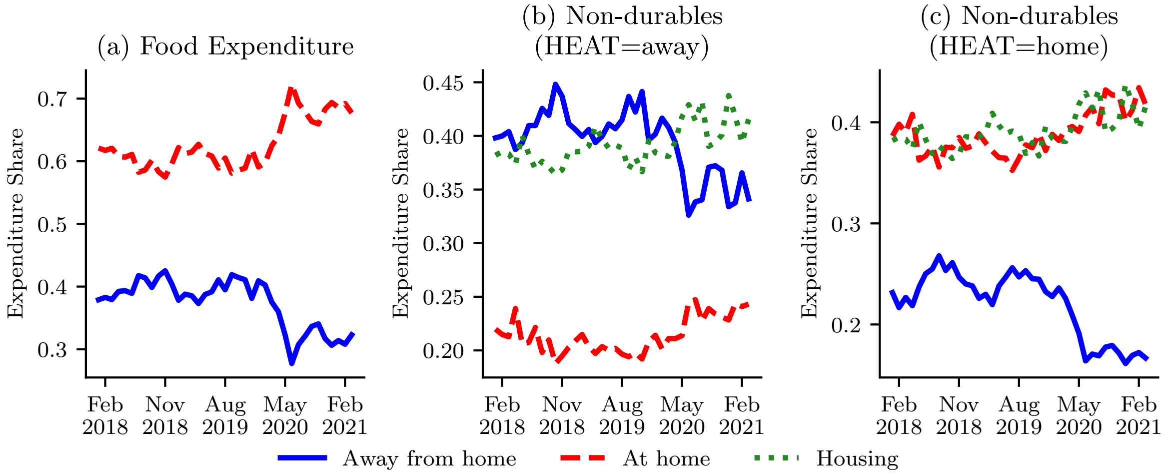
B.1. Additional Motivating Evidence

Figure B.1: Median Consumption Expenditure Shares



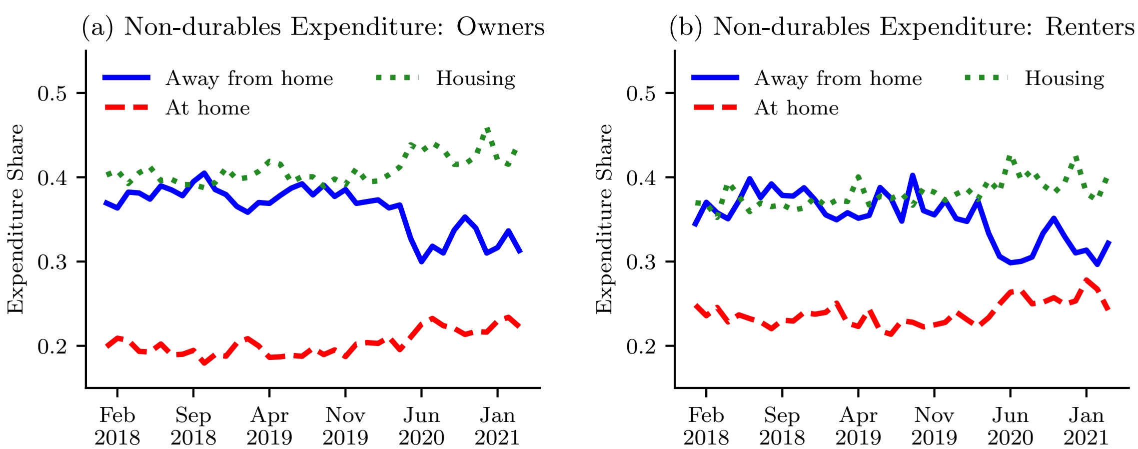
Notes: Median consumption expenditure shares for food only (a), non-durables and housing services ((b) and (c)). In panel (b) spending on health, education, alcohol, and tobacco is allocated to spending away from home. In panel (c) spending on health, education, alcohol, and tobacco is allocated to spending at home.

Figure B.2: Aggregate Consumption Expenditure Shares



Notes: Aggregate consumption expenditure shares for food only (a), non-durables and housing services ((b) and (c)). In panel (b) spending on health, education, alcohol, and tobacco is allocated to spending away from home. In panel (c) spending on health, education, alcohol, and tobacco is allocated to spending at home.

Figure B.3: Median Consumption Expenditure Shares for Homeowners and Renters



Notes: Median consumption expenditure shares non-durables and housing services. Panel (a) reports shares for homeowners, panel (b) reports shares for renters. In each panel, spending on health, education, alcohol, and tobacco is allocated to spending away from home.

B.2. Additional Empirical Results

Table B.1: House Price Response to Changes in Local Mobility: Alternative Specifications

	Real 12-month house price growth				
	(1)	(2)	(3)	(4)	(5)
Δ Time At Home	0.457***	0.465***	0.789*	0.541*	0.581***
	(0.116)	(0.118)	(0.429)	(0.299)	(0.137)
Δ Employment	0.220***	0.223***	0.307*	0.171***	0.283***
	(0.064)	(0.065)	(0.168)	(0.051)	(0.079)
ln(Population)	0.006***	0.007***	0.009***	0.010***	0.006***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.002)
ln(Income Per Capita)	−0.027***	−0.024***	−0.034**	−0.027**	−0.028***
	(0.005)	(0.004)	(0.015)	(0.010)	(0.006)
Land Unavailability	−0.009	−0.009	−0.002	−0.011	−0.005
	(0.006)	(0.006)	(0.008)	(0.008)	(0.006)
Δ Time At Workplace (mean, 2022)		0.038**			
		(0.016)			
$\mathbf{1}(t \leq$June 2020)	−0.009***	−0.009***	−0.013***		−0.009***
	(0.002)	(0.002)	(0.002)		(0.002)
$\mathbf{1}(t \geq$Jan 2021)			0.006		
			(0.010)		
Observations					
Total	13,890	13,890	24,879	7,824	12,979
Counties	1,442	0	1,453	1,392	1,354
Method	2SLS	2SLS	2SLS	2SLS	2SLS
Specification	Baseline	Long run WFH	2020-2021	Jun-Dec 2020	Excl. NY, WA
State Fixed Effects	Y	Y	Y	Y	Y
State-Clustered Standard Errors	Y	Y	Y	Y	Y
First Stage F-statistic	15.21	14.69	3.85	3.41	7.14
Adjusted R-squared	0.15	0.15	0.06	0.26	0.04

Notes: All specifications using instruments for mobility constructed from the share of workers most easily able to work from home (Dingel and Neiman, 2020) interacted with state-level confirmed COVID deaths over time. Column (1) is the baseline specification. Column (2) includes controls for the medium-run mean of time spent at work. Column (3) uses data from both 2020 and 2021. Column (4) restricts the sample from June to December 2020. Column (5) excludes data from the states of New York and Washington. All standard errors and first-stage F-statistics clustered at the state level.

Table B.2: House Price Response to Changes in Local Mobility: Alternative Instruments

	Real 12-month house price growth							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ Time At Home	0.457***		0.507***		0.127***		0.827***	
	(0.116)		(0.088)		(0.029)		(0.243)	
Δ Visits to Retail, Recreation		−0.128***		−0.151***		−0.052***		−0.286***
		(0.036)		(0.026)		(0.012)		(0.101)
Δ Employment	0.220***	0.108***	0.249***	0.136***	0.028	0.017	0.435***	0.299**
	(0.064)	(0.040)	(0.049)	(0.031)	(0.025)	(0.024)	(0.143)	(0.127)
ln(Population)	0.006***	0.004***	0.006***	0.003***	0.008***	0.007***	0.005**	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)
ln(Income Per Capita)	−0.027***	−0.018***	−0.029***	−0.020***	−0.015***	−0.014***	−0.041***	−0.028**
	(0.005)	(0.005)	(0.005)	(0.006)	(0.004)	(0.005)	(0.010)	(0.012)
Land Unavailability	−0.009	−0.004	−0.008	−0.002	−0.014**	−0.011	−0.003	0.011
	(0.006)	(0.008)	(0.006)	(0.007)	(0.006)	(0.007)	(0.008)	(0.013)
$\mathbf{1}(t \leq$June 2020)	−0.009***	−0.009***	−0.009***	−0.010***	−0.007***	−0.008***	−0.011***	−0.013***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.003)	(0.004)
Observations								
Total	13,890	13,890	13,890	13,890	13,890	13,890	13,890	13,890
Counties	1,442	1,442	1,442	1,442	1,442	1,442	NULL	1,442
Method	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
Instrument	Deaths	Deaths	Cases	Cases	Lockdown	Lockdown	Vote Share	Vote Share
State Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
State-Clustered Standard Errors	Y	Y	Y	Y	Y	Y	Y	Y
First Stage F-statistic	15.21	34.96	6.22	8.21	442.06	186.72	4.25	9.55

Notes: All specifications using instruments for mobility constructed from the share of workers most easily able to work from home interacted with state-level measures of pandemic intensity over time. Columns (1) and (2) use the baseline instrument that interacts WFH with the confirmed number of COVID deaths over time. Columns (3) and (4) use an instrument that interacts WFH with the confirmed number of COVID cases over time. Columns (5) and (6) use an instrument that interacts WFH with the stringency of lockdowns over time. Columns (7) and (8) use an instrument that interacts Republican vote shares in the 2016 presidential election with the confirmed number of COVID deaths over time. All standard errors and first-stage F-statistics clustered at the state level.

Table B.3: Rental Rate Response to Changes in Local Mobility

	Real 12-month rental rate growth			
	(1)	(2)	(3)	(4)
Δ Time At Home	0.088***		0.011	
	(0.025)		(0.510)	
Δ Visits to Retail, Recreation		−0.017		−0.002
		(0.012)		(0.115)
Δ Employment	−0.007	−0.042*	−0.062	−0.066
	(0.025)	(0.025)	(0.386)	(0.202)
ln(Population)	−0.006**	−0.006**	−0.005**	−0.005
	(0.002)	(0.003)	(0.002)	(0.003)
ln(Income Per Capita)	−0.032***	−0.030***	−0.029	−0.028**
	(0.004)	(0.004)	(0.024)	(0.011)
Land Unavailability	−0.042*	−0.044*	−0.045	−0.045
	(0.025)	(0.024)	(0.042)	(0.037)
$\mathbf{1}(t \leq \text{June 2020})$	−0.006	−0.005	−0.005	−0.005
	(0.004)	(0.004)	(0.007)	(0.006)
Observations				
Total	2,421	2,421	2,421	2,421
Counties	221	221	221	221
Method	OLS	OLS	2SLS	2SLS
State Fixed Effects	Y	Y	Y	Y
State-Clustered Standard Errors	Y	Y	Y	Y
First Stage F-statistic	–	–	5.68	48.81
Adjusted R-squared	0.18	0.18	0.18	0.18

Notes: Columns (1) and (2) are OLS regressions, and Columns (3) and (4) are 2SLS regressions. The instrument for mobility is the interaction between the county-level share of workers most easily able to work from home with state-level confirmed COVID deaths over time. All specifications include county-level controls for employment growth rates, population, per-capita income, land unavailability, in addition to a dummy for months prior to July 2020, and state fixed effects. All standard errors and first-stage F-statistics clustered at the state level.

B.3. Additional Model Details

B.3.1. Static Model

In this section we use a simple one-period model with the preferences defined in Section 2.3 to analytically explore the effect of stay-at-home shocks on housing demand and house prices. As in the quantitative model, assume that utility is a CES composite of away-from-home consumption and the home bundle:

$$u(c_a, c_h, s) = \left[\alpha c_a^{1-\vartheta} + (1-\alpha) x_h(c_h, s)^{1-\vartheta}\right]^{\frac{1}{1-\vartheta}}$$

Since this is a one period model, we drop the outer CRRA structure. Again, the home bundle is a Cobb-Douglas combination of consumption at home c_h and housing services s:

$$x_h = c_h^{\phi} s^{1-\phi}.$$

The static budget constraint is:

$$c_a + c_h + Ps = W$$

where c_a and c_h have prices normalized to one, P is the price of housing services, and W is available resources. The first order conditions of the household problem yield the demand functions:

$$c_a = \frac{\Omega W}{1+\Omega}, \quad c_h = \frac{\phi W}{1+\Omega}, \quad s = \frac{1}{P}\frac{(1-\phi)W}{1+\Omega}$$

where $\Omega = \phi \left(\frac{\alpha}{\phi(1-\alpha)}\right)^{1/\vartheta} \left(\frac{\phi P}{1-\phi}\right)^{(1-\phi)(1/\vartheta-1)}$.

A stay-at-home pandemic shock is modelled as a decline in preferences for consumption away from home α or, equivalently, as an increase in the preference to consume at home $(1-\alpha)$. In our simple setup, this change in preferences results in both an increase in demand for non-durable consumption at home c_h and housing services s. With fixed housing supply in the short-run, the price of housing services increases with the decline in α. We formalize this argument in a simple proposition:

Proposition 1. Suppose $\alpha, \phi \in (0,1)$ and that the supply of housing is fixed. If the elasticity of substitution satisfies $1/\vartheta > 1$, then $\frac{\partial P}{\partial \alpha} < 0$.

Proof. Suppose the supply of housing is fixed at $\bar{s}$. We can rewrite the demand function for housing services as:

$$P = \frac{1}{\bar{s}} \frac{(1-\phi)W}{1+\Omega}$$

Via the Implicit Function Theorem:

$$\frac{\partial P}{\partial \alpha} = \frac{-\frac{\partial \Omega}{\partial \alpha} \frac{1}{\bar{s}} \frac{(1-\phi)W}{(1+\Omega)^2}}{1 + \frac{\partial \Omega}{\partial P} \frac{1}{\bar{s}} \frac{(1-\phi)W}{(1+\Omega)^2}} = \frac{-\frac{\partial \Omega}{\partial \alpha} \frac{P}{(1+\Omega)}}{1 + \frac{\partial \Omega}{\partial P} \frac{P}{(1+\Omega)}}$$

where the second equality uses the housing services demand function. The partial derivative in the denominator is

$$\frac{\partial \Omega}{\partial \alpha} = \frac{1}{\vartheta} \frac{\Omega}{\alpha(1-\alpha)}$$

and the partial derivative in the numerator is

$$\frac{\partial \Omega}{\partial P} = \frac{(\frac{1}{\vartheta} - 1)(1-\phi)\Omega}{P}.$$

Then the price derivative is:

$$\frac{\partial P}{\partial \alpha} = \frac{-\frac{1}{\vartheta} \frac{P}{\alpha(1-\alpha)}}{(\frac{1}{\vartheta} - 1)(1-\phi) + \Omega^{-1}}$$

Under the assumptions that $\alpha, \phi \in (0,1)$ and $\frac{1}{\vartheta} > 1$, the denominator is positive, and therefore

$$\frac{\partial P}{\partial \alpha} < 0$$

□

That is, if the home consumption bundle and away-from-home consumption are substitutes, a decline in the relative taste for away-from-home consumption α will lead to an increase in the price of housing. Our quantitative model expands on this simple setup, adding realism to the simple framework described here. These additional features allow us to assess the overall importance of the stay-at-home channel for explaining the growth in house prices during the COVID-19 pandemic.

B.3.2. Household First Order Conditions

Here we describe the optimality conditions for households that own houses or are adjusting their housing stock. This characterization of the optimal decisions differs from the first order conditions described in Section B.3.1. In the simple model households make frictionless and continuous house size choices, whereas the renters and homeowners in Section 2.3.2 choose house sizes from a discrete grid subject to costs.

Consider a household that has already chosen a house or rental size $\tilde{h}$. Denote by $\tilde{x}$ the available cash on hand after liquid asset choices a' and any rental payments or housing adjustment costs. The first order conditions with respect to consumption away from home c_a and at home c_h yield:

$$c_a = \left(\frac{\alpha}{\phi(1-\alpha)}\right)^{\frac{1}{\vartheta}} c_h^{\phi+\frac{1}{\vartheta}(1-\phi)} \tilde{h}^{(1-\frac{1}{\vartheta})(1-\phi)}$$

Combining with the expenditure constraint and definition of cash on hand yields

$$\left(\frac{\alpha}{\phi(1-\alpha)}\right)^{\frac{1}{\vartheta}} c_h^{\phi+\frac{1}{\vartheta}(1-\phi)} \tilde{h}^{(1-\frac{1}{\vartheta})(1-\phi)} + c_h = \tilde{x}$$

We solve this non-linear equation to find the choice of home goods c_h, and in combination with the budget constraint recover the solution for away goods c_a. The solution to the consumption choices then only depends on the current state vector, the house size choice $\tilde{h}$, and the liquid asset choice a'.

B.3.3. Additional Model Results

Figure B.4: Change in Fraction of Renters Choosing Each Rental House Size

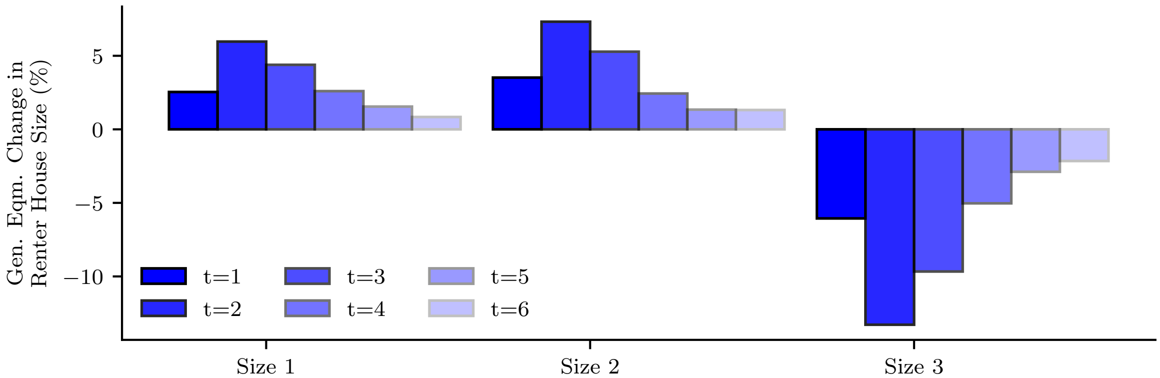


Figure B.5: Change in Fraction of Owners Choosing Each Owner-Occupied House Size

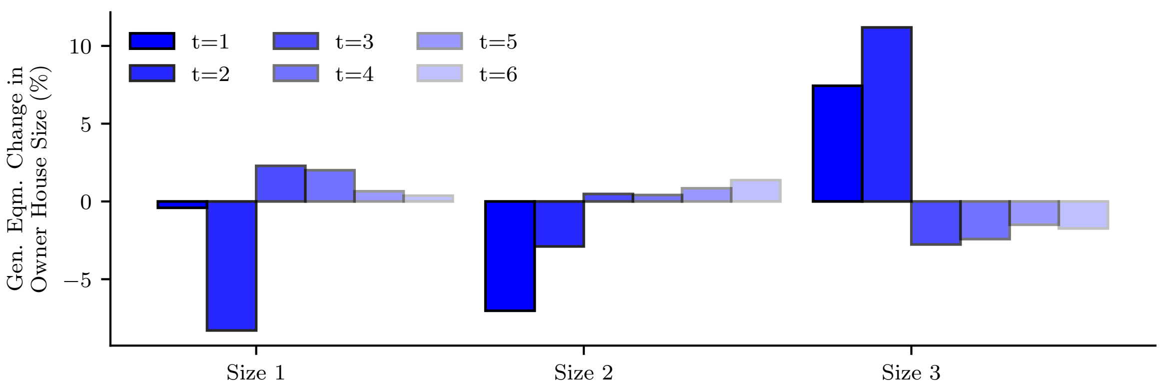


Figure B.6: Impulse Responses: Robustness to Housing and Rental Market Segmentation

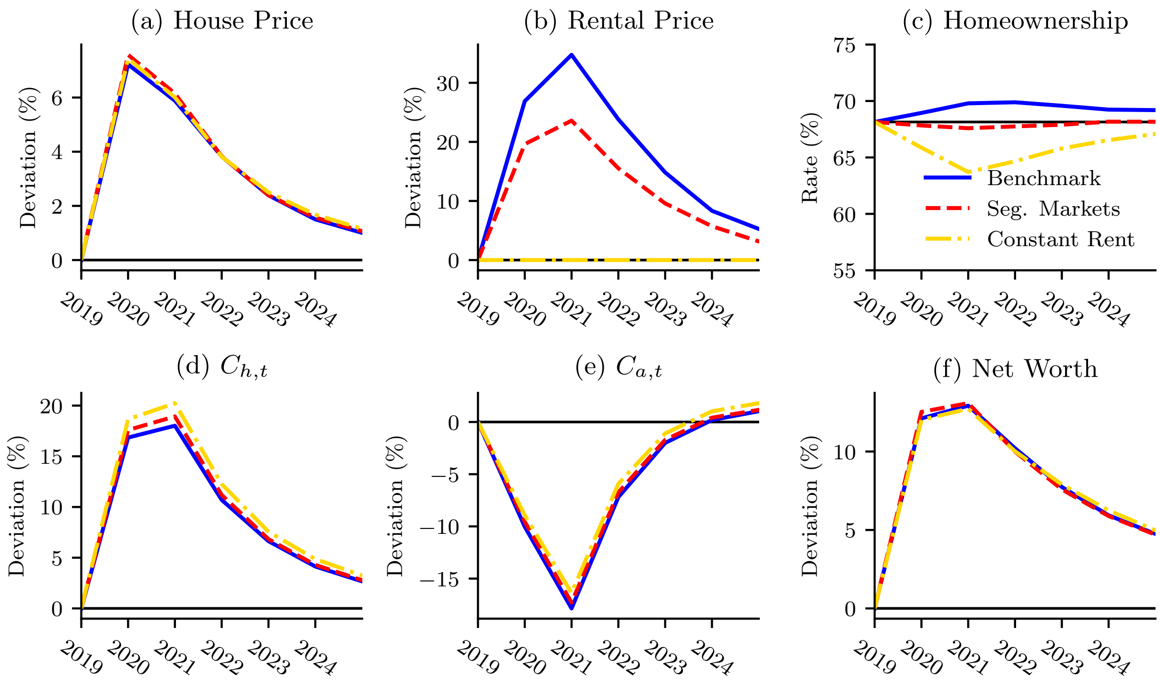
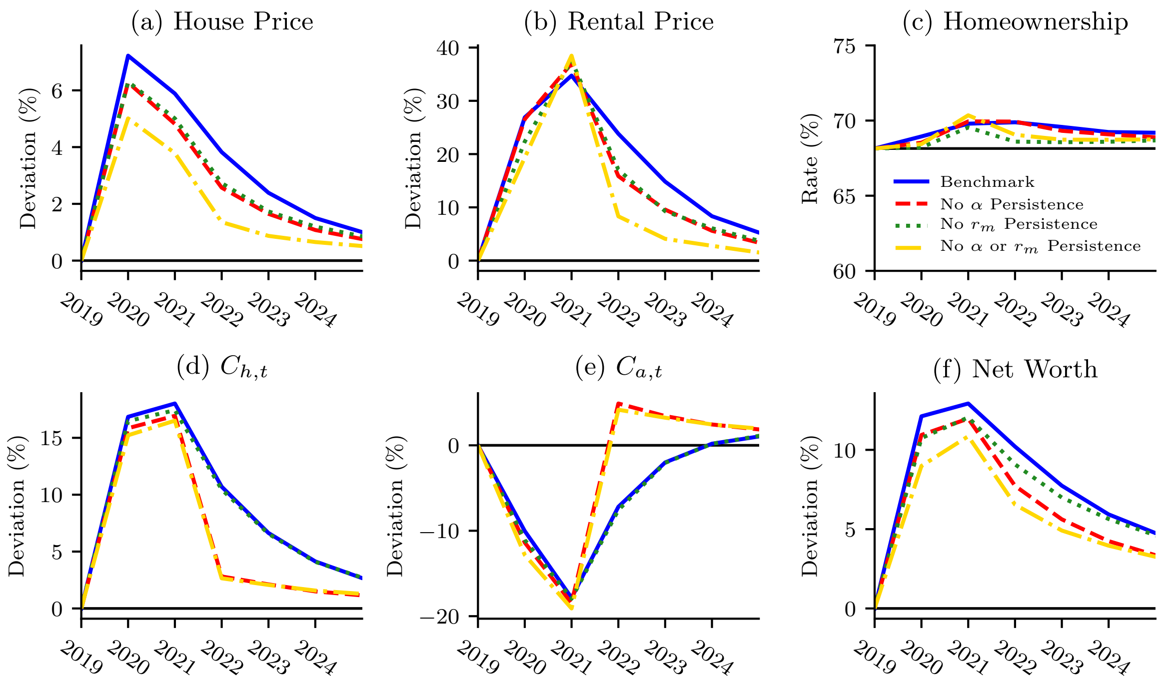


Figure B.7: Impulse Responses: Robustness to Shock Persistence

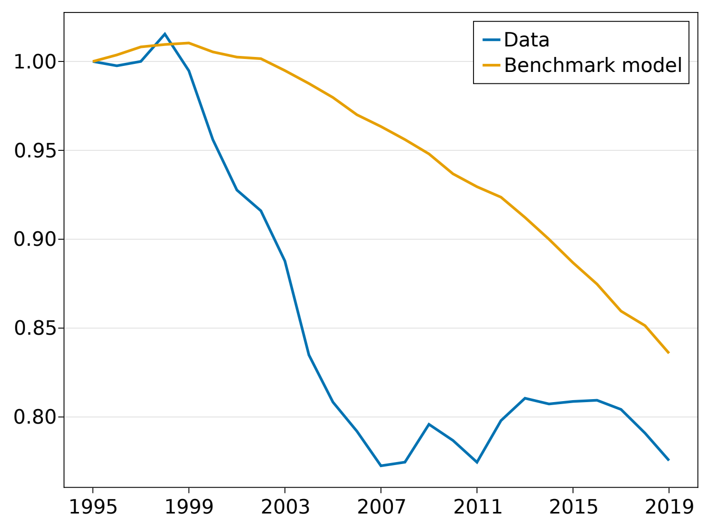


Appendix C

Appendix for Chapter 3

C.1. Additional Figures

Figure C.1: Rent-to-Income Ratio



Notes: Data uses the rent component of the CPI divided by annual household disposable income. Both series are indexed to be 1 in 1995.

C.2. Numerical Computation

C.2.1. Solving the Household's Problem

We adapt Graves's (2021) two-step method to solve the household's problem. The key innovation of this method is that it reduces the bivariate maximization problem faced by households who simultaneously adjust their liquid asset position and their mortgage balance (i.e. households who buy a home or refinance) into a univariate one just over next period's mortgage balance.[61] This approach works by exploiting similarities between the buyer/refiancer problems ("adjusters") and the problem of a household who remains in their home and makes the minimum mortgage repayment ("stayer"). We start by re-writing the age-j problem as:

$$V_j(\mathbf{x}) = \max\{V_j^{\text{rent}}(\mathbf{x}), V_j^{\text{stay}}(\mathbf{x}), V_j^{\text{A}}(\mathbf{x})\}. \tag{C.1}$$

where V_j^{rent} and $V_j^{\text{stay}}(\mathbf{x})$ are defined in equations (3.7)–(3.10), and the value of adjusting $V_j^{\text{A}}(\mathbf{x})$ combines the buyer and refinancing problems in the main text:

$$V_j^{\text{A}}(\mathbf{x}) = \max_{c,a',h',m'} u(c,h') + (1-\phi_j)\nu(w') + \phi_j\beta\mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \tag{C.2}$$

subject to:

$$c + \delta h + a' = y_j + (1+r)a + \mathbf{1}_{h'\neq h}p_h[(1-\kappa_s)h - (1+\kappa_b)h'] - \kappa_m - (1+r_m)m + m',$$
$$w' = a' + p_h h' - m',$$

and the LTV and PTI constraints (3.4,3.5). Next, note that conditional on a choice of next period's owner-occupied house size h' the adjuster's problem is

$$V_j^{\text{A}}(\mathbf{x};h') = \max_{0\leq m'\leq \bar{M}} \tilde{V}(\mathbf{x};h',m')$$

where $\tilde{V}(\mathbf{x};h',m')$ is the intermediate value function of a household who is free to optimally choose their liquid assets a' but must adjust their mortgage to m' and their

[61] One way that some authors deal with this bivariate problem is to restrict the choice of next period's mortgage balance to be on the discretized mortgage grid; for example, see Kaplan, Mitman, and Violante (2020). We do not need to make such a restriction.

house size to h':[62]

$$\tilde{V}(\mathbf{x}; h', m') = \max_{c,a'} u(c, h') + (1 - \phi_j)\nu(w') + \phi_j \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')]$$

subject to:

$$c + \delta h + a' = y_j + (1 + r)a + \mathbf{1}_{h' \neq h} p_h[(1 - \kappa_s)h - (1 + \kappa_b)h'] - \kappa_m - (1 + r_m)m + m'.$$

Next, consider the change-of-variables:

$$m' = (1 + r_m)\tilde{m} - \bar{\pi}(\tilde{m}),$$

so that a household who enters the period with mortgage balance $\tilde{m}$ and makes the minimum repayment has a balance of m' the following period. The key insight of Graves's (2021) method is that the solution to the intermediate problem above is closely related to the solution to the stayer's problem (3.9). In particular:

$$\tilde{V}(\mathbf{x}; h', m') = V_j^{\text{stay}}(a^*, h', \tilde{m}, z)$$

where

$$a^* = a + \frac{1}{1 + r}\left[\mathbf{1}_{h' \neq h} p_h[(1 - \kappa_s)h - (1 + \kappa_b)h'] - \kappa_m - (1 + r_m)m - \delta h + \delta h' + (1 + r_m)\tilde{m}\right].$$

In other words, the value for a household who enters the period with state vector $\mathbf{x} = (a, h, m, z)$ and will choose housing h' and a mortgage balance m' is equal to that of a household who enters the period with state $(a^*, h', \tilde{m}, z)$ and stays in their current owner-occupied home, making the minimum repayment on their mortgage. The budget constraint for a household with current state $(a^*, h', \tilde{m}, z)$ who makes the minimum

[62]The upper bound on mortgage debt $\bar{M}$ is the maximum allowable balance under the LTV and PTI constraints.

mortgage repayment is:

$$c + \delta h + \bar{\pi}(\tilde{m}) + a' = y + (1+r)a + \mathbf{1}_{h' \neq h} p_h[(1-\kappa_s)h - (1+\kappa_b)h'] - \kappa_m - (1+r_m)m ... \\ + (1+r_m)\tilde{m},$$

which is exactly the same as the budget constraint of the intermediate problem above since $m' = (1+r_m)\tilde{m} - \bar{\pi}(\tilde{m})$. Accordingly, the solution to the intermediate problem is:

$$a' = a'_{\text{stay}}(a^*, h', \tilde{m}, z)$$

where $a'_{\text{stay}}(\cdot)$ is the stayer's liquid asset policy function. Putting this all together, the adjuster's problem is equivalent to:

$$V_j^{\text{A}}(\mathbf{x}) = \max_{h', m'} u(c, h') + (1-\phi_j)\nu(w') + \phi_j \beta \mathbb{E}_{z'|z}[V_{j+1}(\mathbf{x}')] \tag{C.3}$$

subject to:

$$c + \delta h + a' = y_j + (1+r)a + \mathbf{1}_{h' \neq h} p_h[(1-\kappa_s)h - (1+\kappa_b)h'] - \kappa_m - (1+r_m)m + m',$$
$$a' = a'_{\text{stay}}(a^*, h', \tilde{m}, z)$$
$$a^* = a + \frac{1}{1+r}\left[\mathbf{1}_{h' \neq h} p_h[(1-\kappa_s)h - (1+\kappa_b)h'] - \kappa_m - (1+r_m)m - \delta h + \delta h' + (1+r_m)\tilde{m}\right]$$
$$m' = (1+r_m)\tilde{m} - \bar{\pi}(\tilde{m}),$$

and the LTV and PTI constraints (3.4,3.5). Conditional on a housing choice h', this is a univariate optimization problem over m', which can be solved using a standard numerical algorithm, such as golden section search.

C.3. Stationarity Equilibrium As a System of Equations

C.3.1. Preliminaries

- Household age is indexed by $j = 1, ..., J$. They enter the period with individual state vector $\mathbf{x} = (a, h, m, z)$ where $a \in \mathcal{A}$ is liquid assets, $h \in 0 \cup \mathcal{H}$ is owner-occupied house size, $m \in \mathcal{M}$ is mortgage debt and $z \in \mathcal{Z}$ is the current period's idiosyncratic income shock. Let $X = \mathcal{A} \times 0 \cup \mathcal{H} \times \mathcal{M} \times \mathcal{Z}$ be the idiosyncratic state space for an age-j household.

- To ease notation slightly, define a household's cash-on-hand b as:

$$b \equiv y + (1+r)a - \delta h - (1+r_m)m + (1-\kappa_s)p_h h.$$

  Dependence of b on the individual state $\mathbf{x}$ is implict below.

- Also, define the maximum mortgage balance at origination $\bar{M}$ as:

$$\bar{M} \equiv \min\left\{\theta_m p_h h', \theta_y y_j \left[\frac{(1+r_m)^N - 1}{r_m(1+r_m)^N}\right]\right\},$$

  where $N = \min\{25, J-j\}$. $\bar{M}$ is the minimum of the maximum mortgage balances implied by the LTV limit and the PTI limit. Dependence of $\bar{M}$ on choice of house size h' and the house price p_h is implicit below.

- Also, recall that the minimum mortgage repayment $\bar{\pi}$ payable by a homeowner that does not adjust its house size or refinance its mortgage is

$$\bar{\pi} = \frac{r_m(1+r_m)^N}{(1+r_m)^N - 1} m.$$

  Dependence of $\bar{\pi}$ on the mortgage balance brought into the period m is implicit below.

C.3.2. Decision problems

Let $K = \{\text{rent}, \text{buy}, \text{refi}, \text{stay}\}$ denote the mutually exclusive and exhaustive options available to a household each period. To save notation in the description of the household's decision problem below we omit the dependence of state and choice variables on age j. For each $k \in K$ the household's Bellman equation is:

$$V_j^k(\mathbf{x}) = \max_{c,a',s,h',m'} u(c,s) + (1-\phi_j)\nu(w') + \phi_j \beta \mathbb{E}[V_{j+1}(\mathbf{x}')] \tag{C.4}$$

subjet to:

$$b + m' = \begin{cases} c + a' + p_r s & \text{if } k = \text{rent} \\ c + a' + (1+\kappa_b)p_h h' + \kappa_m & \text{if } k = \text{buy} \\ c + a' + \kappa_m + (1-\kappa_s)p_h h & \text{if } k = \text{refi} \\ c + a' + (1-\kappa_s)p_h h & \text{if } k = \text{stay} \end{cases} \tag{C.5}$$

and:

$$\begin{aligned}
& w' = a' + p_h h' - m' && \forall k \\
& a' \geq 0 && \forall k && \text{(C.6)} \\
& s = h' && \text{if} \quad k \neq \text{rent} \\
& m' \geq 0 && \text{if} \quad k \neq \text{rent} && \text{(C.7)} \\
& m' \leq \bar{M} && \text{if} \quad k \in \{\text{buy}, \text{refi}\} && \text{(C.8)} \\
& m' = (1+r_m)m - \bar{\pi} && \text{if} \quad k = \text{stay} \\
& m' = 0 && \text{if} \quad k = \text{rent} \\
& c > 0, s \in \mathcal{S}, h' \in \mathcal{H} && \forall k
\end{aligned}$$

The solution to the household's problem is given by

$$V_j(\mathbf{x}) = \max_{k \in K} \{V_j^k(\mathbf{x})\} \tag{C.9}$$

with the corresponding set of policy functions:

$$\{c_j(\mathbf{x}), a'_j(\mathbf{x}), h'_j(\mathbf{x}), s_j(\mathbf{x}), m'_j(\mathbf{x}), g_j^{\text{rent}}(\mathbf{x}), g_j^{\text{buy}}(\mathbf{x}), g_j^{\text{refi}}(\mathbf{x}), g_j^{\text{stay}}(\mathbf{x})\}$$

where $g_j^k(\mathbf{x})$ is a dummy variable that denotes whether the discrete choice $k \in K$ is optimal:

$$g_j^k(\mathbf{x}) = \begin{cases} 1 & \text{if } V_j^k = \max_{l \in K}\{V_j^l\} \\ 0 & \text{otherwise.} \end{cases} \tag{C.10}$$

C.3.3. Optimiality conditions

Liquid assets

The Euler equation for liquid assets is

$$u_c(c, s) - (1 - \phi_j)\nu_w = \phi_j \beta \mathbb{E}\left[\frac{\partial V_{j+1}}{\partial a'}\right] + \lambda_a \tag{C.11}$$

where $\lambda_a \geq 0$ is the Lagrange multiplier on the non-negativity constraint for liquid assets (C.6), and $u_c(\cdot)$ denotes the partial derivative of the utility function with respect to c and $\nu_w(\cdot)$ denotes the first derivative of the bequest function. The associated complementary slackness condition is:

$$\lambda_a a' = 0 \tag{C.12}$$

Mortgages

The optimality condition for mortgages is

$$\begin{cases} m' = 0 & \text{if } g_j^{\text{rent}}(\mathbf{x}) = 1 \\ m' = (1 + r_m)m - \bar{\pi} & \text{if } g_j^{\text{stay}}(\mathbf{x}) = 1 \\ u_c(c, s) - (1 - \phi_j)\nu_w = -\phi_j \beta \mathbb{E}\left[\frac{\partial V_{j+1}}{\partial m'}\right] - \lambda_{m,1} + \lambda_{m,2} & \text{otherwise} \end{cases} \tag{C.13}$$

where $\lambda_{m,1} \geq 0$ is the Lagrange multiplier on the nonegativity constraint for mortgages (C.7), and $\lambda_{m,2} \geq 0$ is the Lagrange multiplier on the borrowing limit (C.8). The associated complementary slackness conditions are:

$$\lambda_{m,1} m' = 0 \tag{C.14}$$

$$\lambda_{m,2}(m' - \bar{M}) = 0 \tag{C.15}$$

Housing

House sizes are discrete. Accordingly, optimal housing services consumption s is given by the house size that maximizes the households value function, conditional on their other choices being optimal:

$$s = \begin{cases} \arg\max_{s \in \mathcal{S}} V_j^{\text{rent}}(\mathbf{x}; c, a', s) & \text{if } g_j^{\text{rent}}(\mathbf{x}) = 1 \\ \arg\max_{h' \in \mathcal{H}} V_j^{\text{buy}}(\mathbf{x}; c, a', m', h') & \text{if } g_j^{\text{buy}}(\mathbf{x}) = 1 \\ h & \text{if } g_j^{\text{refi}}(\mathbf{x}) + g_j^{\text{stay}}(\mathbf{x}) = 1 \end{cases} \tag{C.16}$$

Optimal owner-occupied house size is:

$$h' = \begin{cases} 0 & \text{if if } g_j^{\text{rent}} = 1 \\ s & \text{otherwise} \end{cases} \tag{C.17}$$

C.3.4. System of Equations

Let N_x be the number of grid points in the idiosyncratic state space for an age-j household. Let $\mu_j(\mathbf{x})$ denote the measure of households with individual state $\mathbf{x}$ at the start of age j.

Exogenous variables:

- Income $y_j(\mathbf{x})$ for each j and $\mathbf{x} \in X$
- Initial distribution of households $\mu_1(\mathbf{x})$ for each $\mathbf{x} \in X$

Endogenous variables:

- Values: $\{V_j(\mathbf{x}), V_j^{\text{rent}}(\mathbf{x}), V_j^{\text{buy}}(\mathbf{x}), V_j^{\text{refi}}(\mathbf{x}), V_j^{\text{stay}}(\mathbf{x})\}$ for each j and $\mathbf{x} \in X$

- Policies: $\{c_j(\mathbf{x}), a_j'(\mathbf{x}), h_j'(\mathbf{x}), s_j(\mathbf{x}), m_j'(\mathbf{x}), g_j^{\text{rent}}(\mathbf{x}), g_j^{\text{buy}}(\mathbf{x}), g_j^{\text{refi}}(\mathbf{x}), g_j^{\text{stay}}(\mathbf{x})\}$ for each j and $\mathbf{x} \in X$
- Lagrange multipliers: $\{\lambda_{a,j}(\mathbf{x}), \lambda_{m,1,j}(\mathbf{x}), \lambda_{m,2,j}(\mathbf{x})\}$ for each j and $\mathbf{x} \in X$
- Prices: $\{p_h, p_r\}$
- Distribution of households $\mu_j(\mathbf{x})$ for each $j \in \{2, ..., J\}$ and $\mathbf{x} \in X$

Accordingly, there are $5JN_x + 9JN_x + 3JN_x + 2 + (J-1)N_x = (18J-1)N_x + 2$ variables to be determined in stationary equilibrium.

System of equations:

- Intermediate value functions: equation (C.4) holds for each $k \in K$, j and $\mathbf{x} \in X$.
- Value function: equation (C.9) holds for each j and $\mathbf{x} \in X$
- Optimality condition for liquid assets: equation (C.11) holds for each j and $\mathbf{x} \in X$
- Optimality condition for mortgages equation (C.13) holds for each j and $\mathbf{x} \in X$
- Complementary slackness conditions: equations (C.12), (C.14) and (C.15) hold for each j and $\mathbf{x} \in X$
- Optimality condition for housing services: equation (C.16) holds for each j and $\mathbf{x} \in X$
- Optimality condition for owner-occupied house size: equation (C.17) holds for each j and $\mathbf{x} \in X$
- Optimal discrete choice: equation (C.10) holds for each $k \in K$, j and $\mathbf{x} \in X$
- Budget constraints: for each j and $\mathbf{x} \in X$:

$$c_j(\mathbf{x}) = \begin{cases} b + m_j'(\mathbf{x}) - a_j'(\mathbf{x}) - p_r s_j(\mathbf{x}) & \text{if } g_j^{\text{rent}}(\mathbf{x}) = 1 \\ b + m_j'(\mathbf{x}) - a_j'(\mathbf{x}) - (1+\kappa_b) p_h h_j'(\mathbf{x}) - \kappa_m & \text{if } g_j^{\text{buy}}(\mathbf{x}) = 1 \\ b + m_j'(\mathbf{x}) - a_j'(\mathbf{x}) - \kappa_m - (1-\kappa_s) p_h h & \text{if } g_j^{\text{refi}}(\mathbf{x}) = 1 \\ b + m_j'(\mathbf{x}) - a_j'(\mathbf{x}) - (1-\kappa_s) p_h h & \text{if } g_j^{\text{stay}}(\mathbf{x}) = 1 \end{cases} \tag{C.18}$$

- Rental firm optimality:

$$p_r = \frac{1}{1+r}\left(\delta + (r+\kappa_r)p_h - \mathbb{E}[\Delta p_h']\right). \tag{C.19}$$

- Housing market clearing:

$$\sum_{j=1}^{J}\sum_{X} s_j(\mathbf{x})\mu_j(\mathbf{x}) = \bar{H} \tag{C.20}$$

- Law of motion for the distribution of households: for each $j \in \{1, ..., J-1\}$ and $\mathbf{x}' \in X$:

$$\mu_{j+1}(\mathbf{x}') = \sum_{X} Q_j(\mathbf{x}, \mathbf{x}')\mu_j(\mathbf{x}) \tag{C.21}$$

  where Q_j is a transition function that defines the probability that an age j household transits from its current state $\mathbf{x}$ to the set $\mathbf{x}'$ at age $j+1$, and is induced by the household's decision rules and the exogenous process for income.

Accordingly, there are $4JN_x + JN_x + JN_x + JN_x + 3JN_x + JN_x + JN_x + 4JN_x + JN_x + 2 + (J-1)N_x = (18J-1)N_x + 2$ equations in the system.

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