Australian National University

Crawford School of Public Policy

CAMA

Centre for Applied Macroeconomic Analysis

Monetary Policy and the Homeownership Rate

CAMA Working Paper 43/2024
June 2024

James Graham
University of Sydney
Centre for Applied Macroeconomic Analysis, ANU

Avish Sharma
University of Sydney

Abstract

How does monetary policy affect the homeownership rate? A monetary contraction may have contrasting effects on ownership due to rising interest rates, falling in-comes, and lower house prices. To investigate, we build a heterogeneous household life-cycle model with housing tenure decisions, mortgage finance, and an exogenous stochastic process to capture the macroeconomic effects of monetary policy. Following a contractionary shock, homeownership initially falls due to rising mortgage rates, but rises over the medium term given falling house prices. We also show that differences in mortgage credit conditions, mortgage flexibility, and household expectations formation can amplify homeownership dynamics following a shock.

Keywords

homeownership, monetary policy, interest rates, house prices, heterogeneous households

JEL Classification

E52, E20, R21

Address for correspondence:

(E) cama.admin@anu.edu.au

ISSN 2206-0332

Monetary Policy and the Homeownership Rate

James Graham and Avish Sharma *

June 13, 2024

Abstract

How does monetary policy affect the homeownership rate? A monetary contraction may have contrasting effects on ownership due to rising interest rates, falling incomes, and lower house prices. To investigate, we build a heterogeneous household life-cycle model with housing tenure decisions, mortgage finance, and an exogenous stochastic process to capture the macroeconomic effects of monetary policy. Following a contractionary shock, homeownership initially falls due to rising mortgage rates, but rises over the medium term given falling house prices. We also show that differences in mortgage credit conditions, mortgage flexibility, and household expectations formation can amplify homeownership dynamics following a shock.

Keywords: Homeownership; monetary policy; interest rates; house prices; heterogeneous households

JEL: E52; E20; R21

*James Graham: University of Sydney and CAMA, email: james.a.graham@sydney.edu.au. Avish Sharma: University of Sydney, email: a.sharma@sydney.edu.au. Avish is grateful for the financial support of the Australian Prudential Regulation Authority (APRA) and the Reserve Bank of Australia (RBA) under the Brian Gray Scholarship. The results of this research are those of the authors and do not necessarily reflect the views of APRA or the RBA. For their many helpful comments we thank Thomas Cusbert, Christopher Gibbs, Christian Gillitzer, Mariano Kulish, James Morley, Nalini Prasad, Ekaterina Shabalina, Aarti Singh, and seminar participants at the University of Sydney and the Sydney Macroeconomics Reading Group workshop. We also thank Robert Kirkby for his help with some computational details in our model code.

1. Introduction

The transmission of monetary policy to the macroeconomy via the housing market is of significant interest since most households are homeowners and their homes tend to be their largest single asset.[1] Some of the transmission mechanisms through the housing market are straightforward. For example, higher interest rates raise the cost of mortgage financing which tends to reduce consumption spending among indebted homeowners. But this takes homeownership as given or fixed, as does much of the existing literature. In contrast, in this paper we ask: how does monetary policy affect the homeownership rate itself?

The answer is not obvious because monetary policy has opposing effects on housing affordability. For example, tighter monetary policy raises mortgage costs and tends to reduce household income, both of which discourage homeownership. On the other hand, higher interest rates depress house prices, which encourages new home purchases. In this paper we use a heterogeneous household model of homeownership decisions to disentangle the effects of these monetary policy channels. We show that while higher interest rates lead to a short-run decline in ownership, the effect of persistently lower house prices dominates over the medium term. Thus, we present the surprising conclusion that homeownership can rise for a period of time following a contractionary monetary shock.

To study homeownership decisions we build a heterogeneous household model calibrated to key features of the Australian housing market. We follow a large macroeconomics literature modeling housing markets in the face of various aggregate demand shocks.[2] As in those papers, we incorporate many standard model features such as income risk, housing tenure choice, and long-lived mortgage contracts used to finance house purchases.

Other model features are informed by novel institutional details of the Australian housing market. First, mortgages consist of floating-rate contracts so that monetary policy shocks immediately pass through to mortgage rates.[3] Second, households have access to mortgage offset accounts that both reduce the interest cost and increase the liquidity of existing mortgages.[4] Third, a macroprudential policy regime imposes debt-servicing restrictions at mortgage origination, where the serviceability test uses surplus income (i.e. income after typical consumption spending) and an interest rate buffer over and above the current mortgage rate.

[1] For example, see prior work on the relationship between monetary policy and the housing market by Greenwald (2018), Beraja et al. (2019), Wong (2021), Eichenbaum et al. (2022), and Berger et al. (2021).

[2] See, for example, Favilukis et al. (2017), Kaplan et al. (2020), Garriga et al. (2020), Chen et al. (2020), Wong (2021), Gamber et al. (2022), Diamond et al. (2022), and Eichenbaum et al. (2022).

[3] Almost 80 percent of outstanding mortgages in Australia are on variable rates, which is a significantly higher share than in other advanced economies (Reserve Bank of Australia, 2023a).

[4] La Cava et al. (2021b) reports that mortgages with offset accounts constitute around 40 per cent of mortgages in Australia.

Unlike much of the existing literature, we do not solve for general equilibrium or a housing market equilibrium in our model. Instead, following Chen et al. (2020), Wong (2021), and Eichenbaum et al. (2022), we model the macroeconomic effects of monetary policy via an exogenous stochastic process. Specifically, the evolution of interest rates, aggregate income, and house prices follows a first-order Markov chain derived from an estimated structural Vector Autoregressive (VAR) process. We estimate the VAR on quarterly Australian data and identify the effect of monetary policy shocks using a simple Cholesky rotation of the error covariance matrix. While the heterogeneous agent model is solved in partial equilibrium with respect to the aggregate states, household expectations over macroeconomic aggregates are consistent with the estimated VAR. Thus, when a contractionary monetary policy shock raises interest rates, households understand that this results in declining income and house prices in the periods that follow.

We take the aggregate VAR as given, calibrate the model to features of the Australian housing market, and then use it to study the response of the homeownership rate to contractionary monetary policy shocks. Following a 100 basis point increase in the interest rate, aggregate income falls by around 0.3 percent over two years, while house prices decline by 2 percent within a year. The overall effect of the monetary contraction is a 1 percentage point decline in the homeownership rate in the first year following the shock. This is due to both lower home purchases (i.e. transitions from renting into homeownership) and more housing sales (i.e. transitions from homeownership to renting). Beyond the first year, the ownership rate then rises to 0.75 percentage points above steady state and remains elevated for another three to four years.

We then conduct a monetary policy channel decomposition exercise in the spirit of Kaplan et al. (2018) and Auclert (2019). We solve for the dynamics of the homeownership rate under the influence of shocks to interest rates, aggregate income, and house prices in isolation. In each experiment, one aggregate variable follows the impulse response function induced by the estimated VAR while the remaining aggregate variables are held fixed at their steady state values.

Following a shock to the interest rate in isolation, homeownership declines sharply. Higher mortgage finance costs both encourage households to wait to purchase a house and restrict mortgage borrowing for those up against their debt servicing constraint. Following a shock to aggregate income, homeownership is little changed since aggregate income is itself fairly weakly correlated with the monetary policy shock. But following a shock to house prices, the homeownership rate rises to around 0.7 percentage points above steady state after two years, and slowly returns to steady state over the next three to four years. While house prices hit their trough just one year after the monetary policy shock, a number of renters transition to homeownership over this period and remain in their houses even as house prices return to steady state. Thus, the medium-run expansion in homeownership following a monetary contraction is entirely due to the indirect effect of falling house prices.

Finally, we conduct a series of experiments to understand the effect of various non-monetary policy channels on the evolution of the homeownership rate. First, we consider the influence of mortgage credit credit conditions by varying the strength of mortgage borrowing constraints. Second, we consider the effect of mortgage flexibility and liquidity by varying mortgage maturity length and removing the use of mortgage offset accounts. Finally, we consider the role of household expectations formation about the evolution of the aggregate state variables. We find that varying borrowing constraints, mortgage flexibility, and household expectations can increase the volatility of the homeownership rate. Additionally, across each of these experiments we find that this amplification primarily occurs through the interest rate channel.

1.1. Related Literature

Our paper fills a notable gap in the literature regarding the effect of monetary policy on homeownership. While several papers consider the impacts of monetary policy given fixed housing tenure, few study effects on homeownership itself.

The closest paper to our own is Dias et al. (2022). They first estimate the effects of monetary policy on homewnership in a structural-VAR with quarterly US data. They then build a two-agent New Keynesian model to study the transmission of monetary policy through the homeownership channel. In their empirical work, Dias et al. (2022) find that a 25 basis point contraction in monetary policy persistently reduces homeownership by 0.05 percentage points.[5] In their model, a 25 basis point contraction in monetary policy leads to a temporary 0.25 percentage point decline in the homeownership rate, which slowly returns to steady state over the next 5 years. The short-run results of their model are very similar to our own, where a 1 percentage point monetary contraction leads to a 1 percentage point decline in the homeownership rate. Our model differs, however, in generating a 0.75 percentage point overshooting of the homeownership rate after two years.

Our modeling work differs from Dias et al. (2022) in several respects. First, we build a rich heterogeneous household model to study the direct and indirect effect of monetary policy on the homeownership rate itself. While we also find that a contractionary monetary policy shock decreases homeownership in the short-term, we then find that homeownership can rise over the medium-term. By decomposing the various channels of monetary policy, we show that the initial decline in homeownership is driven by high interest rates while the subsequent increase is due to a large and persistent decline in house prices. Our model features a stronger house price channel than Dias et al. (2022)

[5] In related work, Ringo (2024) estimates the effect of exogenous changes in mortgage interest rates on the share of home purchases among low-income households. He finds that a 1 percentage point increase in mortgage interest rates reduces the share of low-income home purchases by 1 to 2 percentage points.

due to larger and more persistent house price fluctuations, the presence of binding debt servicing constraints, and idiosyncratic household income risk.

Second, whereas Dias et al. (2022) study homeownership in the US we consider the Australian context where the housing market is arguably more important. While the total value of the housing stock in the US is around 1.5 to 2 times annual GDP, the Australian housing market is valued at around 4.2 times annual GDP.[6] Housing is known to be especially expensive in Australia, with an average price-to-income ratio of around 5.5 (Reserve Bank of Australia, 2024b). Additionally, house prices in Australia are also known to be particularly sensitive to monetary policy shocks (Otto, 2007; Saunders et al., 2020; La Cava et al., 2021a; Graham et al., 2022). In combination, the house price channel of monetary policy is likely to play an especially large role in homeownership decisions in Australia.

More broadly, we follow a large literature studying heterogeneous household models of the housing market in the face of housing demand shocks. A large body of work grew out the aftermath of the US housing boom and bust of the mid-2000s (Favilukis et al., 2017; Kaplan et al., 2020; Garriga et al., 2020; Graham, 2019; Greenwald et al., 2021), while more recent papers have studied the evolution of housing markets during the COVID-19 pandemic (Gamber et al., 2022; Diamond et al., 2022). Many of these papers are not directly comparable to the current study, as they either do not track homeownership directly (Favilukis et al., 2017; Diamond et al., 2022) or they study broad shocks to mortgage credit rather than interest rates in isolation (Kaplan et al., 2020; Garriga et al., 2020). However, Gamber et al. (2022) show that in partial equilibrium, an isolated 1.5 percentage point decline in mortgage interest rates would increase homeownership rates by 2 to 4 percentage points among households under age 45. In the current paper, an isolated 1 percentage point rise in mortgage interest rates reduces overall homeownership by 1 percentage point, and homeownership among 20 to 50 year olds by 1 to 2 percentage points.

We employ many standard heterogeneous household model features: income uncertainty, incomplete asset markets, housing tenure decisions, and mortgage financing constraints. However, we differ from much of the existing literature in that we do not embed a rational expectations housing market equilibrium in our model. Instead, we follow Chen et al. (2020), Wong (2021), and Eichenbaum et al. (2022) in eschewing housing market equilibrium but taking the evolution of aggregate state variables as given. Similar to those papers, we assume that interest rates, aggregate income, and house prices

[6] To compute the US housing market-to-GDP ratio, we use the total value of real estate for households and non-profits (Board of Governors of the Federal Reserve System (US), 2023) divided by annual gross domestic product (U.S. Bureau of Economic Analysis, 2023), each taken from the Federal Reserve Economic Database. For Australia, we use the total value of dwellings owned by households (Australian Bureau of Statistics, 2023c) divided by annual gross domestic product (Australian Bureau of Statistics, 2023a), both taken from the Australian Bureau of Statistics.

follow an estimated VAR process. Household beliefs are consistent with the evolution of these aggregate state variables, and thus consistent with the behavior of these variables in the data. This approach ensures that model variables such as the homeownership rate respond to realistic macroeconomic dynamics.

Our paper is also related to a small recent literature that studies different features of the Australian housing market using heterogeneous household models. Cho et al. (2023) and Cho et al. (2021) build general equilibrium life-cycle models with housing tenure and mortgage finance decisions to study the effects of housing investor tax credits and homeowner sales duties, respectively. Ong et al. (2023) builds a similar model to study the effect of the long-run decline in real interest rates on the homeownership rate in Australia. Graham (2024) uses a partial equilibrium model to study the use and benefits of mortgage offset accounts among Australian homeowners. Whereas these papers study steady states and comparative statics, the current paper models the high-frequency dynamics of the Australian housing market in response to monetary policy shocks.

To the best of our knowledge, no prior research has studied the effect of monetary policy on homeownership in Australia. This is largely because Australia does not produce high-frequency estimates of the homeownership rate, unlike the US.[7] However, a large empirical literature does study the effect of monetary policy on Australian house prices. Empirical estimates by Fry et al. (2010), La Cava et al. (2021a), and Graham et al. (2022) suggest that a 1 percent increase in the central bank's interest rate is associated with a 1 to 4 percent decline in real house prices. Our VAR estimates are consistent with these findings, suggesting that a 1 percentage point increase in interest rates leads to a 2 percent decline in real house prices.

2. Model

We build a heterogeneous household life-cycle model featuring differences in age, income, liquid assets, housing tenure, and mortgage debt. We also incorporate several novel institutional features of the Australian housing market that we think are important in shaping Australian housing market outcomes. This includes mortgage offset accounts, and macroprudential policies that require mortgage borrowers to satisfy conditions on their ability to service a mortgage.

We then model the influence of monetary policy via an exogenous Vector Autoregressive (VAR) process capturing the relationship between interest rates, aggregate income, and house prices. Households hold rational expectations consistent with the VAR, and

[7] The Australian census provides whole-of-population estimates of the homeownership rate every five years, while the Survey of Income and Housing has sampled several thousand households annually and bi-annually since 1994 https://www.abs.gov.au/statistics/detailed-methodology-information/concepts-sources-methods/survey-income-and-housing-user-guide-australia/2019-20/historical-information.

take the evolution of aggregate state variables into account when making homeownership decisions. Note that we do not explicitly model general equilibrium in goods, labor or asset markets. However, the VAR accurately captures the evolution of the aggregate state variables observed in Australian data, and thus provides a reasonable approximation to real-world market clearing conditions.

2.1. Households

Demographics Time is discrete and one model period is equivalent to one quarter of a year. We model household working life only, so households enter the model at age 20 and retire after age 65. We denote age by $j = 1, \cdots, J$, with retirement and exit from the model at age $J+1$.

Preferences Households maximize expected lifetime utility, given by:

$$E_0 \left[\sum_{j=1}^{J} \beta^{j-1} u(c_j,\ s_j) + \beta^J \nu(w_{J+1}) \right]$$

where $u(\cdot)$ is the intra-period utility function, β is the discount factor, and $\nu(\cdot)$ represents preferences over networth carried into retirement. We assume a CRRA utility function over a Cobb-Douglas aggregator of nondurable consumption c and housing services s:

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

where α is the nondurable consumption share, and $\frac{1}{\sigma}$ is the intertemporal elasticity of substitution. Preferences over retirement networth are given by a weighted CRRA function:

$$\nu(w) = \omega \frac{w^{1-\sigma}}{1-\sigma}$$

where ω governs the desirability of holding wealth in retirement. This is similar to the assumption in the working-life model of Gourinchas et al. (2002), and related to a common assumption in life-cycle models that households enjoy warm glow bequests at the end of life (see De Nardi, 2004).

Endowments Households are born without any liquid assets, housing, or a mortgage.

Household income consists of a deterministic life-cycle profile, an idiosyncratic shock, and idiosyncratic exposures to aggregate income. In order to match average household income over the life-cycle, the deterministic component of income is a simple quadratic function of age:

$$\Gamma_j = \gamma_1 + \gamma_2 \left(\frac{j}{J}\right) - \gamma_3 \left(\frac{j}{J}\right)^2$$

The idiosyncratic component of income z_j follows a log-AR(1) process:

$$\log(z_j) = \rho_z \log(z_{j-1}) + \varepsilon_{z,j}$$

where ρ_z governs the persistence of income shocks, and innovations follow a normal distribution $\varepsilon_{z,j} \sim N(0, \sigma_z^2)$ with mean zero and standard deviation σ_z. Income at birth z_1 is drawn from the stationary distribution for the log-AR(1) process.

Households are also differentially exposed to aggregate income shocks according their position in the overall income distribution, following evidence from Stone (2016). Aggregate income Y evolves according to the stochastic process described in Section 2.3. Household exposures are then given by

$$f(\Gamma_j, z_j, Y) = 1 + (Y - 1) \times [\chi_1 + \chi_2 \exp(\chi_3 \Gamma_j z_j)]$$

where the parameters χ_1, χ_2, and χ_3 determine the sensitivity of households at different points in the income distribution to aggregate shocks. In steady state, aggregate income is normalized to 1 and there is no adjustment of individual income: $f(\Gamma_j, z_j, 1) = 1$. But outside of steady state, richer and poorer households may be differentially affected by aggregate income shocks.

Finally, total household income at age j is given by

$$m_j(z_j, Y) = \Gamma_j z_j f(\Gamma_j, z_j, Y)$$

Housing Households can choose to be renters or homeowners, and they enjoy housing services s associated with their tenure choice. Rental services can be purchased at a constant unit cost of P_r per period. The size of a rental house can be chosen flexibly and adjusted each period without cost. Thus, conditional on renting, housing services are a continuous choice variable within each period.

For computational tractability, we assume that households can purchase a single size of house, so that owner-occupied housing services are given by $s = H$ for all homeowners. This simplification means that households cannot purchase different sizes of house or purchase multiple properties.[8] Thus, the housing state variable is such that $h \in [0, H]$, with zero denoting renters and H denoting homeowners.

Houses may be purchased at a per-unit cost of P_h. While the rental rate P_r is constant,

[8] See Cho et al. (2021) for a model of the Australian housing market featuring multiple house sizes, and see Cho et al. (2023) for a model of the Australian housing market featuring landlord-home buyers.

house prices P_h evolve according the stochastic process described in Section 2.3.[9] Each period homeowners must pay maintenance costs given by a fraction δ of the value of the house. If homeowners choose to sell their homes and move back to renting, they must pay a housing transaction cost of f_h that is proportional to the value of the house.

Liquid Assets Households can save in a liquid asset a. Liquid assets earn an interest rate r, which evolves according the stochastic process described in Section 2.3. Households cannot borrow using the liquid asset, so their choices are subject to the constraint $a' \geq 0$

Mortgages Homeowners can use a mortgage b to finance the purchase of their house. New mortgages require borrowers to pay an origination cost f_b proportional to the size of the mortgage. We then make several assumptions about the use of mortgages for computational tractability.

First, mortgages are long-term contracts with a fixed amortization schedule that specifies a required repayment each period. This means that households cannot prepay a mortgage. We follow Karlman et al. (2021), where the required mortgage payment on an outstanding mortgage balance b is

$$\pi_j(b, r_b) = b \times \left(\sum_{k=1}^{M_j} \left[\frac{1}{1+r_b} \right]^k \right)^{-1} = b \times \frac{r_b(1+r_b)^{M_j}}{(1+r_b)^{M_j} - 1}$$

where r_b is the mortgage interest rate, and the mortgage maturity is $M_j = \min\{30 \times 4, J+1-j\}$. This means that the required payment is similar to that of an annuity mortgage with either 30 years remaining (120 model periods) or the number of periods until retirement at $J+1$.

Second, all borrowing is via fully adjustable-rate mortgages. This is consistent with the fact that almost 80 percent of outstanding mortgages in Australia are on variable rates, which is a significantly higher share than in other advanced economies (Reserve Bank of Australia, 2023a).[10] The interest rate on a mortgage is $r_b = r + \kappa$, where κ is a fixed spread over the liquid asset interest rate r. Thus, the mortgage rate inherits the time-series properties of the deposit rate, as determined by the stochastic process in Section 2.3.

Third, we do not allow for household choice in the size of mortgage originated. Instead, households always take the largest mortgage allowed under their borrowing constraints. Mortgages are limited by a maximum loan-to-value (LTV) ratio as well as a maximum net income surplus (NIS) ratio. The latter is similar to the payment-to-income (PTI) ratio constraint introduced by Greenwald (2018). The amount borrowed b' is the minimum of

[9] In Section 2.3 and the Online Appendix, we show that empirically rents move very little in response to monetary policy shocks. For tractability, in the model we assume that they remain constant throughout our experiments.

[10] Even fixed rate mortgages in Australia have relatively short fixed periods of around two years on average.

the mortgage sizes implied by the LTV and NIS constraints:

$$b' = \min\{b'_{LTV}, b'_{NIS}\}$$

A mortgage under the LTV constraint is

$$b'_{LTV} = \theta_b P_h H \tag{1}$$

where θ_b is the maximum LTV ratio, and $P_h H$ is the value of the home purchased or owned by the household. While similar to a PTI constraint, the NIS constraint reflects two novel institutional features of the Australian mortgage market: assessed mortgage rates and the notion of surplus income. The NIS constraint is given by

$$\pi_j(b'_{NIS}, \widehat{r}_b) = \theta_m(1-\alpha)m_j(z_j, Y) \tag{2}$$

where $\pi_j(\cdots)$ is the required mortgage payment, $\widehat{r}_b$ is the assessed mortgage interest rate, θ_m is the maximum borrowing capacity as a share of net surplus income, and $(1-\alpha)m_j(z_j, Y)$ is surplus income.

The assessed mortgage interest rate is given by $\widehat{r}_b = r_b + \phi$. As required by the Australian Prudential Regulation Authority (APRA), new mortgages must satisfy a NIS constraint evaluated at an interest rate that includes a servicability buffer (Australian Prudential Regulation Authority, 2022a). This buffer is an additional spread ϕ over the current mortgage interest rate r_b. Note that the assessed rate is only used for the purpose of mortgage origination, but households repay mortgages at the actual mortgage rate r_b.

The net income surplus itself reflects income left over after typical household spending (Australian Prudential Regulation Authority, 2022b). To calculate surplus income, mortgage originators typically require households to provide bank statements documenting their recent spending patterns excluding rental costs. We approximate this calculation under the conservative assumptions that households spend all of their income each period and that the expenditure share allocated to non-durable consumption is α.[11] We compute net surplus income as: $(1-\alpha)m_j(z_j, Y)$.

Mortgages Offset Accounts Following Graham (2024), we assume that homeowners with a mortgage may use a mortgage offset account. An offset account enables a borrower to hold liquid assets against an outstanding mortgage balance to reduce mortgage interest costs. Since $r_b > r$, mortgage holders with an offset account earn a higher effective rate of interest on their liquid assets. Additionally, unlike the mortgage balance itself, assets held in the offset account remain liquid and can be drawn upon at any time with no

[11] Our assumption means that we can avoid keeping track of past spending as a state variable. It also implies that households cannot act strategically by reducing consumption and increasing their net income surplus in order to increase borrowing capacity.

additional cost.

Use of an offset account does not change the required mortgage payment $\pi_j(b, r_b)$ in a given period, but instead affects how mortgage interest is accumulated. For households repaying a mortgage without an offset account, mortgage balances evolve according to:

$$b' = (1 + r_b)b - \pi_j(b, r_b)$$

For households repaying a mortgage while using an offset account, mortgage balances evolve according to:

$$b' = b + r_b \times \max\{b - a, 0\} - \pi_j(b, r_b)$$

Any liquid assets a held in the offset account reduce the interest accumulated on the mortgage balance b. Since the mortgage payment $\pi_j(b, r_b)$ is held fixed, mortgage balances are repaid more quickly under an offset account.

Finally, access to an offset account requires payment of a fixed cost f_o in each period that funds are held in the account. Conditional on using the account, all liquid assets up to the size of the mortgage balance are held in the account. Any liquid assets held in excess of the mortgage balance, $\max\{a - b, 0\}$, earn the liquid asset interest rate r.

2.2. Household Decision Problems

A household enters age j with state variables $\mathbf{s} = \{a, h, b, z, S\}$ where a are liquid assets, h denotes housing tenure, b is the outstanding mortgage balance, z is the idiosyncratic component of income, and $S = \{P_h, Y, r\}$ is the aggregate state vector consisting of real house prices P_h, aggregate income Y, and the interest rate r.

Each period households make discrete choices over: renting (R), buying a new house (B), making mortgage payments without an offset account (N), and making mortgage payments with an offset account (O). The value function over the discrete choice problem is characterized by:

$$V_j(\mathbf{s}) = \max\left\{V_j^R(\mathbf{s}), V_j^B(\mathbf{s}), V_j^N(\mathbf{s}), V_j^O(\mathbf{s})\right\} \tag{3}$$

Renter Problem Renters choose the size of rental property s, non-durable consumption

c, and liquid assets a'. The value function for renters is:

$$
\begin{aligned}
V_j^R(\mathbf{s}) = \max_{s,c,a'} & \, u(c,s) + \beta\mathbb{E}[V_{j+1}(\mathbf{s}')] \\
\text{s.t.} \quad & c + P_r s + a' + (1+r_b)b = m_j(z,Y) + (1+r)a + (1-f_h)P_h h \\
& a' \geq 0 \\
& h' = 0, b' = 0
\end{aligned} \tag{4}
$$

where β is the discount factor, expectations $\mathbb{E}$ are taken over the value function in Equation (3) with respect to the evolution of next period idiosyncratic income z' and the aggregate state vector S'. Notice that a current renter may be selling a previously owned property h and repaying an outstanding mortgage b.

Home Buyer Problem Buyers purchase a new home h', and choose a new mortgage balance b', consumption c, and liquid assets a'. The value function for a home buyer is:

$$
\begin{aligned}
V_j^B(\mathbf{s}) = \max_{c,a',b'} & \, u(c,h') + \beta\mathbb{E}[V_{j+1}(\mathbf{s}')] \\
\text{s.t.} \quad & c + a' + (1+\delta)P_h h' + (1+r_b)b = \\
& \qquad m_j(z,Y) + (1-f_b)b' + (1+r)a + (1-f_h)P_h h \\
& a' \geq 0 \\
& h' = H \\
& b' = \min\{b'_{LTV}, b'_{NIS}\}
\end{aligned} \tag{5}
$$

where the house size $h' = H$ is the same for all buyers, and the new mortgage choice b' is restricted to the minimum of the amount allowed under the maximum LTV and NIS constraints in Equations (1) and (2). The household sells any existing housing h and repays any outstanding mortgage debt b at the beginning of the period. The household buys a new home and pays housing maintenance costs during the period.

Mortgage Payment Without Offset Account Problem A homeowner making mortgage repayments without an offset account chooses consumption c and liquid assets a'. The value function is

$$
\begin{aligned}
V_j^N(\mathbf{s}) = \max_{c,a'} & \, u(c,h) + \beta\mathbb{E}[V_{j+1}(\mathbf{s}')] \\
\text{s.t.} \quad & c + a' + \delta P_h h + \pi_j(b,r_b) = m_j(z,Y) + (1+r)a \\
& a' \geq 0 \\
& h' = h \\
& b' = (1+r_b)b - \pi_j(b,r_b)
\end{aligned} \tag{6}
$$

where the household keeps the same house h that they entered the period with, pays maintenance costs on the house, and makes the required mortgage payment $\pi_j(b, r_b)$.

Mortgage Payment With Offset Account Problem A homeowner making mortgage repayments while using an offset account chooses consumption c and liquid assets a'. The value function is

$$\begin{aligned} V_j^O(\mathbf{s}) &= \max_{c,a'} u(c,h) + \beta\mathbb{E}[V_{j+1}(\mathbf{s}')] \qquad (7) \\ \text{s.t.} \quad & c + a' + \delta P_h h + \pi_j(b, r_b) + f_o = \\ & \qquad m_j(z, Y) + a + r\max\{a - b, 0\} \\ & a' \geq 0 \\ & h' = h \\ & b' = b + r_b \times \max\{b - a, 0\} - \pi_j(b, r_b) \end{aligned}$$

where the household keeps the same house h that they entered the period with, pays maintenance costs on the house, pays the fixed offset account access cost f_o, earns interest on any liquid assets held in excess of the mortgage balance, and the mortgage accumulates according to the interest accumulated on net-of-offset mortgage balances less the required repayment.

2.3. Aggregate State Variables

Finally, we describe the evolution of the aggregate state variables in the model. The aggregate state variables are the real risk-free interest rate on savings r, real aggregate income Y, and the real unit-price of houses P_h. Rather than model these aggregate states as outcomes of equilibrium in asset, goods, and housing markets, we assume an exogenous, stochastic time series process for the state vector $S = \{r, Y, P_h\}$.

Following Chen et al. (2020), Eichenbaum et al. (2022), and Wong (2021) the evolution of the aggregate state vector is given by a vector autoregressive (VAR) process. For computational tractability, we restrict the VAR to capture one lag of each variable in the aggregate state vector.

We estimate the VAR using quarterly data for Australia between 1994 and 2018. The real interest rate is the yield on 90-day bank bills in Australia less CPI inflation (Organization for Economic Co-operation and Development, 2023c). CPI inflation is computed using the average of the year-ended weighted-median and year-ended trimmed-mean inflation measures (Reserve Bank of Australia, 2024a).[12]

[12] This is inflation measure most commonly used to construct real interest rates by the Reserve Bank of Australia. See, for example, reported real interest rates at https://www.rba.gov.au/chart-pack/pdf/chart-pack.pdf?v=2024-06-03-14-21-29. Unlike headline CPI, the weighted-median and trimmed-mean measures exclude interest charges prior to the September 1998 and are adjusted for tax changes that took place in 1999-2000.

Aggregate income is real domestic final demand (DFD) (Australian Bureau of Statistics, 2023a). DFD is the sum of consumption and investment by both the private and government sectors. We use DFD, which excludes net exports, because Australia is known to experience large cyclical fluctuations in GDP due to an outsized commodity export sector. As a result, we found that GDP only responds very weakly to monetary policy shocks. House prices are a weighted average of the real sale prices of new and existing residential dwellings in Australia's eight capital cities (Organization for Economic Co-operation and Development, 2023b).

We de-trend the data for each of our aggregate variables using a third-order polynomial in time. We then estimate the following VAR on the de-trended data:

$$S_t = AS_{t-1} + u_t$$

where A is a 3×3 matrix of coefficients and u_t is a 3×1 vector of Gaussian innovations. To identify the effect of monetary policy shocks, we use a simple Cholesky decomposition of the variance-covariance matrix of the residual vector u_t. We impose the common identifying assumption that monetary policy shocks do not contemporaneously impact the other macroeconomic variables.[13] Additional details regarding our identification scheme are described in Appendix A.

The solid blue lines in Figure 1 illustrate estimated IRFs of interest rates, aggregate income, and house prices in response to a 1 percentage point monetary policy contraction. These IRFs are consistent with the empirical literature on macroeconomic fluctuations in Australia. Regarding aggregate income responses, Hartigan et al. (2020) and Beckers (2020) estimate identified VARs and find that real output declines by around 1 percent in response to a 1 percentage point monetary contraction, albeit with large standard errors. And using both VAR and local projection methods, Fry et al. (2010), La Cava et al. (2021a), and Graham et al. (2022) estimate troughs in real house prices of between 1 and 4 percent following a 1 percentage point monetary contraction.

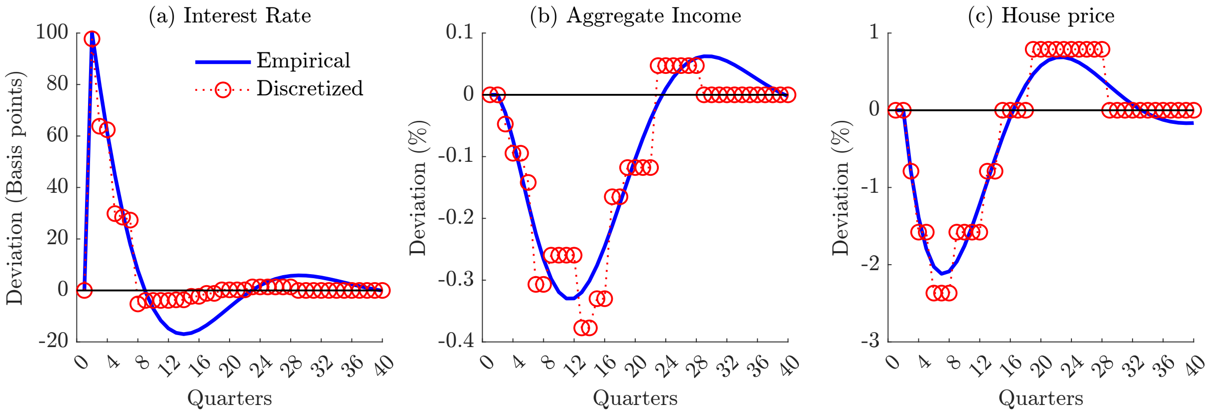
To embed the evolution of the aggregate state variables into the model we discretize the Markov chain associated with the VAR following Tauchen (1986).[14] Figure 1 compares IRFs to a monetary policy shock in the original VAR and in the discretized approximation to the VAR. Note that the VAR is embedded in the household decision problem which is itself a high-dimensional object. Thus, in order to maintain computational tractability we are restricted in the degree of accuracy we can attain via discretization. Nevertheless, our discretized VAR provides a reasonable approximation to the dynamics of interest rates, aggregate income, and house prices.

We explore the robustness of our VAR assumptions in the Online Appendix. We con-

[13] This identification assumption for monetary policy shocks is common in the Australian VAR literature. See, for example, Dungey et al. (2000), Hartigan et al. (2020), and Beckers (2020).

[14] For computational details, see Appendix B. We thank Robert Kirkby for his help with the code.

Figure 1: Aggregate Responses to Contractionary Monetary Policy Shock



Notes: IRFs in response to a 100 basis point contractionary monetary policy shock. Aggregate state variables follow the estimated VAR discussed in Section 2.3. The VAR process is discretized following Tauchen (1986). See Appendix B for details.

sider different de-trending procedures, the use of GDP instead of domestic final demand as the measure of aggregate income, and the addition of lags to the VAR model. In most cases, these changes have small quantitative effects on IRFs in response to a monetary shock.

Finally, note that in our model we assume that rents P_r are constant, and we exclude them from our VAR over macroeconomic variables. We make this assumption because rents move very little in response to monetary policy shocks and because the direction of their movement would tend to reinforce our results about movements in homeownership rate. In Figure 15 in the Online Appendix, we illustrate IRFs for an alternative VAR that incorporates real rents. In response to a 1 percentage point monetary policy contraction, rents increase by 0.3 percent over a period of two years. This is small in comparison to the large changes observed in house prices. Additionally, since this result implies that the rent-to-price ratio increases by (marginally) more than we allow in our restricted model, we would expect homeownership to rise by (marginally) more than we currently find in response to the decline of house prices. Nevertheless, for tractability we choose to ignore these small rental rate movements.

3. Calibration

We calibrate a subset of model parameters to be consistent with the existing macro-housing literature, Australian data, and institutional features of the Australian housing market. We then calibrate a small subset of parameters via a Simulated Method of Moments (SMM) algorithm to match key statistics on housing service costs, life-cycle wealth accumulation, homeownership, and mortgage offset usage. Note that we compute model statistics in the stochastic steady state, where the aggregate state vector is held constant at steady state but households maintain rational expectations over the distribution of shocks to and evolution of the aggregate states.

Table 1 reports our model parameters. Panel (a) reports parameters that are chosen consistent with information external to the model. The model period is one quarter, households enter the model at age 20, all households exit the model after retirement at age 65, so the total number of model periods is 180. We fix the discount factor β at 0.95, and risk aversion σ is set to 2.

The persistence ρ_z and standard deviation σ_z of income shocks are borrowed from Cho et al. (2023). They estimate an idiosyncratic income process using panel data from the Household, Income and Labour Dynamics in Australia (HILDA) survey from 2001 to 2015. HILDA is annual survey, whereas our model is calibrated to a quarterly frequency. Assuming that income shocks are IID across quarters, we map parameters for the annual AR(1) process in Cho et al. (2023) to our quarterly model. The persistence parameter is given by $\rho_z = \left(\rho_z^{annual}\right)^{1/4}$ and the standard deviation is $\sigma_z = \sigma_z^{annual}/\sqrt{(}1+\rho_z^2+\rho_z^4+\rho_z^6)$. In Table 1 we report the annualized values $\sigma_z^{annual}, \rho_z^{annual}$ from Cho et al. (2023).

We construct the deterministic life-cycle profile of income Γ_j by estimating a quadratic function for average incomes across age groups in the Australian Survey of Income and Housing (SIH) (Australian Bureau of Statistics, 2020a).[15] Our life-cycle profile is given by $\Gamma_j = \Gamma_1 + \Gamma_2(j/J) - \Gamma_3(j/J)^2$, and we estimate the parameters $\Gamma_1, \Gamma_2, \Gamma_3$ so that average income by age group matches the observed averages by age groups 15–24, 25–34, 35–44, 45–54, 55–64 in the SIH data.

We construct the idiosyncratic income exposures $f(\Gamma_j, z_j, Y)$ to aggregate income fluctuations using the estimates reported in Stone (2016). For a sample of working-age Australian households, Stone (2016) find that the lowest (highest) quintile of income earners experience a 7.07 (-0.07) percent increase in income in response to a 1 percent increase in GDP.[16] We take the stochastic steady state distribution of household income in the model and assume that exposures to aggregate income fluctuations are captured by $f(\Gamma_j, z_j, Y) = \chi_1 + \chi_2 \exp(\chi_3 \Gamma_j z_j Y)$. We estimate the parameters χ_1, χ_2, χ_3 to match average income exposures across quintiles of the household income distribution in the model and to thoise in Stone (2016).

We take the steady state interest rate on liquid assets r to be the average real 10-year Australian treasury yield over the years 2000 to 2019 (Organization for Economic Co-operation and Development, 2023d; Organization for Economic Co-operation and Development, 2023a). The mortgage interest rate spread $\kappa = r_b - r$ is calculated from the average offered floating rate mortgage contract over the years 2000 to 2019 (Reserve Bank of Australia, 2023b). The maximum LTV and NIS ratios are set to $\theta_b = 0.8$ and

[15] For our income, wealth, and housing statstics we use averages of SIH data from 2014 to 2020, since these waves of the survey provide publicly accessible cross-section data by age.

[16] Prior literature has estimated individual income sensitivities to aggregate income for the US (Guvenen et al., 2017; Patterson, 2023) and several European countries (Busch et al., 2022).

$\theta_y = 0.7$. The Australian Prudential Regulation Authority (APRA) has not imposed required maximum LTV ratios on Australian lenders, however, it reserves the right to do so and requires lenders to hold the ability to limit the extent of lending with LTV ratios of greater than or equal to 80 or 90 percent (see Attachment C of Australian Prudential Regulation Authority, 2022a). The Reserve Bank of Australia reports that the maximum allowable NIS ratio is 90 percent, but shows that more than 65 percent of new mortgages have an NIS ratio of 70 percent or less (Reserve Bank of Australia, 2018). APRA does set mortgage lending regulations over required mortgage servicability buffers (Australian Prudential Regulation Authority, 2022a). These servicability buffers have varied between 2 and 3 percent over the last decade.[17] We use an annual servicability buffer ϕ of 2.5 percent.

There are no authoritative sources on the cost of mortgage originations in Australia, so we set $f_b = 0.01$ as in the US (Freddie Mac, 2022). Australian housing sales costs f_h are estimated at around 3 percent in Fox et al. (2014).[18] The depreciation rate or maintenance cost of housing δ is set to 2 percent at an annual rate, as in Cho et al. (2023).

Since homeownership rates are determined by house prices P_h and house size H (see discussion below), we normalize the per-unit rental cost of housing P_r to 1.

Panel (b) of Table 1 reports model parameters chosen via the SMM algorithm. We choose five parameters $\{\alpha, \omega, P_h, H, \underline{h}, f_o\}$ to match the observed statistics reported in Table 2. All of our targeted moments are taken from the Australian Survey of Income and Housing (SIH). For our income, wealth, and housing statstics we use SIH data from 2014 to 2020, since these waves of the survey provide publicly accessible cross-section data by age (Australian Bureau of Statistics, 2020a). For our rental costs statistics we use SIH data on housing and occupancy costs from 2000 to 2019 (Australian Bureau of Statistics, 2020b).

We set the non-durable consumption share α in the utility function to match average rental costs relative to income among all renters. Holding fixed the discount factor β, the retirement utility parameter ω governs the level of wealth accumulated for retirement. So we choose ω to target the ratio of average net worth for households aged 55–65 to average income for households aged 55–65. We choose the steady state house price P_h to match the Australian homeownership rate. We then match the homeownership rate amoung young households, aged less than 25, by choosing the default house size H. Finally, we choose the fixed cost of holding a mortgage offset account f_o to target the ratio of total

[17] See, for example, historical directives on buffers to be applied to mortgage lending: https://www.apra.gov.au/news-and-publications/apra-finalises-amendments-to-guidance-on-residential-mortgage-lending and https://www.apra.gov.au/sites/default/files/2021-10/Letter%20to%20ADIs_Strengthening%20residential%20mortgage%20lending%20assessment.pdf.

[18] Cho et al. (2023) model housing sales and purchase costs separately. Because there is only one house size in our model households do not repeatedly transact housing and so transaction costs do not play a significant role in our analysis.

Table 1: Model Parameters

Parameter	Symbol	Value	Source
Panel (a): Externally Calibrated Parameters			
Model period		1 quarter	Authors
Minimum age		20	Authors
Retirement age		65	Authors
Discount factor (annualized)	β	0.95	Authors
Risk aversion coefficient	σ	2	Authors
AR(1) income, persistence	ρ_z	0.9400	Cho et al. (2023)
AR(1) income, std. dev. shocks	σ_z	0.1700	Cho et al. (2023)
Income: age profile, intercept	Γ_1	-0.3634	SIH, 2014–2020
Income: age profile, coefficient	Γ_2	5.3139	SIH, 2014–2020
Income: age profile, curvature	Γ_3	3.7750	SIH, 2014–2020
Income: GDP exposure, intercept	χ_1	-0.1597	Stone (2016)
Income: GDP exposure, coefficient	χ_2	28.0283	Stone (2016)
Income: GDP exposure, curvature	χ_3	-2.5354	Stone (2016)
Interest rate on bonds	r	0.0190	OECD (2023a,b)
Mortgage interest rate spread	κ	0.0217	RBA (2023)
Maximum LTV ratio	θ_b	0.8000	Authors
Mortgage servicability buffer	ϕ	0.0250	APRA (2022)
Maximum servicability ratio	θ_y	0.7000	Authors
House sale cost	f_h	0.0300	Fox et al. (2014)
Mortgage origination cost	f_b	0.0100	Freddie Mac (2022)
Housing maintenance cost	δ	0.0200	Cho et al. (2023)
Panel (b): Internally Calibrated Parameters			
Nondurable consumption share	α	0.7940	SMM
Utility weight on retirement wealth	ω	764.5980	SMM
House price	P_h	16.1930	SMM
Minimum house size	H	1.1290	SMM
Fixed cost of offset account	f_o	0.0250	SMM

Notes: Interest rate, mortgage rate spread, servicability buffer, maintenance cost, AR(1) income parameters, and discount factor reported at annual rates and frequencies.

assets held in offset accounts relative to total liquid assets. Our calibration implies that: households allocate around 20 percent of total expenditure to housing costs; the average house value is a little over twice average annual household income; and the implied cost of using an offset account is around $275 per quarter.[19]

[19]The model offset account cost f_o is equivalent to 0.47% of annual average income, while mean per-capita disposable income in the 2020 SIH is $1124 per week.

Table 2: Model Fit to Targeted and Untargeted Statistics

Moment	Data	Model	Source
Panel (a): Targeted Moments			
Mean rent-to-income ratio, renters	0.1919	0.1881	SIH, 2000–2019
Mean networth/Mean income, age 55—65	5.9464	6.0314	SIH, 2014–2020
Homeownership rate	0.6680	0.6589	SIH, 2014–2020
Homeownership rate, age ≤ 25	0.1197	0.1099	SIH, 2014–2020
Total offset accounts/Total liquid assets	0.1634	0.1565	SIH, 2014–2020
Panel (b): Untargeted Moments			
Mean house value/Mean income	5.0395	2.2411	SIH, 2014–2020
Mean mortgage/Mean income	1.0624	0.7102	SIH, 2014–2020
Mean costs-to-income ratio, mortgagors	0.1727	0.1706	SIH, 2000–2019
Fraction mortgage holders with offsets	0.4000	0.3409	La Cava et al. (2021b)
Renter-to-owner transitions	0.0550	0.0236	Cho et al. (2021)
Owner-to-renter transitions	0.0210	0.0083	Cho et al. (2021)
Housing turnover rate	0.0520	0.0358	Leal et al. (2017)

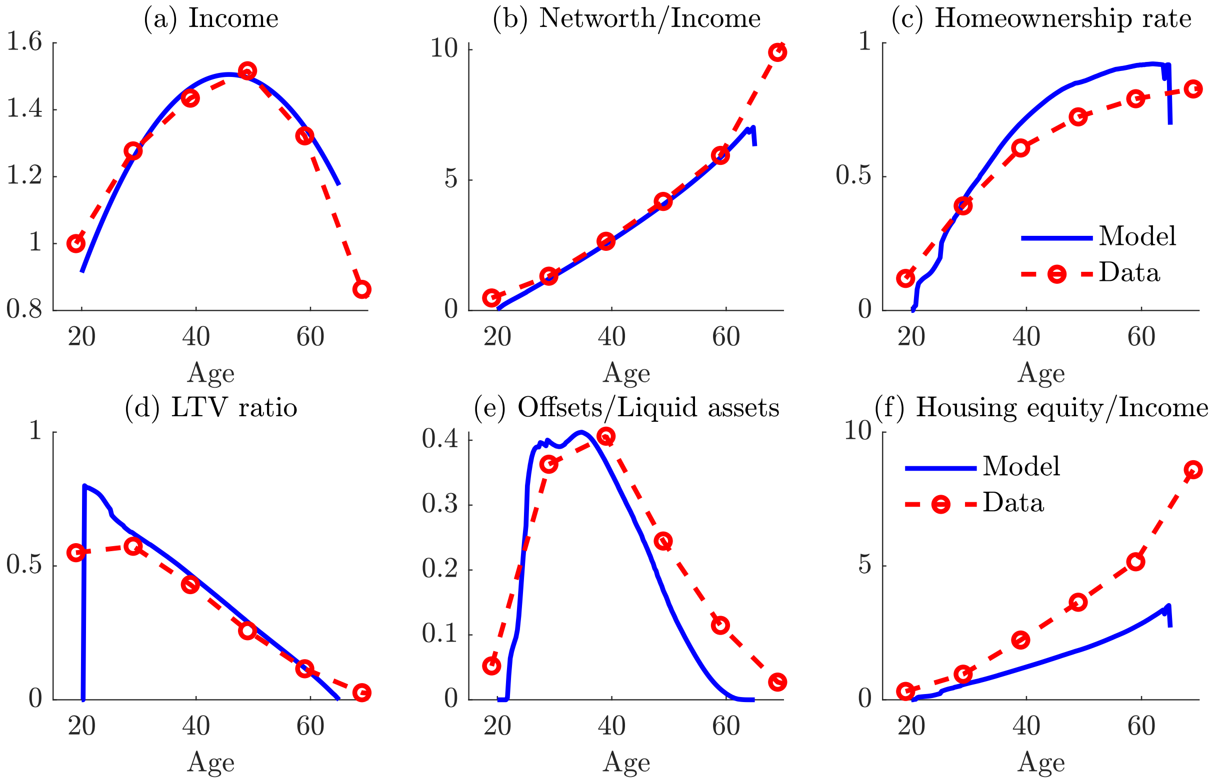
Notes: Mean income computed at annualized rate. Cost of housing for mortgagors includes: mortgage payments, depreciation costs, offset account costs.

3.1. Model Fit

Table 2 reports the model fit to statistics targeted in the SMM calibration process, as well as a selection of untargeted statistics. In panel (a) we show that the model fits the targeted statistics very well. The rental costs-to-income ratio is around 0.2, as in the data. Households accumulate significant networth as they approach retirement, holding around 6 times as much wealth as income between ages 55 and 65. The overall homeownership rate is around 66 percent and the homeownership rate for households aged 25 and under is around 11 percent, as observed in Australia over the last decade. The share of offset account balances in total liquid assets is around 16 percent, as seen in the data.

Panel (b) of Table 2 reports untargeted statistics that are not part of the calibration process. We find that the average house value and average mortgage size relative to income (2.24 and 0.71, respectively) are significantly lower than their observed values in the data (5.0 and 1.1, respectively). This is for two reasons. First, our model only features a single house size so wealthier households cannot increase housing wealth by upsizing. Second, there are no housing capital gains in our model, so the value of a given owner-occupied property does not grow relative to income over time. Although the model understates house values and mortgage balances, average housing costs for mortgage holders – mortgage payments, depreciation, and offset account costs – are the same as in the data (17 percent of income). While we target the size of mortgage offset account balances relative to liquid assets, our model also produces a similar number of mortgage offset accounts as in the data (34 vs. 40 percent, respectively). Owner-to-renter and renter-to-owner tenure transitions (2.4 and 0.8 percent, respectively) are a little under half the transitions observed in the data (5.5 and 2.1 percent, respectively). Finally, the housing turnover rate (3.6 percent) is a little over half of the rate in the data (5.2 percent).

Figure 2: Model fit to data across the life-cycle

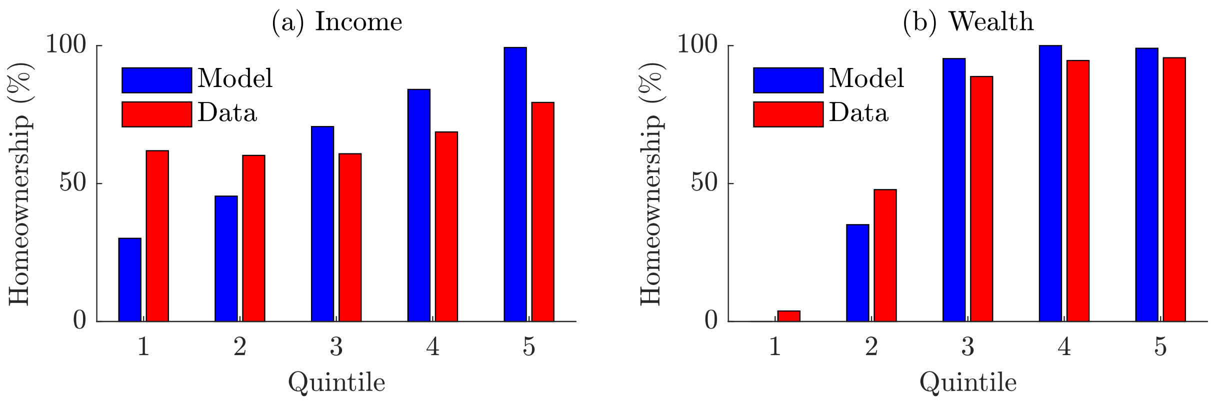


Note: Panel (a) is normalized to average income at age 15–24. Statistics in the data are computed as time-averages over 2014–2020.
Source: Authors' calculations using Survey of Income and Housing (Australian Bureau of Statistics, 2020a).

Figure 2 compares the life-cycle profiles of various statistics in the model and the data. We illustrate life-cycle patterns of income, wealth, and housing variables, where solid blue lines are model statistics and dashed red lines with circle markers show data averages by 10-year age group in the SIH (Australian Bureau of Statistics, 2020a). Panel (a) shows that average household income follows a hump-shaped life-cycle profile. Panel (b) shows that households accumulate significant networth relative to income as they age. Panel (c) illustrates the rising profile of homeownership by age. Panel (d) reports a measure of the aggregate mortgage LTV, that is, the average value of loans relative to the average value of housing. Panel (e) shows the size of mortgage offset account balances relative to total liquid assets. Panel (f) shows average housing equity-to-average income.

Overall, Figure 2 shows that households begin life as renters and slowly move into homeownership over their working lives. Around half of all households become homeowners by age 35 and homeownership rates continue to grow, albeit more slowly, until retirement. The biggest barrier to homeownership for young households is the down-payment required to purchase a house. Young households begin life with no assets, and must accumulate liquid assets prior to house purchase. First time home-buyers then borrow up to the largest feasible mortgage implied by their LTV and NIS constraints. Thus, the aggregate LTV sits at around 80 percent for the youngest households. After borrowing to enter the housing market, the fixed mortgage amortization schedule implies a near-linear decline in mortgage balances over the life-cycle. However, households can and do reduce their mortgage interest costs by accumulating liquid assets in mortgage offset accounts. Offset account usage peaks between ages 30 and 40. By this time, many households are homeowners and have had time to accumulate enough assets that the mortgage interest cost savings outweigh the offset account fixed cost. Later in life, mortgage balances have been paid down and the interest savings produced by an offset account are not worth the fixed cost of use. Finally, as noted above, households in the model under-accumulate housing equity relative to the data. Taken together, Panels (b) and (f) suggest that households significantly overaccumulate liquid assets relative to the data.

Figure 3: Homeownership Rates by Income and Wealth



Note: There are zero homeowners in quintile 1 of the wealth distribution of the model.
Source: Authors' calculations using Survey of Income and Housing (Australian Bureau of Statistics, 2020a).

Finally, Figures 3 compares homeownership rates across the household income and wealth distributions in the model and data. In the model, homeownership is rising in both income and wealth. In the data, homeownership is fairly flat across the income distribution as it includes low-income retirees who are very likely to own their own homes. The model matches the rise in homeownership across the wealth distribution reasonably well.

4. Effects of Monetary Policy Shocks

We now use the model to study homeownership responses to changes in monetary policy. To do this we induce a monetary policy shock in the model, which is transmitted to the other aggregate state variables via the estimated VAR from Section 2.3. We study a contractionary monetary policy shock associated with an 100 basis point increase in interest rates, as illustrated in Figure 1.

The monetary policy shock and associated changes in the aggregate state vector has several effects on household behavior. First, the rise in interest rates directly increases the rate of return on liquid assets for household savers. Second, the rise in interest rates passes through to mortgage interest rates. Since mortgages are floating rate contracts, interest costs immediately increase for new and existing borrowers. Additionally, higher rates decrease the size of mortgages available to new borrowers via the maximum NIS constraint in Equation (2). Third, the fall in GDP reduces household incomes. Fourth, lower house prices reduce the cost of purchasing a new home and lower the value of existing homes.

Beyond the direct effects of the monetary policy shock, recall that households hold rational expectations over the evolution of the aggregate state variables. This has several model implications. First, households understand the distribution of shocks to monetary policy, and account for this aggregate risk in their decision-making. Second, the IRFs in Figure 1 represent the expected paths of interest rates, aggregate income, and house prices following a contractionary monetary policy shock. Third, households understand the joint dynamics of the aggregate state variables, so that if just one of the aggregate states is away from steady state the other aggregate states are expected to evolve consistent with the dynamics captured by the VAR. We explore these implications further in Sections 4.1 and 4.4.

4.1. Monetary Policy Shocks in the Baseline Model

In this section, we first show the overall effect of the monetary policy shock on the homeownership rate. The economy starts in the stochastic steady state, we feed the IRFs from Figure 1 through the model, and we keep track of the distribution of household decisions along the transition path. Second, we show the isolated effect of the different macroeconomic channels of monetary policy on housing decisions. To do this, we feed the IRFs from panels (a), (b), and (c) through the model one at a time, holding the other aggregate state variables at their steady state values.

Figure 4 shows responses to the monetary policy shock. Solid blue lines illustrate our baseline results. Following a monetary policy shock the homeownership rate declines by a little more than 1 percentage point over the first year. Homeownership hits a trough after one year before rising again. Overall, ownership remains below steady state for nearly 8 quarters. It then rises to around 0.8 percentage points above steady state, and remains elevated over the next three years.

Figure 4: Homeownership Responses to Monetary Policy Shock and its Components

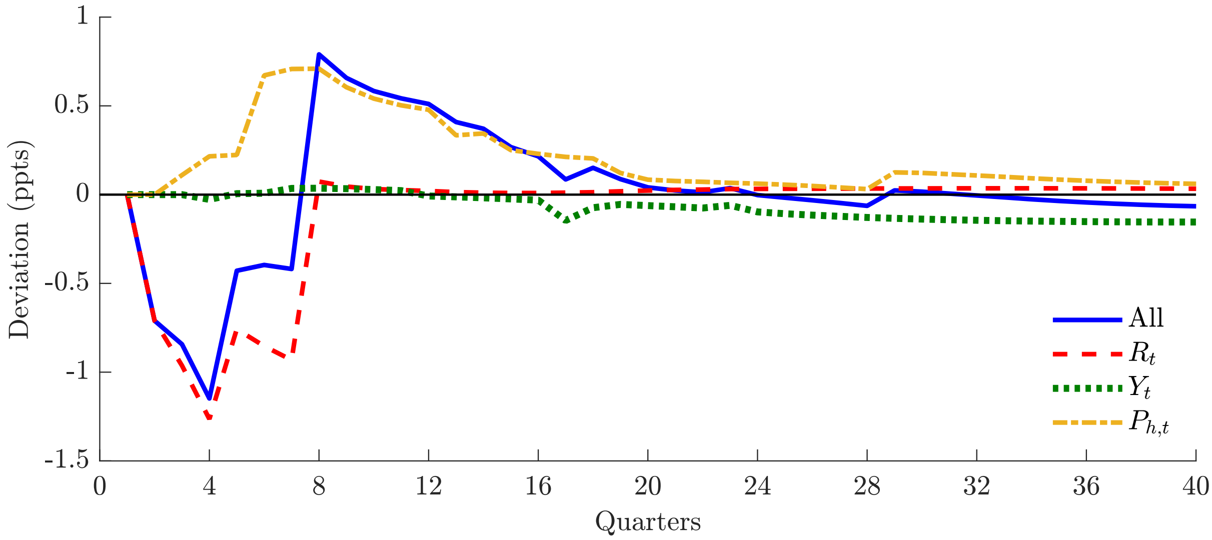
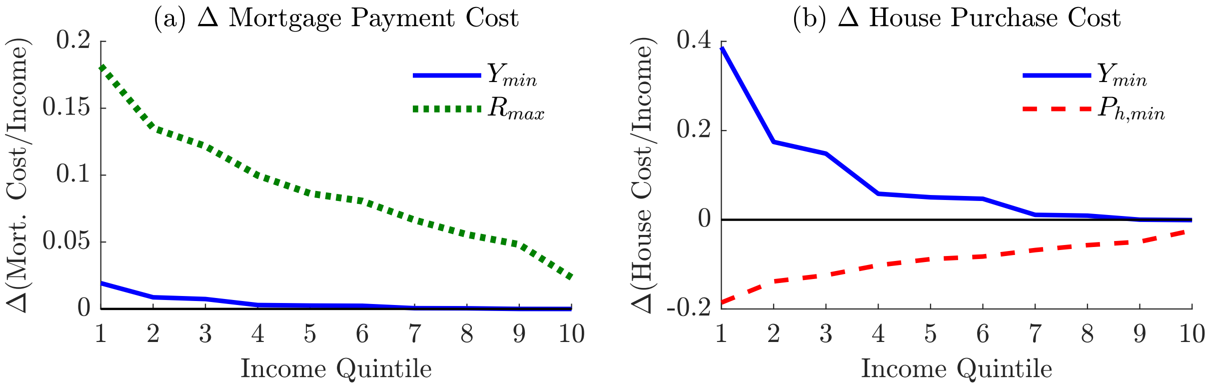


Figure 4 also illustrates the effects of the different monetary policy channels in isolation. Red dashed lines are the effect of the changes in interest rates in isolation, green dotted lines are the effect of the changes in aggregate income, and yellow dash-dotted lines are the effect of changes in house prices. Note that the effects of the individual channels do not necessarily sum to the overall effect of the monetary policy shock (i.e. this is not technically a decomposition exercise), as conditional expectations are different for each experiment.

We find that the initial decline in homeownership is explained by high interest rates. Under the interest rate path alone, homeownership would also remain lower for longer, only beginning to return to steady state 2 years after the shock. Over the medium run, 8 to 20 quarters following the shock, high homeownership rates are entirely explained by low house prices. Under the house price path on its own, ownership begins to rise immediately, hits a peak 6 quarters after the shock, and only slowly returns to steady state. Finally, the decline in aggregate income has little effect on homeownership in the short run, but has a small, persistent, negative effect over the medium-to-long run.

To provide more context for the importance of these monetary policy channels, Figure 5 shows the effects of interest rate, income, and house price changes on mortgage payments and house purchase costs across the distribution of household income. In panel (a), we hold fixed initial mortgage size at the median mortgage under the NIS constraint. We then compute payments relative to income when aggregate income falls to its trough Y_{min} or when interest rates rise to their peak R_{max}. Changes in interest rates have the largest effect. For the highest income households payments rise by a little under 5 percent of quarterly income, while for the lowest income households payments would rise by nearly

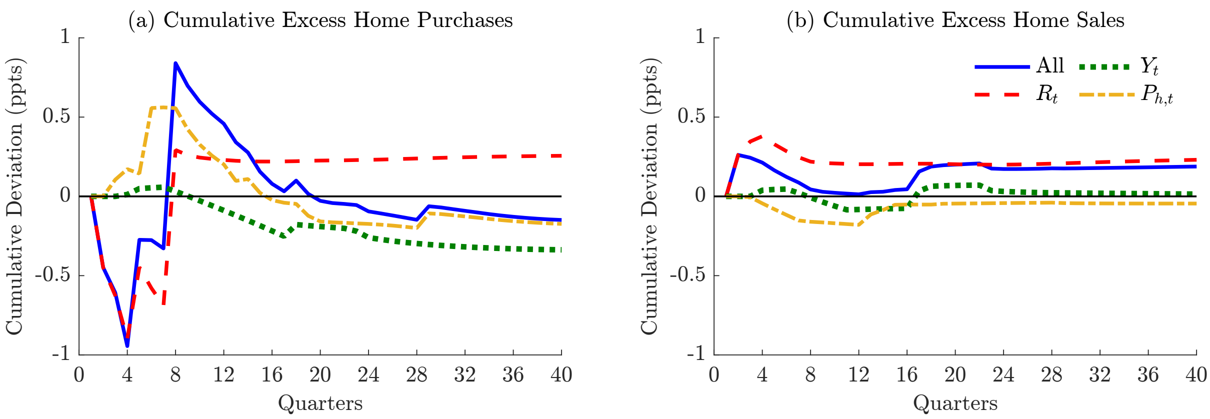
Figure 5: Change in Home Purchase and Mortgage Costs Given Monetary Policy Shock



Notes: In Panel (a), initial mortgage size is held fixed at steady state median mortgage under NIS constraint. In Panel (b), house size is held fixed at H and housing costs computed as fraction of annual income.

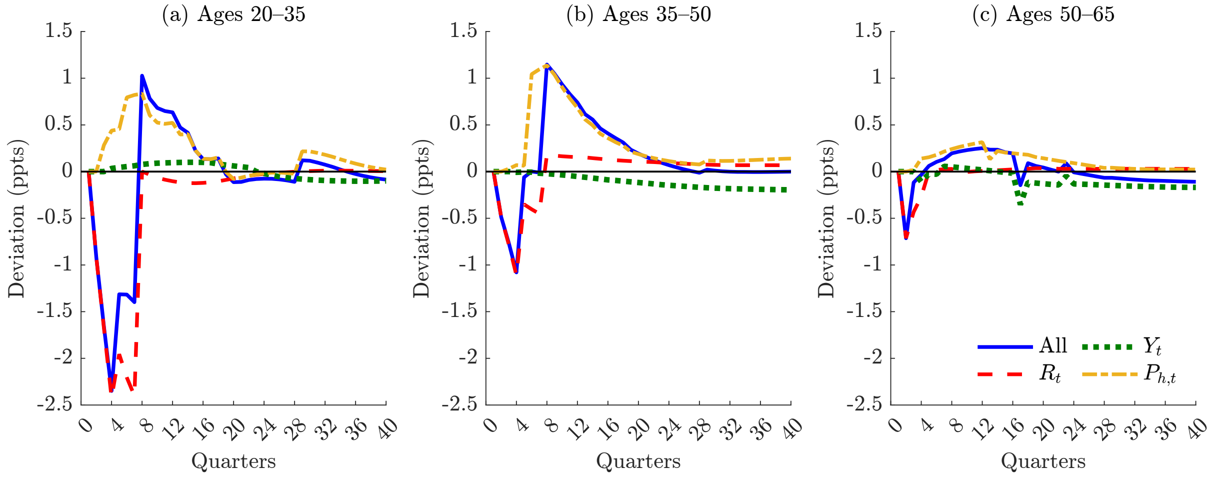
20 percent of income. In panel (b) we hold fixed the house purchase size at H and compute the change in house purchase costs as a fraction of annual income when aggregate income or house prices fall to their troughs Y_{min} and P_{min}. When prices fall, the total house purchase cost falls by 20 percent of annual income for the lowest income households. But when income falls, house purchase costs rise by 40 percent of annual income for these households. Effects on the highest income households are much smaller.

Figure 6: Home Purchases and Sales Following a Monetary Policy Shock



Are fluctuations in the homeownership rate driven by changes in home purchases or home sales? Recall that renter-to-owner transitions are nearly three times larger than owner-to-renter transitions (see panel (b) of Table 2). So it may not be surprising that Figure 6 shows that variation in the homeownership rate is mostly driven by changes in house purchases and changes in house sales only play a small role. Panel (a) shows that purchases initially fall by 1 percentage point, while panel (b) shows that sales rise by around 0.25 percentage points. In the short run, these responses are mostly accounted for by the isolated effect of higher interest rates. Over the medium run, lower house prices explain higher house purchases but they also lead to a somewhat lower rate of home sales.

Figure 7: Homeownership Responses to Monetary Policy Shock, by Age



Finally, Figure 7 illustrates the effect of monetary policy shocks on homeownership rates over the life-cycle. Panel (a) shows that young households are especially sensitive to rising interest rates, with homeownership rates falling by more than 2 percentage points within the first year of the monetary policy shock. As interest rates normalize but house prices remain low, young households quickly enter the housing market with ownership rates rising to 1 percentage point above steady state two years after the shock. Panel (b) shows that middle-aged households are less sensitive to interest rates, but are at least as sensitive to low house prices as young households. Finally, panel (c) suggests that a small number of older households exit homeownership in response to high interest rates. Some of those with remaining mortgage debt sell in order to avoid higher financing costs, while others take the opportunity to sell property and invest in liquid assets with a higher rate of return immediately prior to retirement.

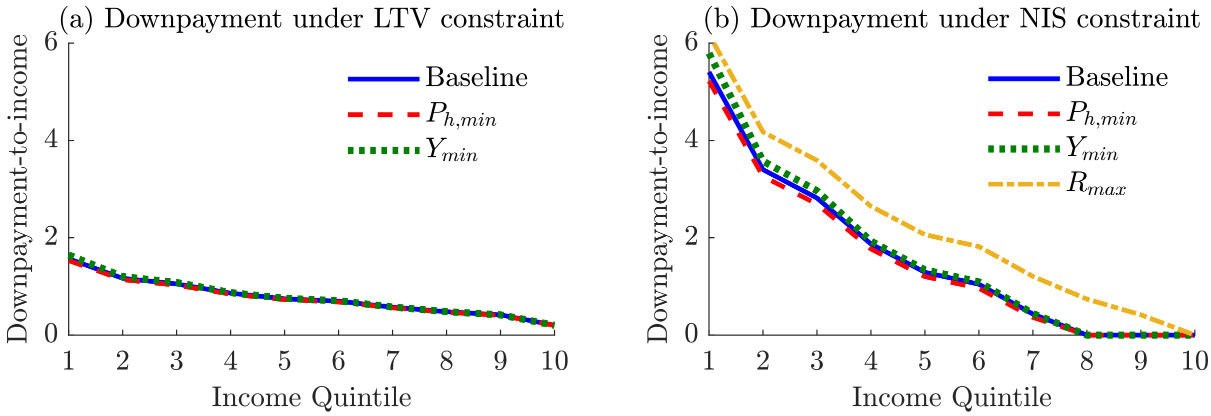
4.2. Monetary Policy and Borrowing Constraints

We now study the effect that mortgage borrowing restrictions have on the transmission of monetary policy shocks to the homeownership rate.

In Figure 8, we first consider how shocks to aggregate state variables affect the required downpayment on a house under the LTV and NIS constraints. The solid blue lines in panels (a) and (b) show required downpayments-to-income in steady state across quintiles of the income distribution. Downpayments are declining with income, but are generally larger under the NIS constraint than the LTV constraint. That is, the NIS constraint on mortgage borrowing is generally more binding than the LTV constraint. This is consistent with the results of Ma et al. (2021) who find that most households in the US are constrained by their payment-to-income constraint rather than their LTV constraint.

Figure 8 then illustrates required downpayments at the troughs in house prices $P_{h,min}$ and aggregate income Y_{min} and the peak in interest rates R_{max} following the monetary policy shock. The aggregate shocks have very little noticeable effect on downpayments under the LTV constraint. Under the NIS constraint lower house prices reduce required downpayments, lower aggregate incomes raise downpayments, and higher interest rates increase required downpayments dramatically. Given these results, we expect the NIS constraint to have a significant impact on the evolution of homeownership in response to monetary policy shocks.

Figure 8: Required Downpayment Given Effects of Monetary Policy Shock



Now consider the effects of monetary policy shocks under looser mortgage borrowing constraints. To conduct these exercises, we first solve for new steady states assuming the mortgage borrowing constraints are relaxed one at a time. First, we assume there is no maximum LTV constraint, then we assume there is no maximum NIS constraint, and finally we assume there is no required mortgage servicability buffer ϕ. Table 3 compares steady state values for the the homeownership rate, mortgage size, and mortgage payment amounts under each of these changes. Since the LTV constraint is rarely binding in the baseline model (see Figure 8), the steady state is little changed when the maximum LTV constraint is removed. Removing the NIS constraint significantly increases the homeownership rate, mortgage size, and mortgage payments. And removing the servicability buffer moderately increases homeownership, mortgages, and mortgage payments.

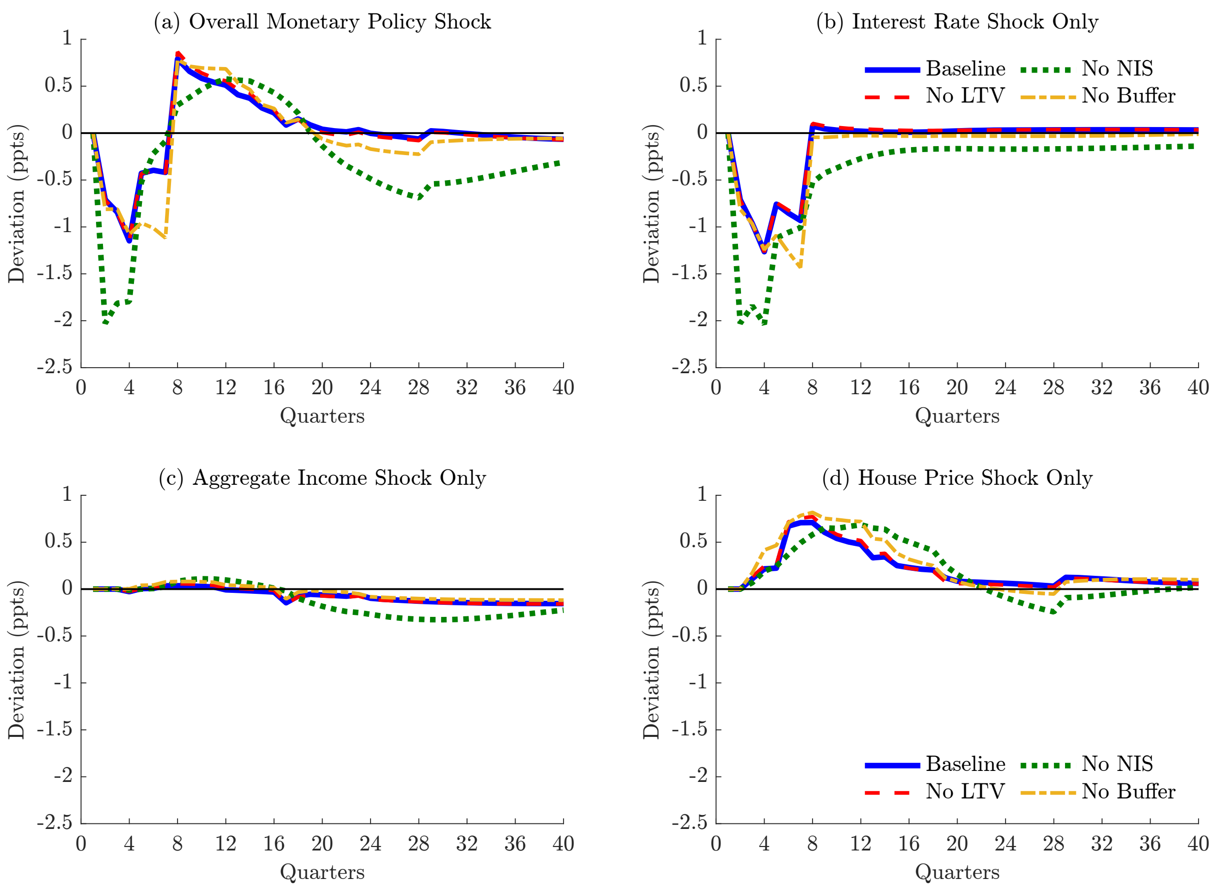
We then feed the monetary policy shocks from Figure 1 into the model and track the evolution of the homeownership rate. Figure 9 reports deviations of homeownership rates in each economy from the steady states reported in Table 3. Panels (a)–(d) show homeownership responses under the overall monetary policy shock, the interest rate shock only, the aggregate income shock only, and the house price shock only. Solid blue lines show the baseline model, red dashed lines show the model with no LTV constraint, green dotted lines show the model with no NIS constraint, and yellow dash-dotted lines show the model with no mortgage servicability buffer.

Removing the LTV constraint has very little effect on the homeownership rate following a monetary policy shock. This is because very few households are LTV constrained in the first place. Removing the NIS constraint leads to a larger initial fall in home-

Table 3: Steady States Under Alternative Assumptions

	Homeownership	Mortgage/Income	Payment/Income
Baseline	0.659	2.841	0.059
No LTV constraint	0.652	2.822	0.059
No NIS constraint	0.828	4.860	0.103
No servicability buffer	0.710	3.573	0.072
No offset accounts	0.659	3.351	0.073
Short mortgage maturity	0.610	1.718	0.046
Temporary Expectations	0.659	2.834	0.059
Permanent Expectations	0.659	2.834	0.059

Figure 9: Response to Shocks with Loose Borrowing Constraints



ownership, and panel (b) shows that this is because households are much more sensitive to interest rate shocks. This contrasts with Greenwald (2018), who argues that households would be more sensitive to interest rates under binding payment-to-income type constraints. In our model, the NIS constraint is binding on most households, and this leads to smaller mortgage balances than in the absence of the constraint (see Table 3). Without the NIS constraint, homeowners are more indebted so for a fixed increase in the interest rate they face a larger increase in mortgage costs, and a larger disincentive to purchase housing. Finally, removing the mortgage servicability buffer is akin to partially relaxing the NIS constraint. Absent the servicability buffer, potential homeowners are slightly more sensitive to both interest rates and house prices than in the baseline model.

Our results follow a recent literature emphasizing the importance of modeling both loan-to-value and payment-to-income constraints in order to understand housing market boom and bust dynamics (Greenwald, 2018; Ma et al., 2021; Kinnerud, 2022; Balke et al., 2023). In our model, NIS (i.e. payment-to-income) constraints are generally binding so relaxing these constraints endogenously increases mortgage debt. This increase in debt burdens shifts the sensitivity of homeownership from fluctuations in house prices towards fluctuations in interest rates. This can lead to a relative decline in medium-run fluctuations in homeownership at the expense of larger short-run fluctuations.

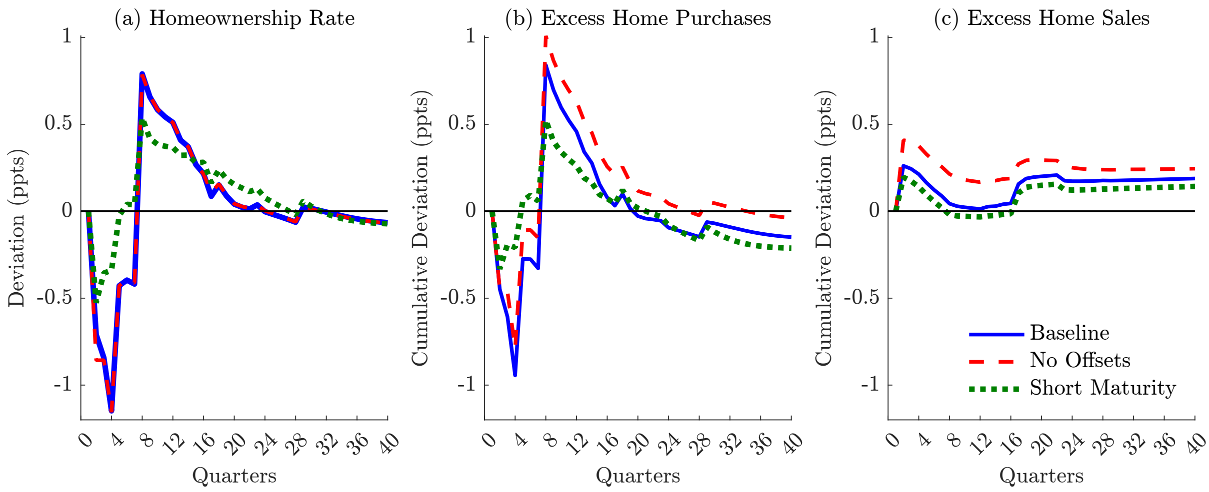
4.3. Monetary Policy and Mortgage Flexibility

We now study the effect that mortgage flexibility has on the transmission of monetary policy shocks to the homeownership rate. Boar et al. (2022) argue that many US homeowners find themselves constrained by the illiquidity of their housing assets and mortgage debts. Australia is unusual in offering mortgage offset accounts that both reduce mortgage interest costs and increase the liquidity of an otherwise rigid mortgage contract. On the one hand, our model captures the flexibility of mortgage offset accounts, but on the other we assume that mortgage payments follow a strict amortization schedule and no pre-payment is allowed.

In this section, we explore the role of mortgage flexibility in propagating monetary policy shocks to the housing market. To do this we compare the effects of monetary policy shocks under less flexible mortgage contracts than in the baseline model. First, we eliminate mortgage offset accounts, then we reduce the mortgage maturity length from 30 years to 15 years. Table 3 compares steady states under each of these changes to the baseline economy. Eliminating offset accounts does not change the homeownership rate, but does increase average debt as households repay mortgages more slowly when accumulating interest (see, also, Graham, 2024). Reducing mortgage maturity length decreases the homeownership rate because of the need to repay more quickly.

Figure 10 illustrates the evolution of homeownership, home purchases, and home sales in response to the monetary policy shock under each economy. Panel (a) shows that removing offset accounts has little effect on the evolution of the homeownership rate. However, panels (b) and (c) show that there is a significant increase in gross housing flows in the absence of offset accounts. In particular, home purchases fall less following the rise in interest rates but house sales rise by more. The rise in sales reflects the fact that households now have less ability to avoid high interest rates by offsetting their mortgage with accumulated liquid assets.

Figure 10: Responses to Shocks with Less Mortgage Flexibility



Panel (a) shows that shortening the maturity of mortgage debt significantly dampens fluctuations in the homeownership rate. Panel (b) and (c) show that this largely occurs through a decline in the volatility of home purchases. Shorter mortgage maturities are associated with larger mortgage payments in each period. However, a larger fraction of payments is associated with principal repayment, and a smaller fraction is associated with interest payments. Thus rising interest rates have a relatively smaller impact on the cost of mortgage finance. Additionally, for a given decline in house prices, fewer households are in a position to purchase their first home than in the baseline model because of larger required downpayments under the binding NIS constraint. Thus, our results suggest that longer mortgage maturity lengths tend to amplify the response of homeownership to house price fluctuations.

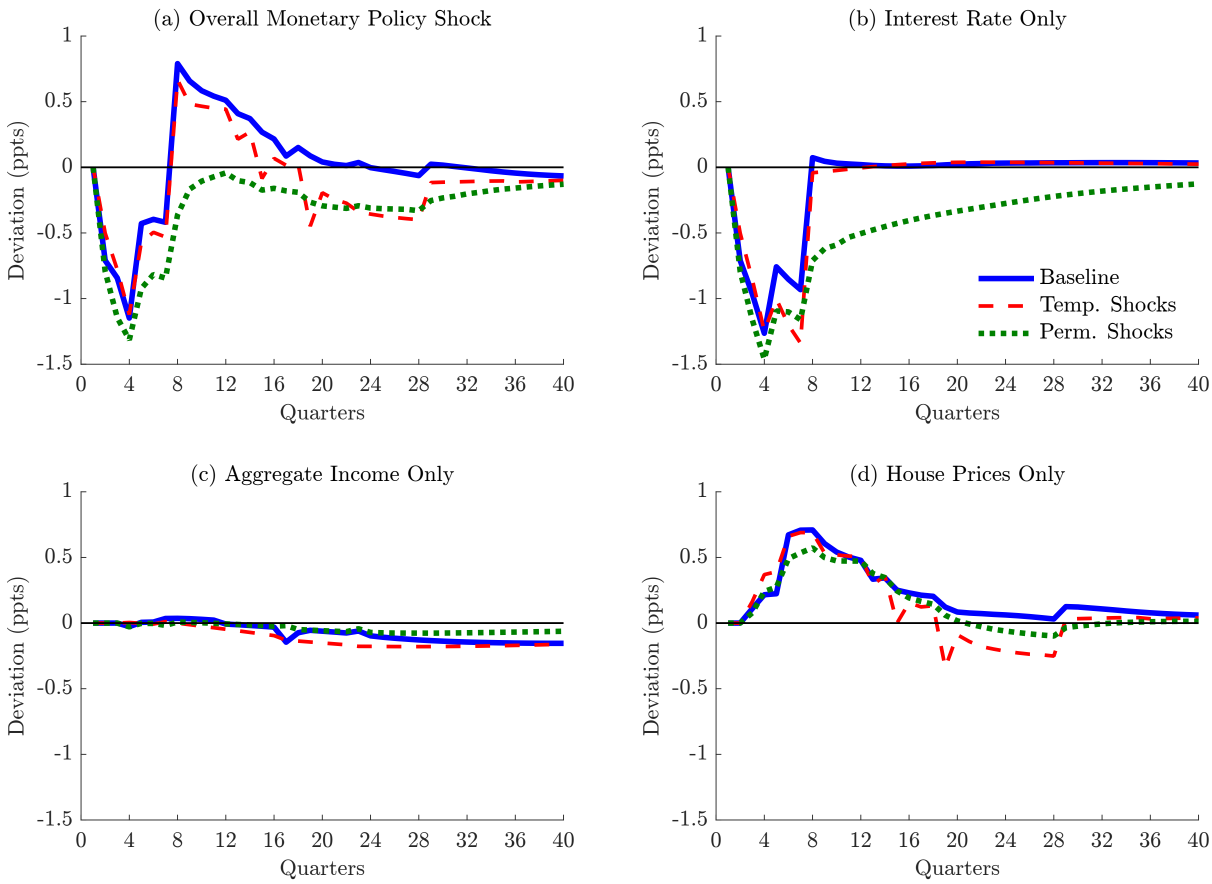
4.4. Monetary Policy and Household Expectations

In our final exercise, we study the role of household expectations over the evolution of the aggregate state variables in the transmission of monetary policy shocks to homeownership decisions. First, we assume that households believe that all shocks are transitory. That is, regardless of the current aggregate state households expect an immediate return to steady state in the next period. Second, we assume that households believe that all shocks are permanent so that the current aggregate state persists forever. Note that in both of these experiments there is no aggregate uncertainty.

Figure 11 shows responses of the homeownership rate to monetary policy shocks in the baseline model (solid blue lines), the model with expectations of transitory shocks (dashed red lines), and the model with expectations of permanent shocks (dotted green lines). Panels (b) to (d) illustrate the effects of each of the channels of monetary policy in isolation.

When shocks are expected to be transitory we find there is little difference in the

Figure 11: Responses to Shocks with Alternative Household Expectations

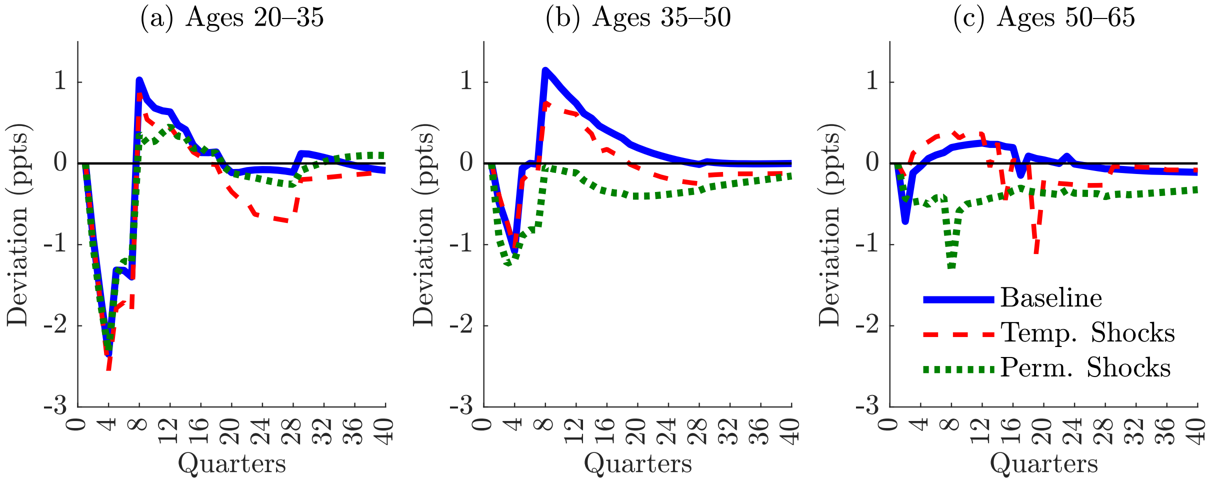


short-run evolution of the homeownership rate compared with the baseline model. Over the medium run, however, homeownership declines more quickly and even undershoots steady state around 5 years after the shock. Panel (d) shows that this is largely due to the response to house prices, itself overshoots steady state 4 years after the shock (see Figure 1). While house prices remain above steady state, potential homeowners prefer to wait until next period to purchase a house when they believe house prices are sure to fall back to steady state.

When shocks are expected to be permanent, homeownership rates fall by slightly more over the short run but are significantly lower over the medium run. Panel (b) shows that this is almost entirely due to the response of homeownership to interest rates. In the first two years while interest rates remain above steady state, homeownership remains 1 percentage point lower than steady state. After two years, when interest rates have normalized, the homeownership rate remains low and only slowly returns to steady state.

Figure 12 shows that much of the unusual response to shocks that are believed to be permanent comes from older households. Believing that interest rates are permanently higher, older households exit the housing market to transfer housing equity to liquid savings accounts. Many of these households do not return to owning even after interest rates return to steady state, as the transactions costs involved in purchasing another house outweigh the benefits of homeownership for the short time they have left until retirement.

Figure 12: Responses with Alternative Household Expectations, by Age



5. Conclusion

In this paper we study the effects of monetary policy on homeownership rates, taking Australia as our setting. We build a detailed, life-cycle, heterogeneous household model that features novel aspects of the Australian housing and mortgage markets. We then incorporate an estimated exogenous stochastic process to capture the effects of monetary policy on interest rates, aggregate income, and house prices. While we abstract from general equilibrium, our approach allows us to model household tenure decisions in the face of realistic macroeconomic dynamics following a monetary policy shock.

We use the model to study changes in homeownership following contractionary monetary policy shocks. In the short run, higher interest rates sharply curtail the homeownership rate as households delay house purchases in the face of higher mortgage financing costs. Over the medium run, however, homeownership rises due to the stimulating effect of persistently low house prices on housing affordability. We also explore the role of borrowing constraints, mortgage flexibility, and household expectations formation in the monetary policy transmission mechanism. Overall, our results highlight the complex and conditional relationship between monetary policy and housing market.

Our paper presents a novel contribution to the macro-housing literature by providing detailed micro-foundations for homeownership decisions in the face of high-frequency monetary policy shocks. This contrasts with prior research that takes homeownership as given (Beraja et al., 2019), abstracts from detailed household heterogeneity (Greenwald, 2018; Dias et al., 2022), aggregates decisions at a lower time frequency (Wong, 2021; Kinnerud, 2022), or focuses on outcomes other than the homeownership rate itself. We hope that future research might build on the foundations provided in the current paper to explore the effects of monetary through the housing market with a detailed picture of the homeownership decisions that households make therein.

References

Auclert, Adrien, "Monetary policy and the redistribution channel", *American Economic Review* 109 (2019), 2333–67.

Australian Bureau of Statistics, *Australian National Accounts: National Income, Expenditure and Product [dataset]*, Data retrieved from the ABS: https://www.abs.gov.au/statistics/economy/national-accounts/australian-national-accounts-national-income-expenditure-and-product/latest-release, 2023.

— *CPI: Group, Sub-group and Expenditure Class, Index Numbers by Capital City [dataset]*, Data retrieved from the ABS: https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/latest-release, 2023.

— *Survey of Income and Housing [dataset]*, Data retrieved from the ABS: https://www.abs.gov.au/statistics/detailed-methodology-information/concepts-sources-methods/survey-income-and-housing-user-guide-australia, 2020.

— *Survey of Income and Housing: Housing Occupancy and Costs [dataset]*, Data retrieved from the ABS: https://www.abs.gov.au/statistics/people/housing/housing-occupancy-and-costs/latest-release, 2020.

— *Total Value of Dwellings [dataset]*, Data retrieved from the ABS: https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/total-value-dwellings/latest-release, 2023.

Australian Prudential Regulation Authority, *Banking (prudential standard) determination No. 14 of 2022*, Retrieved from Australian Government Federal Register of Legislation: https://www.legislation.gov.au/F2022L01576/latest/text, 2022.

— *Prudential Practice Guide - APG 223 Residential Mortgage Lending*, 2022.

Balke, KK, M Karlman, and K Kinnerud, *Down-payment requirements: Implications for portfolio choice and consumption*, tech. rep., Working Paper, 2023.

Beckers, Benjamin, *Credit spreads, monetary policy and the price puzzle*, tech. rep., Reserve Bank of Australia, 2020.

Beraja, Martin, Andreas Fuster, Erik Hurst, and Joseph Vavra, "Regional heterogeneity and the refinancing channel of monetary policy", *The Quarterly Journal of Economics* 134 (2019), 109–183.

Berger, David, Konstantin Milbradt, Fabrice Tourre, and Joseph Vavra, "Mortgage prepayment and path-dependent effects of monetary policy", *American Economic Review* 111 (2021), 2829–2878.

Boar, Corina, Denis Gorea, and Virgiliu Midrigan, "Liquidity constraints in the US housing market", *The Review of Economic Studies* 89 (2022), 1120–1154.

Board of Governors of the Federal Reserve System (US), *Households and Nonprofit Organizations; Real Estate at Market Value, Market Value Levels [HNOREMV]*, Data retrieved from FRED (Federal Reserve Bank of St. Louis): https://fred.stlouisfed.org/series/HNOREMV, 2023.

Busch, Christopher, David Domeij, Fatih Guvenen, and Rocio Madera, "Skewed idiosyncratic income risk over the business cycle: Sources and insurance", *American Economic Journal: Macroeconomics* 14 (2022), 207–242.

Chen, Hui, Michael Michaux, and Nikolai Roussanov, "Houses as ATMs: mortgage refinancing and macroeconomic uncertainty", *The Journal of Finance* 75 (2020), 323–375.

Cho, Yunho, Shuyun May Li, and Lawrence Uren, "Investment Housing Tax Concessions and Welfare: A Quantitative Study for Australia", *International Economic Review* (2023).

— "Stamping out stamp duty: Property or consumption taxes?" (2021).

De Nardi, Mariacristina, "Wealth inequality and intergenerational links", *The Review of Economic Studies* 71 (2004), 743–768.

Diamond, William, Tim Landvoigt, and German Sanchez, "Printing away the mortgages: Fiscal inflation and the post-covid housing boom", *Jacobs Levy Equity Management Center for Quantitative Financial Research Paper* (2022).

Dias, Daniel A and Joao B Duarte, *Monetary Policy and Homeownership: Empirical Evidence, Theory, and Policy Implications*, tech. rep., Board of Governors of the Federal Reserve System (US), 2022.

Dungey, Mardi and Adrian Pagan, "A structural VAR model of the Australian economy", *Economic record* 76 (2000), 321–342.

Eichenbaum, Martin, Sergio Rebelo, and Arlene Wong, "State-dependent effects of monetary policy: The refinancing channel", *American Economic Review* 112 (2022), 721–61.

Favilukis, Jack, Sydney C Ludvigson, and Stijn Van Nieuwerburgh, "The macroeconomic effects of housing wealth, housing finance, and limited risk sharing in general equilibrium", *Journal of Political Economy* 125 (2017), 140–223.

Fox, Ryan and Peter Tulip, "Is Housing Overvalued" (2014).

Freddie Mac, *Origination Fees and Discount Points for 30-Year Fixed Rate Mortgage in the United States (DISCONTINUED) [MORTPTS30US]*, Data retrieved from FRED (Federal Reserve Bank of St. Louis): https://fred.stlouisfed.org/series/MORTPTS30US, 2022.

Fry, Renée A, Vance L Martin, and Nicholas Voukelatos, "Overvaluation in Australian housing and equity markets: wealth effects or monetary policy?", *Economic Record* 86 (2010), 465–485.

Gamber, William, James Graham, and Anirudh Yadav, "Stuck at home: Housing demand during the COVID-19 pandemic" (2022).

Garriga, Carlos and Aaron Hedlund, "Mortgage debt, consumption, and illiquid housing markets in the great recession", *American Economic Review* 110 (2020), 1603–1634.

Gourinchas, Pierre-Olivier and Jonathan A Parker, "Consumption over the life cycle", *Econometrica* 70 (2002), 47–89.

Graham, James, "A Structural Model of Mortgage Offset Accounts in the Australian Housing Market" (2024).

— "House prices, investors, and credit in the Great Housing Bust", *NYU Job Market Paper* (2019).

Graham, James and Alistair Read, "House Prices, Monetary Policy, and Commodities: Evidence from Australia" (2022).

Greenwald, Daniel, "The mortgage credit channel of macroeconomic transmission" (2018).

Greenwald, Daniel L and Adam Guren, *Do credit conditions move house prices?*, tech. rep., National Bureau of Economic Research, 2021.

Guvenen, Fatih, Sam Schulhofer-Wohl, Jae Song, and Motohiro Yogo, "Worker betas: Five facts about systematic earnings risk", *American Economic Review* 107 (2017), 398–403.

Hartigan, Luke and James Morley, "A factor model analysis of the Australian economy and the effects of inflation targeting", *Economic record* 96 (2020), 271–293.

Kaplan, Greg, Kurt Mitman, and Giovanni L Violante, "The housing boom and bust: Model meets evidence", *Journal of Political Economy* 128 (2020), 3285–3345.

Kaplan, Greg, Benjamin Moll, and Giovanni L Violante, "Monetary policy according to HANK", *American Economic Review* 108 (2018), 697–743.

Karlman, Markus, Karin Kinnerud, and Kasper Kragh-Sørensen, "Costly reversals of bad policies: The case of the mortgage interest deduction", *Review of Economic Dynamics* 40 (2021), 85–107.

Kinnerud, Karin, *The effects of monetary policy through housing and mortgage choices on aggregate demand*, tech. rep., Working Paper, 2022.

La Cava, Gianni and Calvin He, "The Distributional Effects of Monetary Policy: Evidence from Local Housing Markets in Australia", *Australian Economic Review* 54 (2021), 387–397.

La Cava, Gianni, Lydia Wang, et al., "RDP 2021-10: The Rise in Household Liquidity", *Reserve Bank of Australia Research Discussion Papers* (2021).

Leal, Hannah, Stephanie Parsons, Graham White, and Andrew Zurawski, "Housing Market Turnover", *RBA Bulletin, March* (2017), 21–30.

Ma, Eunseong and Sarah Zubairy, "Homeownership and housing transitions: Explaining the demographic composition", *International Economic Review* 62 (2021), 599–638.

Ong, Rachel, James Graham, Melek Cigdem-Bayram, Christopher Phelps, and Stephen Whelan, "Financing first home ownership: modelling policy impacts at market and individual levels", *AHURI Final Report* (2023).

Organization for Economic Co-operation and Development, *Consumer Price Index: All Items: Total for Australia [AUSCPIALLQINMEI]*, Data retrieved from FRED (Federal Reserve Bank of St. Louis): https://fred.stlouisfed.org/series/AUSCPIALLQINMEI, 2023.

— *Housing prices [dataset]*, Data retrieved from the OECD: https://data.oecd.org/price/housing-prices.htm, 2023.

— *Interest Rates: 3-Month or 90-Day Rates and Yields: Bank Bills: Total for Australia [IR3TBB01AUM156N]*, Data retrieved from FRED (Federal Reserve Bank of St. Louis): https://fred.stlouisfed.org/series/IR3TBB01AUM156N, 2023.

— *Interest Rates: Long-Term Government Bond Yields: 10-Year: Main (Including Benchmark) for Australia [IRLTLT01AUM156N]*, Data retrieved from FRED (Federal Reserve Bank of St. Louis): https://fred.stlouisfed.org/series/IRLTLT01AUM156N, 2023.

Otto, Glenn, "The growth of house prices in Australian capital cities: What do economic fundamentals explain?", *Australian Economic Review* 40 (2007), 225–238.

Patterson, Christina, "The matching multiplier and the amplification of recessions", *American Economic Review* 113 (2023), 982–1012.

Reserve Bank of Australia, *Box A: Mortgage Interest Payments in Advanced Economies – One Channel of Monetary Policy*, Statement on Monetary Policy, https://www.rba.gov.au/publications/smp/2023/feb/, Feb. 2023.

— *Box B: The Impact of Lending Standards on Loan Sizes*, Financial Stability Review, https://www.rba.gov.au/publications/fsr/2018/oct/, Oct. 2018.

— *Table F5: Indicator Lending Rates [dataset]*, Data retrieved from https://www.rba.gov.au/statistics/tables/, 2023.

— *Table G1: Consumer Price Inflation [dataset]*, Data retrieved from https://www.rba.gov.au/statistics/tables/, 2024.

— *The Australian Economy and Financial Markets Chartpack*, Retrieved from https://www.rba.gov.au/chart-pack/pdf/chart-pack.pdf, 2024.

Ringo, Daniel, "Monetary policy and home buying inequality", *Review of Economics and Statistics* (2024), 1–46.

Saunders, Trent and Peter Tulip, "A model of the Australian housing market", *Economic record* 96 (2020), 1–25.

Stone, Tahlee, “The Sensitivity of Personal Income to GDP Growth”, *RBA Bulletin, December* (2016), 1–10.

Tauchen, George, “Finite state markov-chain approximations to univariate and vector autoregressions”, *Economics letters* 20 (1986), 177–181.

U.S. Bureau of Economic Analysis, *Gross Domestic Product [GDP]*, Data retrieved from FRED (Federal Reserve Bank of St. Louis): https://fred.stlouisfed.org/series/GDP, 2023.

Wong, Arlene, “Refinancing and the transmission of monetary policy to consumption” (2021).

ONLINE APPENDIX

A. Identifying Monetary Policy Shocks in the Estimated VAR

As detailed in Section 2.3, the evolution of the aggregate states is described using a VAR. This section outlines the procedure of how this VAR is embedded into the structural lifecycle model.

The first step is to estimate a reduced-form VAR(1) of the following form:

$$S_t = AS_{t-1} + u_t$$

where $S_t = \{r_t, \log(\gamma_t), \log(P_{ht})\}$ is the vector of aggregate states that have been detrended using a cubic trend. The reduced form residuals are denoted by $u_t \sim iid\ N(0, \Sigma)$, with its variance-covariance matrix given by Σ. As the lifecycle model is solved on discrete grids, the VAR must be transformed into a number of discrete aggregate states with an associated Markov chain. To do this, the method of Tauchen (1986) is employed, however, it requires that the variance-covariance matrix of the shocks are diagonal. As Σ is not necessarily diagonal, the system of equations arising from the VAR is rewritten in such a way to guarantee a diagonal variance-covariance matrix of shocks. This is done by establishing a SVAR (structural VAR), in which the reduced form residuals u_t are considered as linear combinations of the structural shocks ε_t:

$$u_t = B\varepsilon_t$$

where $\varepsilon_t \sim iid\ N(0, \Lambda)$ arise independently of one another such that Λ is an identity matrix (the identity matrix is diagonal). To identify the structural shocks and the effects they have on the aggregate states variables, a solution to the B matrix must be found. This can be done by exploiting the relationship between the reduced-form residuals and the structural shocks:

$$\Sigma = \mathbb{E}[u_t u_t'] = \mathbb{E}[B\varepsilon_t(B\varepsilon_t)'] = B\mathbb{E}(\varepsilon_t\varepsilon_t')B' = B\Lambda B' = BB'$$

and by restricting B to be upper triangular:

$$B = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ 0 & b_{22} & b_{23} \\ 0 & 0 & b_{33} \end{pmatrix}$$

This identifying assumption imposes the typical assumption that the policy rate does not affect macroeconomic variables in the quarter of the shock, as standard in the SVAR literature. As B is upper triangular, a Cholesky decomposition of the variance-covariance matrix of the reduced-form residuals Σ is undertaken to identify B.

Once B is found, the VAR can be expressed as follows:

$$Q_t = AQ_{t-1} + B\varepsilon_t$$

where $Q = S$. This substitution is made for ease of notation. Although the variance-coviance matrix of shocks ε_t is diagonal, we can only discretise a VAR via the Tauchen (1986) method if it is in the following form:

$$x_t = \rho x_{t-1} + \Psi_t$$

where $\Psi_t \sim iid\ N(0, \Omega)$ and Ω is a diagonal matrix. As a result, the VAR must be rewritten once again, and this is done in the following way:

$$\begin{aligned} Q_t &= AQ_{t-1} + B\varepsilon_t \\ B^{-1}Q_t &= B^{-1}AQ_{t-1} + \varepsilon_t \\ B^{-1}Q_t &= B^{-1}ABB^{-1}Q_{t-1} + \varepsilon_t \end{aligned}$$

where we define $x_t = B^{-1}Q_t$, $\rho = B^{-1}ABB^{-1}$, $\Psi_t = \varepsilon_t$ and $\Omega = \Lambda$.

B. Discrete Approximation to the VAR

This transformed VAR can now be discretised, although, x_t is no longer a vector containing the aggregate state variables, separately. Instead, discretising this transformed VAR leads to states over linear combinations of aggregate variables, rather than all three of them individually. Whilst, this is a well-ordered state space for MATLAB to conduct interpolation over, it is problematic for solving the household problem, since they make decisions over the individual aggregate states. However, as the state space expressed as linear combinations of the aggregate variables x_t and individually S_t are related by a bijective mapping, the individual state variables can be extracted once B is found. Since we are also only interested in the movement of the aggregate states in response to the interest rate shock, the variances of the other shocks on the diagonal entries of Ω are set to zero.

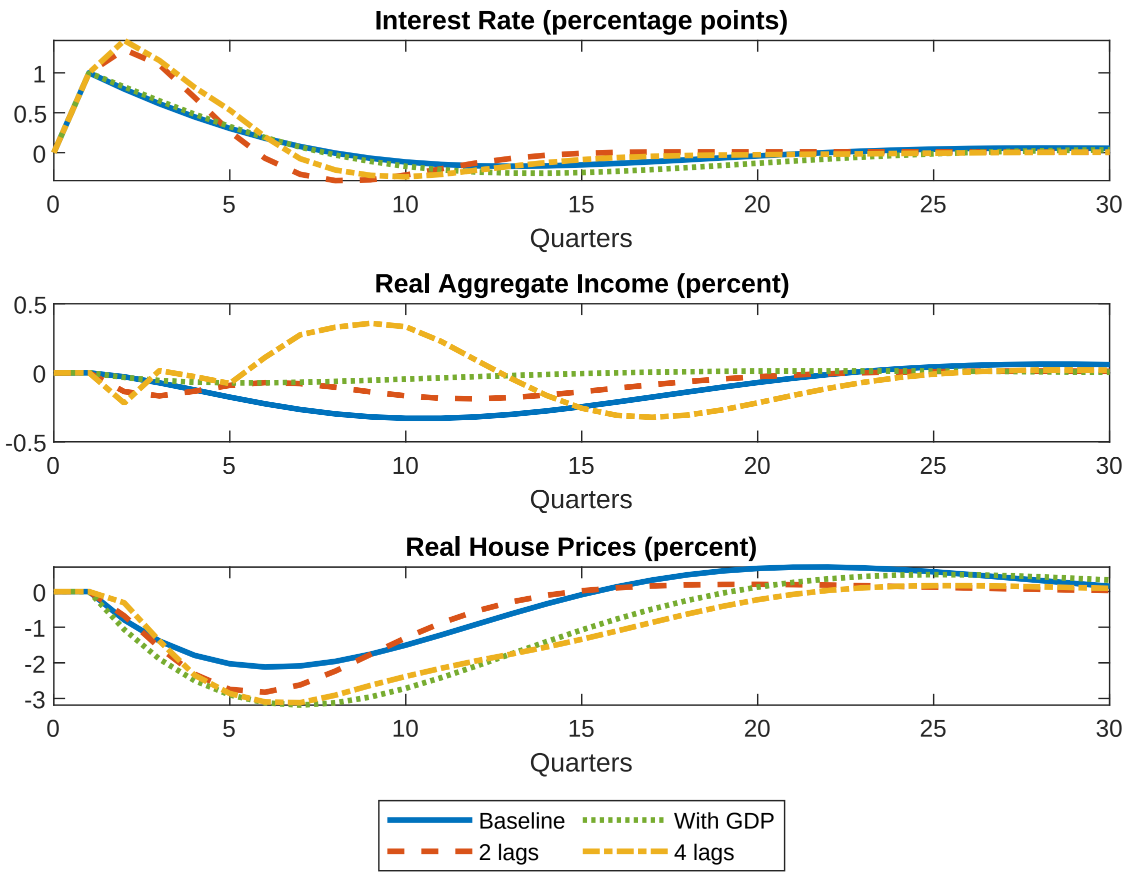
In order to incorporate the evolution of the aggregate states into our household model, we approximate the VAR with a finite-state Markov chain using the method of Tauchen (1986).[20] This produces a transition probability matrix over a finite state space of size $N_r \times N_y \times N_p$. We set $N_r = 7$, $N_y = 5$, and $N_p = 7$ (i.e. a total of 245 aggregate state grid points). Figure 1 compares the IRF to a monetary policy shock for the original VAR and for the discrete approximation to the VAR.

[20] We thank Robert Kirkby for help with this code.

C. Alternative Specifications of the VAR

Here we consider alternative specifications of the VAR for the aggregate state variables.

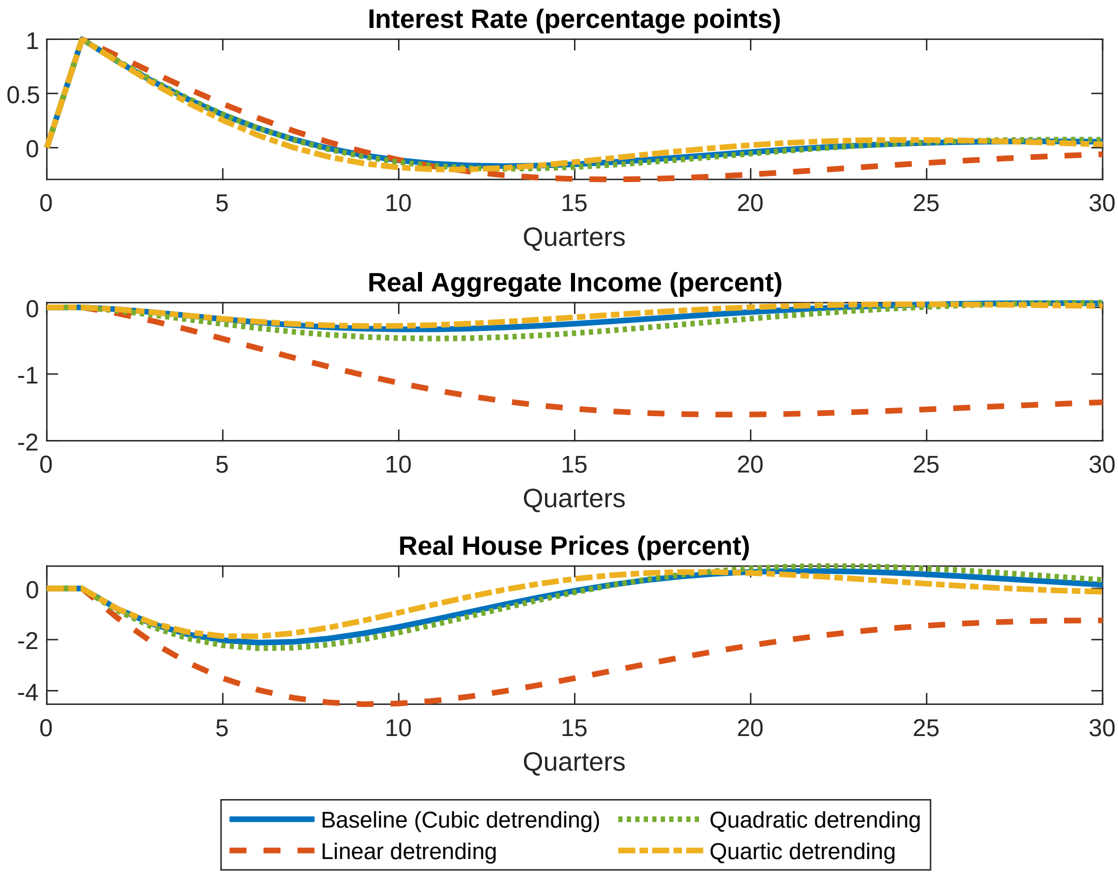
Figure 13: IRFs from the VAR with Alternative Specifications



In Figure 13 we compare IRFs from the baseline VAR model (solid blue lines) to alternative models with: 2 lags in each state variable (red dashed lines); 4 lags in each state variable (yellow dash-dotted lines); and real GDP used as the measure of aggregate income (green dotted lines). As might be expected, VAR models with additional lags display larger peaks and troughs and more persistence in both interest rates and house prices than in the VAR(1) model. Overall, however, the evolution of interest rates and house prices is not significantly different from baseline. In contrast, the models with additional lags show very different paths of aggregate income following a shock. The model with 2 lags leads to a very flat path of aggregate income, while the model with 4 lags leads to significant income volatility. A model using GDP to measure of aggregate income has no effect on the evolution of interest rates, leads to a very flat path of aggregate income, and amplifies the volatility and persistence of house prices.

In Figure 14 we compare IRFs from the baseline VAR model (solid blue lines) to

Figure 14: IRFs from the VAR with Alternative De-Trending



models that use alternative de-trending assumptions: linear (red dashed lines); quadratic (yellow dash-dotted lines); and quartic (green dotted lines). Linear de-trending results in much larger aggregate fluctuations in aggregate income and house prices. However, quadratic, cubic, and quartic de-trending results in very similar IRFs for interest rates, aggregate income, and house prices.

Overall, we find that the path of interest rates is not significantly affected by the VAR model specification or choice of de-trending. The response of house prices to shocks is moderately affected by the number of VAR lags and choice of income measure. While the response of aggregate income is very sensitive to model specification. In the end we are not overly concerned about the sensitivity of the aggregate income variable since the absolute homeownership rates in our model are not especially sensitive to the income component of monetary policy (see results in Section 4.1).

In Figure 15 we compare IRFs from the baseline VAR model (solid blue lines) to a models that also includes rents as measured in the CPI for Australian capital cities (Australian Bureau of Statistics, 2023b) and deflated by the overall CPI. As for the other variables in the baseline VAR, real rents are detrended using a cubic polynomial in time. Panels (a)–(c) show that the responses of the interest rate, aggregate income, and house

Figure 15: IRFs from the VAR Including Real Rents

prices are largely unaffected by the inclusion of the real rents series. Panel (d) shows that following a 1 percentage point contraction in monetary policy, real rents rise by 0.3 percent after 2 years, before slowly returning to steady state.