The Impact of Monetary Policy on Homeownership

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Supervised by Dr James Graham

Statement of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no material previously published or written by another person. Nor does it contain any material which has been accepted for the award of any other degree or diploma at the University of Sydney or at any other educational institution, except where due acknowledgment is made in this thesis.

Any contributions made to the research by others with whom I have had the benefit of working at the University of Sydney is explicitly acknowledged.

I also declare that the intellectual content of this study is the product of my own work and research, except to the extent that assistance from others in the project's conception and design is acknowledged.

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Abstract

From a theoretical perspective, monetary policy has an ambiguous impact on homeownership. For instance, contractionary monetary policy leads to higher interest rates and lower incomes making housing more unaffordable, but counteracting this is lower house prices. I build a heterogeneous agent overlapping generations model of the Australian housing market parameterising these three key transmission channels to study the sign and magnitude of the response of homeownership to monetary policy. I find there is a small positive effect of homeownership to a one standard deviation unanticipated contractionary monetary policy shock, with the shift in house prices explaining much of the movement in the homeownership rate.

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Contents

1 Introduction

How does monetary policy affect homeownership? While tighter monetary policy induces higher interest rates and lower incomes which restrain household's capacity to borrow for housing, lower house prices may offset these effects. Although it is widely accepted that a transmission mechanism of monetary policy operates through the housing market, less is known about the impact of monetary policy on homeownership. In this paper, I explore how monetary policy impacts homeownership, examining the competing effects of its transmission channels. I also investigate the heterogeneous response of homeownership rates to monetary policy, by age and income.

Monetary policy is a powerful tool for stabilising aggregate demand over the business cycle. As the property market influences economic conditions, this research is relevant for policymakers looking to understand how housing tenure choices are impacted by monetary policy. Although central banks are typically concerned with the response of aggregate demand, my research suggests that there are implications for consumption fluctuations through homeownership that must be considered. To the extent policymakers have an interest in the redistributive effects of monetary policy, such research may also inform policy debates in this area.

To answer my research question, I construct a heterogeneous agent overlapping generations (OLG) model, calibrated to the Australian economy. This model features heterogeneous lifecycle households whose incomes fluctuate during working life. At every age, households choose consumption and housing services, which may be acquired through either renting or owning a home. Should households choose to purchase a home in the model, this can be financed with mortgages, subject to borrowing constraints. I also calibrate the model to match key homeownership related statistics from the Australian housing market. This is important as the model is only as relevant to the extent it matches the data.

With this quantitative model in hand, monetary policy impacts homeownership through three key channels. First, I study how monetary policy has a direct pass-though into interest rates, for both savers and mortgagors. Second, monetary policy affects incomes through its effect on aggregate demand. Third, like other assets, monetary policy impacts the net present value of housing, and in turn, house prices.

These three transmission channels result in contrasting effects on homeownership. In the case of contractionary monetary policy, higher lending rates by banks increase mortgage servicing costs and reduce the borrowing power of prospective homebuyers, making purchasing a home less affordable. Likewise, lower incomes makes saving for a home deposit more challenging, thereby making homeownership less attainable. In contrast, lower house prices makes purchasing a home easier, all else equal. Furthermore, the size of these rival effects vary among households. For instance, prospective young homebuyers will lose the most from higher mortgage repayments given they will have larger loan balances. Meanwhile, renters with high incomes (households at the margin of homeownership) are in the best position to leverage lower house prices and become homeowners.

To decide whether they wish to be homeowners or not, households in the model need to form expectations about the path of interest rates, aggregate income and house prices. As my model is partial equilibrium in nature, these variables are exogenously specified. In this way, I depart from common general equilibrium modelling techniques, such as those employed in Kaplan, Moll, and Violante (2018) and Kinnerud (2022). Instead, I follow Chen, Michaux, and Roussanov (2020) and Eichenbaum, Rebelo, and Wong (2022), who characterise the evolution of aggregate states with exogenous Markov chains, to represent each transmission channel of monetary policy. The Markov chain for these aggregate states is an approximation of an estimated vector-autoregression (VAR) that characterises their evolution. I use Australian data to estimate this VAR and address the endogeneity of policy interest rates with identified monetary policy shocks by Beckers (2020).

This shock series is created using a narrative approach, in a similar method to Romer and Romer (2004). Once estimated, I embed the Markov chain approximation to the VAR in the model as a representation of the expectations that households use to inform their homeownership decisions. The benefit of this partial equilibrium approach is that it allows my structural model to capture realistic dynamics in the movement of interest rates, aggregate income and house prices.[1]

To obtain my results, I generate an impulse response to a monetary policy shock using the estimated VAR. This is then mapped into the structural model, allowing households to respond to movements in interest rates, aggregate income and house prices. I observe how this impacts homeownership as well as other key variables of interest.

Since the direction of the aggregate effect of monetary policy on homeownership is theoretically ambiguous, I undertake a decomposition exercise, partitioning the impacts of monetary policy by its three transmission channels. This framework is similar to Kaplan, Moll, and Violante (2018) and Auclert (2019) who decompose the effect of monetary policy on consumption. Whilst I focus on homeownership, Kaplan, Moll, and Violante divide monetary policy effects as being 'direct' (via interest rates and intertemporal substitution) and 'indirect' (through aggregate demand and income). Finally, I explore the heterogeneity in responses by age group and income quintile.

I find that there is a small positive effect to homeownership in response to a one standard deviation unanticipated contractionary monetary policy shock. The model suggests that the impact of monetary policy on house prices is largely responsible for this change. Older working-age renters becoming mortgagors are the main beneficiaries of this change in conditions. The model also suggests that there is a large movement of existing mort-

[1] It also enables a richer analysis of the homeownership response across time, that would be substantially more computationally complex to implement in general equilibrium.

gagors into outright homeownership by retirees because of the monetary policy shock. In addition, the response of consumption, whilst largely driven by changes to interest rates and incomes, is affected by homeownership decisions.

1.1 Related Literature

My thesis draws on three key strands of related literature. The first is an extensive literature studying the macroeconomics of housing in an OLG framework. Many of these papers focus on the transmission of monetary policy to consumption, considering a select number of transmission channels. Wong (2021) and Kinnerud (2022), examine how mortgage refinancing and adjusted housing choices in response to interest rate changes, drive significant changes to household consumption. Although these papers recognise the importance of the housing market and heterogeneity within the economy for the transmission of monetary policy, I go further and explore its distributional consequences with an emphasis on homeownership. Outside the context of monetary policy, overlapping generations models have examined the effect of taxation policies (Sommer and Sullivan, 2018) and the Global Financial Crisis on the housing market and house prices (Kaplan, Mitman, and Violante, 2020). Still, the tie in of monetary policy and homeownership together is absent and the closest my thesis is in this respect is to Gamber, Graham, and Yadav (2022), who study the response of homeownership due to COVID-19 pandemic-related monetary policy, fiscal and preference shocks.

Second, my thesis is motivated by an empirical literature which studies the relationship between homeownership and monetary policy. In the US, Dias and Duarte (2022) explicitly model this link, using aggregate data to find that monetary policy explains a substantial proportion of the variation in the aggregate homeownership rate. Using microdata for the US and the UK, Cloyne, Ferreira, and Surico (2020) find the consumption response to monetary policy differs by housing tenure type. In Australia, La Cava and He

(2021) gain insights into the transmission of monetary policy and some of its distributional consequences, but focus on house prices in neighbourhoods, as opposed to homeownership among household cohorts. Due to a lack of high frequency homeownership data in Australia, I employ a theoretical approach to study the impact of monetary policy on homeownership.

Finally, my thesis also contributes to the Australian literature around monetary policy, housing markets and inequality. While there is an abundance of empirical research linking housing markets (as opposed to homeownership, more specifically) and monetary policy, for example, Wadud, Bashar, and Ahmed (2012), Graham and Read (2022), Fry, Martin, and Voukelatos (2010), there has been relatively little use of heterogeneous agent models to simulate the Australian housing market. There are four recent exceptions. Cho, Li, and Uren (2021a) and Cho, Li, and Uren (2021b) model the housing market as it responds to changes in the stamp duty tax regime and investment housing tax concessions, Fehr, Hofmann, and Kudrna (2021) model the impact of Australia's tax and pension system on homeownership, while Day (2018) models Australian house prices using a two period OLG period. Like these papers, I pay particular attention to the impact of policy changes on homeownership rates, but explicitly focus on the distributional effects of monetary policy. I also go further and study the response of this class of models to high frequency shocks, whereas most of these papers focus on steady state comparisons.

The rest of the paper is structured as follows. Section 2 outlines features of the model, while Section 3 discusses the calibration methodology. Section 4 provides an analysis of the results obtained from the model. Section 5 concludes.

2 Quantitative Model

I build a quantitative, heterogeneous agent lifecycle model of households who differ by age, income, liquid assets/debt and housing tenure type. Given the prices of houses, the rental rate and the cost of borrowing, households decide whether to be renters or homeowners. Finally, exogenous changes in monetary policy affect interest rates, household incomes and house prices. I study how these shocks affect homeownership decisions.

2.1 Households

Demographics – Time is discrete, and households live for a finite number of periods, indexed from $j \in (1, \ldots, J)$, which describe their age. Households split their life between working and retirement, with retirement occurring at age J^{RET}. Households live for a maximum age of J and face an age-dependent survival probability, π_j.

Preferences – Households maximise lifetime expected utility, given by:

$$E_0 \sum_{j=1}^{J} \beta^{j-1}[\pi_j u(c,\ s) + (1 - \pi_j) b(w_j)]$$

where $u(\cdot)$ is the intra-period utility function, $b(\cdot)$ is a warm-glow bequest function, β is the discount factor, and π_j is the probability of surviving into the next period at age j. Intra-period utility is defined over consumption, c and housing services, s. The intra-period utility function is the standard CRRA (constant relative risk aversion) function over a Cobb-Douglas aggregator of 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 non-housing consumption share, and $\frac{1}{\sigma}$ is the intertemporal elasticity of substitution.

Bequests – Similar to De Nardi (2004), households derive warm-glow utility from bequests, if dying at age j:

$$b\left(w_j\right) = B\frac{w_j^{1-\sigma}}{1-\sigma}$$

where $B > 0$ captures the strength of the bequest motive and w_j represents net wealth: the sum of any liquid assets and owned housing subtracted by outstanding mortgage debt.

Endowments - Households receive stochastic labour income during working life and once retired, are given an age-dependent income with certainty. [2] During working life, household income is a combination of a deterministic lifecycle component χ_j and a stochastic component z_j. The stochastic component z_j follows a log-AR(1) process:

$$\log(z_j) = \rho_z \log(z_{j-1}) + u_z \qquad u_z \sim N(0, \sigma_z^2)$$

where ρ_z governs the persistence of income shocks and σ_z characterises the standard deviation of innovations. This autoregressive process is approximated with a Markov chain such that discrete states over the stochastic component of income z are obtained.

Retirees are not subject to idiosyncratic shocks to their income, but face a deterministic income χ_j which declines in retirement age. This reflects the transition to retirement and/or the death of old age adults within the household.

The income of working households also fluctuates due to changes in the aggregate level of income (real GDP) γ_t in the economy. For notational

[2] For simplicity, I abstract from the effects of the Australian superannuation system on retirement income.

simplicity, I suppress any dependence on t moving forward.

The income process for a household can now be fully described as follows:

$$y_j = \begin{cases} \gamma \chi_j z_j & \text{if } j \leq J^{RET} \text{ (working age)} \\ \chi_j & \text{if } j > J^{RET} \text{ (retired)} \end{cases}$$

where y_j denotes household earnings at age j.

Housing – Households have the option to either rent or purchase a home to receive housing services s. Households cannot own multiple properties and be landlords.

A household who wishes to purchase a home must pay a per-unit house price of P_h. Homeowners must pay a transaction cost, F_h, proportional to the value of the house whenever they sell their property. This reflects moving costs, real estate fees and the social costs of moving to a new community. Homeowners also pay a maintenance cost of δ every period, to offset the physical depreciation of their properties, which is again, proportional to the cost of their home. Owner-occupied housing is chosen from a discrete set, $\mathcal{H}_o$.

If the household decides to rent, they pay a per-unit rental price of P_r and can adjust their size of rental property without cost. For simplicity, rental rates are modelled as a constant proportion of house prices, parameterised by the rent-to-price ratio η. Rental properties are chosen from a discrete set, $\mathcal{H}_r$.

Liquid Assets – Households can save in a risk-free liquid asset, a, whose return when saving is r. This interest rate r is determined by monetary policy as discussed in Section 2.2. To purchase a property, households can borrow against the value of their property and have a negative liquid asset balance, but face a higher mortgage interest rate. As a result, interest rates are a function of a household's liquid asset balance:

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

with $\kappa > 0$, reflecting the greater risk that lenders face in financing mortgages.

If households borrow, they are restricted to borrowing up to a fraction of the value of their house:

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

where θ_m is the maximum loan-to-value (LTV) ratio. Unsecured borrowing is not permitted in the model, so renters cannot borrow. Households do not enter the model in their first period of life with any debt nor owned housing, but may have a positive liquid asset balance from any received bequests.

2.2 Aggregate States

A reasonable assertion is that an individual household is unlikely to believe that they themselves alone, can influence interest rates, aggregate demand and house prices in the economy. This justifies the partial equilibrium nature of the model, in which households make choices, taking aggregate economic conditions as given. To implement this modelling choice, I represent each transmission channel of monetary policy with a state variable which feeds into a household's decision problem. An aggregate vector $S = \{r, \log(\gamma), \log(P_h)\}$, fully describes the state of the economy and consists of the real interest rate on liquid assets r, the logarithm of real aggregate income (measured by real GDP) γ and the logarithm of real house prices P_h. This allows households to react to changes in economic conditions caused by monetary policy.

Nevertheless, it is not enough for households to respond to current changes in economic conditions. To solve their decision problem, they must also form expectations over the future path of the aggregate states, since homeownership decisions depend on future interest rates, aggregate income and house prices. I assume they must be exogenously specified and in this case, it seems natural to characterise their evolution with a time series model with reasonably good forecasting properties. In this regard, I follow Chen, Michaux, and Roussanov (2020) and Eichenbaum, Rebelo, and Wong (2022).

To obtain the time series model, a vector autoregression (VAR) is estimated for the aggregate state vector $S_t = \{r_t, \log(\gamma_t), \log(P_{ht})\}$. This is done using quarterly data for Australia between 1994 and 2018.[3] As the structural model abstracts from growth, the aggregate states are treated as deviations from a balanced growth path, and the following functional form was selected to ensure stationarity:

$$\Delta S_t = A\Delta S_{t-1} + u_t$$

where A is a 3×3 matrix of coefficients and u_t is a 3×1 vector of Gaussian innovations. This parsimonious specification is essential for model tractability.

However, the monetary policy interest rate (cash rate) is likely to be endogenous, as policymakers take action in anticipation to moving macroeconomic aggregates and as financial market participants price in movements to interest rates. Since this paper is concerned with studying the impact of monetary policy alone, this means an exogenous sequence of shocks are required instead. As a result, changes in the cash rate Δr_t are replaced with a monetary policy shock series from Beckers (2020). This series adapts a narrative based approach to identify shocks from Romer and Romer (2004), by purging the policy rate of its anticipated component. The resulting shock series is then exogenous, isolating the unanticipated effect of monetary policy on real GDP and real house prices. In this instance, the chosen functional

[3]Data for real GDP is sourced from National Accounts data released by the Australian Bureau of Statistics. Data for real house prices is sourced from the OECD (https://data.oecd.org/price/housing-prices.htm)

form of the VAR is quite useful as it means shocks can be represented as one-off changes to the aggregate states which feed into the household problem.

Before using the VAR in the structural model, it is translated to an annual frequency, by raising the autoregressive matrix A to the power of four.[4] The VAR is then converted into a finite number of discrete aggregate states, using the method of Tauchen (1986).[5] The resultant Markov chain generated through discretising the VAR, enables households to incorporate the dynamics of the aggregate variables into their expectations about how the macroeconomy evolves. Thus, households have consistent beliefs about the evolution of the aggregate state variables. Section 6.1 of the Appendix contains further technical details about the treatment of the aggregate states.

The number of grid points for the aggregate variables is chosen to balance computational tractability with goodness of fit. Figure 1 illustrates that the discretised VAR manages to match the historical cyclical movement of the aggregate variables between 1994 to 2018, very well.[6]

2.3 Household Decision Rules

State Variables - The state variables in the model are denoted by $\mathbf{s} = \{a, h, z, S\}$, where a, h and z are liquid assets, owner-occupied housing stock and idiosyncratic labour income, respectively. The aggregate state of the economy is described by $S = \{r, \log(\gamma), \log(P_h)\}$ which consists of the real interest rate on liquid assets r, the logarithm of real aggregate income (measured by real GDP) γ and the logarithm of real house prices P_h.

[4]Although it would be ideal to conduct the study at a quarterly frequency, the model is already very slow to solve.

[5]I use MATLAB code from Robert Kirkby to apply this discretisation algorithm. The code can be found online and is available here: https://github.com/vfitoolkit/VFIToolkit-matlab/tree/master/DiscretizationMethods/discretizeVAR1_Tauchen. One of the major contributions of this thesis is to implement this algorithm into a lifecycle model with aggregate states. See Section 6.1 in the Appendix for more details.

[6]This fit was obtained with 245 joint aggregates states.

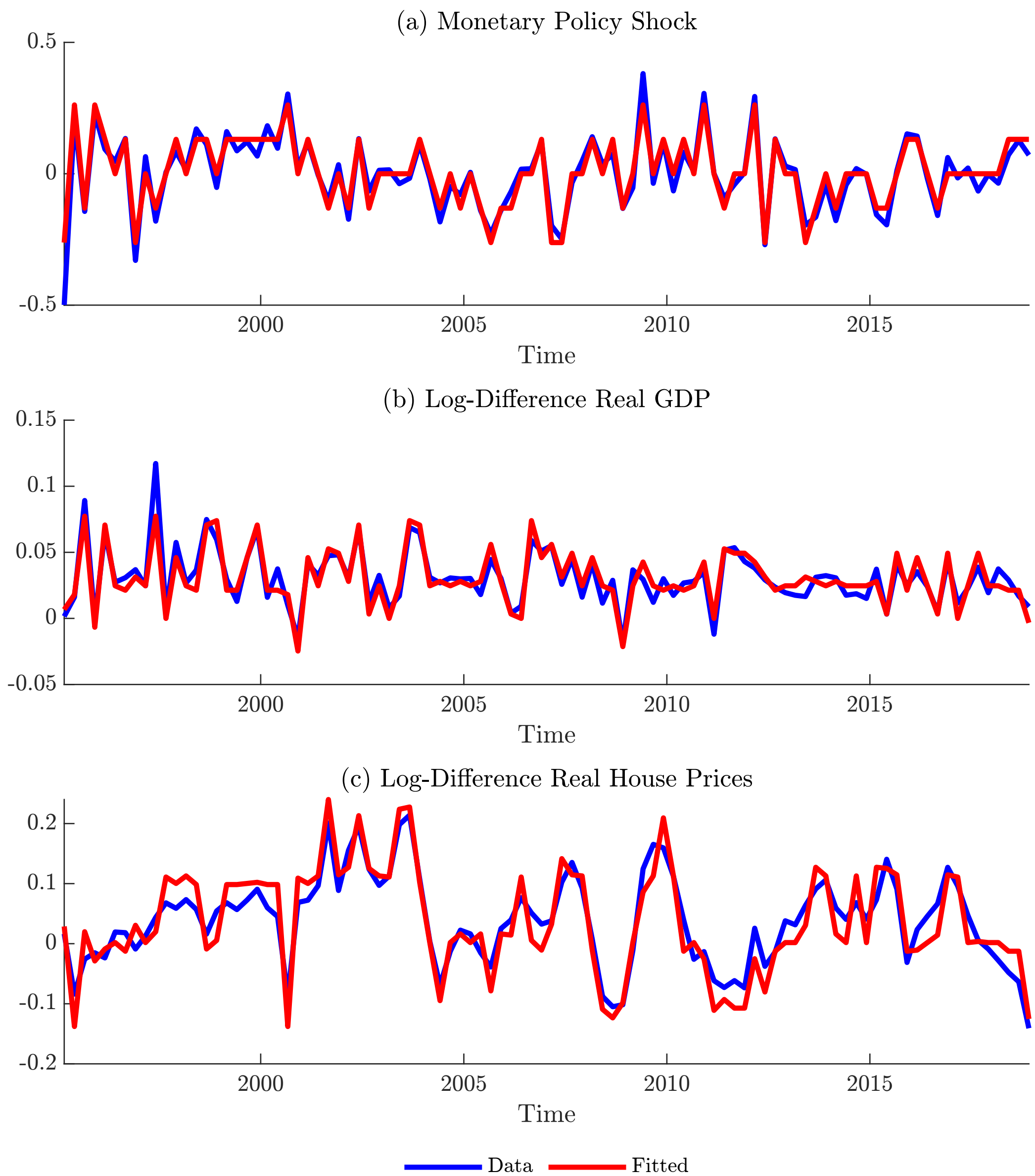

Figure 1: Time series of actual and fitted aggregate state variables

Value Functions - To solve the model, a value function iteration (VFI) method is used. At each age households can choose to either rent or own a home, as well as their level of consumption, liquid assets and housing services. For ease of notation, I suppress the dependence of the aggregate state variables on time t. To characterise the discrete choice over owning and renting, I write the value function as:

$$V_j\left(\mathbf{s}\right) = \max\left\{V_j\left(\mathbf{s}\right)^{OWN}, V_j\left(\mathbf{s}\right)^{RENT}\right\}$$

That is, the overall value function for a household at age j will be the maximum of the value functions yielded by either owning or renting a home at the same age.

If the household decides to rent, it solves the following problem:

$$V_j\left(\mathbf{s}\right)^{RENT} = \max_{c,a',s} u\left(c, s\right) + \beta\mathbb{E}[V_j(\mathbf{s}')]$$

subject to the budget constraint,

$$c + a' = y_j + a\left(1 + a\left(r\right)\right) + \left(1 - F_h\right)P_h h - P_r s$$

the no unsecured borrowing condition imposed upon renters,

$$a' \geq 0$$

the implication that renters own zero housing stock,

$$h' = 0$$

and that their choice of housing services is chosen from the discrete set of rental properties:

$$s \in \mathcal{H}_r$$

If the household decides to own a home, it solves the following problem:

$$V_j\left(\mathbf{s}\right)^{OWN} = \max_{c,a',h'} u\left(c, h'\right) + \beta\mathbb{E}[V_j(\mathbf{s}')]$$

subject to the budget constraint,

$$c + a' + \delta P_h h' + \omega_j(a, a', h, h') = y_j + a\,(1 + a\,(r)) + \mathbb{1}_{h' \neq h}[(1 - F_h)P_h h - P_h h']$$

where $\mathbb{1}_{h' \neq h}$ is an indicator variable, equal to one whenever the household changes the size of their owned home. This ensures homeowners only receive the net profit from selling their home if they are changing the size of their house. Mortgage origination costs are reflected by the function $\omega_j(a, a', h')$ which is incurred whenever households wish to increase the value of their mortgage (mortgage refinancing), purchase a new home or purchase a home of a different size. In addition, retired households are restricted from increasing their mortgage balance. The mortgage cost function can be expressed as:

$$\omega_j(a, a', h, h') = \begin{cases} \mathrm{F}_m|a'| & \text{if } h' \neq h \text{ and } a < 0 \text{ and } j \leq J^{RET} \\ \mathrm{F}_m|a'| & \text{if } h' > 0 \text{ and } a' < a < 0 \text{ and } j \leq J^{RET} \\ \infty & \text{if } h' > 0 \text{ and } a' < a < 0 \text{ and } j > J^{RET} \\ 0 & \text{otherwise} \end{cases}$$

Homeowners are also subject to a loan-to-value constraint,

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

constraining borrowing up to the maximum LTV ratio. Finally, homeowners' choice of property must come from the following discrete set:

$$h' \in \mathcal{H}_o$$

In the case of both homeowners and renters, their expectations over the value function in the following age $\mathbb{E}[V_j(\mathbf{s}')]$, is formed over the idiosyncratic component of income z and the aggregate states S. This means households forecast their income and the aggregate state of the economy prior to making their decision. Section 6.2 in the Appendix provides further information about the solution method.

3 Calibration

The model is calibrated to match key lifecycle moments related to homeownership, as seen in Figure 2. This is done in the stochastic steady state of the model in which the aggregate shocks are not active and where there are a sufficiently large number of households in each age group.[7] By the Law of Large Numbers, this ensures average cohort characteristics and the distribution of income do not change among different draws of the idiosyncratic component of income.

Tables 1 and 2 summarise the chosen parameter values.

3.1 Externally Calibrated Parameters

The values for parameters in this section were assigned directly from Australian data or taken from the literature. Three main sources of data were used to calibrate the model: the 2017-2018 Survey of Income and Housing (SIH), 2015-2016 Household Expenditure Survey (HES) and the 2018 Household, Income and Labour Dynamics in Australia (HILDA) Survey. A summary of the externally calibrated parameters is provided in Table 1.

Demographics - The model period is annual. Households enter the model at age 21, retire at age 65 ($J^{RET} = 45$) and exit the model at age 80 ($J = 60$). The age-dependent survival probabilities π_j are obtained from the Australian Bureau of Statistics' (ABS) Life Tables 2018-2020.

Preferences - As standard in the literature, the coefficient of risk aversion is $\sigma = 2$, implying an elasticity of substitution of 0.5. The non-housing share of consumption is set such that $\alpha = 0.80$, as per Piazzesi and Schneider

[7] In the stochastic steady state of the model, aggregate income and house prices are normalised to 1. Interest rates are set to their steady state value $\bar{r}$, see Section 3.1.

[8] Accessed from the AURIN (Australian Urban Research Infrastructure Network) Data Portal: https://aurin.org.au/).

Description	Parameter	Value	Source
Non-housing share of consumption	α	0.80	Piazzesi and Schneider (2016)
Coefficient of risk aversion	σ	2	Standard
Persistence of idiosyncratic income process	ρ_z	0.94	Cho, Li, and Uren (2021a)
Standard deviation of idiosyncratic shocks	σ_z	0.17	Cho, Li, and Uren (2021a)
Steady state risk-free real interest rate	$\bar{r}$	0.0168	RBA
Mortgage interest rate spread	κ	0.0236	RBA
Maximum loan-to-value ratio	θ_m	0.8	Standard
Mortgage origination cost	F_m	0.01	Estimate
Housing depreciation rate	δ	0.02	Cho, Li, and Uren (2021a)
Seller transaction cost	ϕ	0.03	Fox and Tulip (2014)
Rent-to-price ratio	η	0.05	CoreLogic[8]
Bequest-to-income ratio	λ	0.49	SIH 2017-2018

Table 1: Externally Calibrated Parameters

(2016). I use this figure from the United States, since Australian estimates are unavailable.[9]

Endowments - The deterministic lifecycle profile of income χ_j takes an asymmetric tent-shape, which is a slightly modified specification of Ma and Zubairy (2021):

$$\chi_j = \begin{cases} 1 + \xi(1 - \frac{|j - J_{peak}|}{J_{peak} - 1}) & \text{if } j \leq J_{peak} \\ 1 + \xi(1 - \zeta\frac{|j - J_{peak}|}{J_{peak} - 1}) & \text{if } j > J_{peak} \end{cases}$$

Here, ξ is the growth in household earnings over the lifecycle, whereas ζ enables household incomes to fall at a different rate than the increase to peak earnings. J_{peak} is the age maximum incomes are attained, and in the model this is set to occur at age 50 ($J_{peak} = 30$). To achieve a good match with the lifecycle profile of mean income in the 2017-2018 SIH the following are set: $\xi = 0.6$ and $\zeta = 1.75$. In this way, household incomes rise, on average, by 60 percent from labour force entry to peak earnings age, but fall 75 percent faster (see Panel (a) of Figure 2).

[9]In Cho, Li, and Uren (2021a) and Cho, Li, and Uren (2021b) values of $\alpha = 0.85$ and $\alpha = 0.77$ are internally calibrated for models of the Australian economy, respectively.

For the idiosyncratic income process, I follow Cho, Li, and Uren (2021a) and calibrate the annual persistence of income shocks $\rho_z = 0.94$ and the standard deviation of innovations $\sigma_z = 0.17$. They estimated these parameters using data from HILDA. The income process is discretised using the Rouwenhorst (1995) method, with seven states.[10]

All households enter the model with a positive liquid asset balance, having received a bequest. The size of this bequest is a proportion λ of their initial period income. This fraction is calculated using the median net-worth to income ratio for households aged 15-24 in the 2017-2018 SIH, such that $\lambda = 0.49$.[11]

Interest rates - Using data on the average Australian 10-year government bond yield between 2000 and 2019, the steady state risk-free real interest rate is set so that $\bar{r} = 0.0168$. The wedge between mortgage rates and the risk-free rate is set as $\kappa = 0.0236$. This is calculated by taking the difference between average lending rates on variable-interest home loans for owner-occupiers, compiled by the RBA, and the 10-year Australian government bond yield, between 2000 and 2019.

Housing - The maximum loan to value ratio is set to $\theta_m = 0.8$. This is standard as most banks in Australia require a 20 percent deposit on a new home loan, without incurring lender's mortgage insurance. The mortgage origination cost is assigned a value of $F_m = 0.01$. Although this is difficult to gauge in Australia, Gamber, Graham, and Yadav (2022) find it is 0.005 for the United States, and it seems safe to assume that such costs are no more than a percent of the total loan amount. Following Cho, Li, and Uren (2021a) and Cho, Li, and Uren (2021b), the depreciation rate is set to $\delta = 0.02$. As per Fox and Tulip (2014), the transaction cost on selling a home is set to

[10] Kopecky and Suen (2010) find that the Rouwenhorst method for discretising highly persistent AR(1) processes is the most reliable.

[11] This is the youngest household group in the 2017-2018 SIH.

$\phi = 0.03$. The rent-to-price ratio is calibrated to $\eta = 0.05$ by obtaining the median rent-to-price ratio within Level 2 Statistical Areas (SA2s) across Australia between 2010 and 2017.[12]

For model tractability, the size of housing that households may rent is discretised into three sizes, while there is only one non-zero size of housing households can purchase. This size is called $h_{min} = h$. This means this paper is limited to studying homeownership decisions on the extensive margin (decisions about housing tenure status) as opposed to observing the intensive margin (e.g. decisions about upsizing/downsizing). I let $h^{rent} = (h^{rent}(1), h^{rent}(2), h^{rent}(3))$ with $h^{rent}(1) = h_{min}/3, h^{rent}(2) = h_{min}/2$ and $h^{rent}(3) = 3h_{min}/4$.

3.2 Internally Calibrated Parameters

I calibrate three parameters by hand to match some key moments. A summary is provided in Table 2.

Description	Parameter	Value	Moment	Model	Data	Source
Minimum House Size	h_{min}	2.045	Homeownership	0.71	0.66	SIH 2017-18
Bequest Motive Strength	B	13.65	Old Outright Homeownership	0.77	0.80	SIH 2017-18
Discount Factor	β	0.87	Median LTV Ratio	0.44	0.48	HILDA 2018

Table 2: Internally Calibrated Parameters

Note: The calibrated value for h_{min} implies that the cost for the smallest owner-occupied size home is $191,944 AUD.

First, h_{min} is used to calibrate the homeownership rate. Determining the size of the lowest, and in this case, only house size, directly influences homeownership since it determines the overall cost of becoming a homeowner. Second, B is used to discipline the end-of-life (age 80) outright homeownership rate. The strength of the bequest motive becomes increasingly relevant during old age and governs the value of assets and housing wealth households have with them when they die. In this model, only once households pay off

[12] According to the ABS, SA2s have an average population of 10,000 people.

their mortgage and become outright homeowners can they begin to have a positive liquid asset balance that can form a part of their bequest. Finally, β is used to target the median LTV ratio of borrowers in the economy. This is appropriate as the discount factor governs savings and borrowing behaviours.

3.3 Model Fit

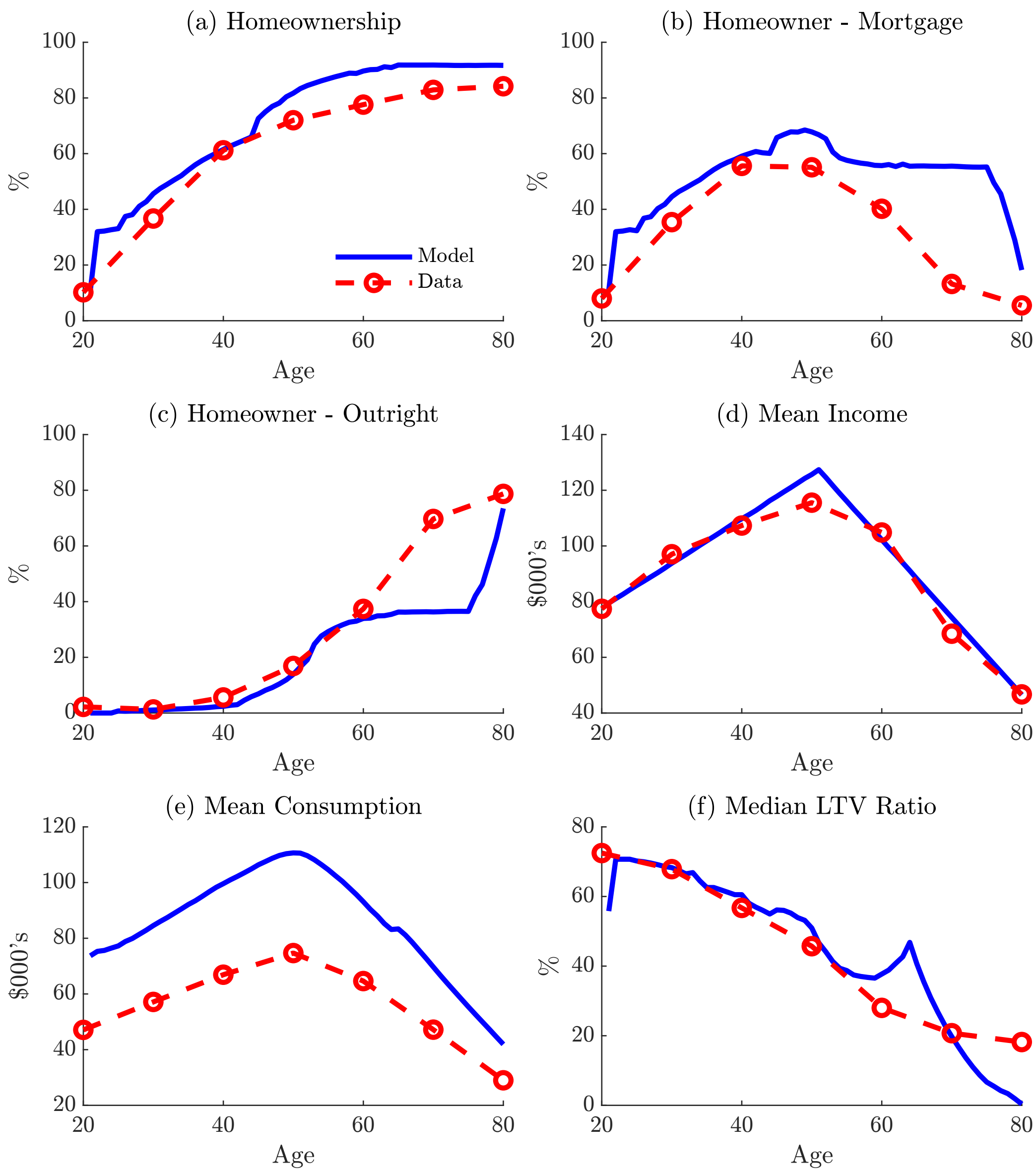

Figure 2: Lifecycle Profiles

Note: The median LTV ratio calculated is for mortgagors. Data for the homeownership, mortgagor homeownership, outright homeownership rates and mean income is obtained from the 2017-2018 SIH. Data for mean consumption is obtained by deducting housing costs from the total average consumption measure in the 2015-2016 HES. The median LTV ratio of borrowers is extracted from 2018 HILDA data reported by the RBA.

As seen in Figure 2, the model closely matches the shape of the lifecycle profiles for both targeted and non-targeted variables. Homeownership rises steadily with age in the model, consistent with the data. The lifecycle profiles for the proportion of mortgagors and outright owners is also mostly consistent with the data. As described earlier, mean income follows the expected ‘hump-shape’ in earnings, rising in early life, before declining through to retirement. The median LTV ratio for borrowers steadily decreases as households repay their mortgages, both in the model and the data. This is important to match, as it ensures realistic leverage effects are generated from changes to monetary policy. Finally, even though consumption was not targeted, it still displays the same ‘hump-shape’ as the lifecycle profile of consumption does in the data. However, it is significantly higher in the model. This could be because households cannot invest in higher return riskier assets, so the opportunity cost of consumption is lower, encouraging further consumption than seen in the data.

4 Response to Monetary Policy Shocks

The central task of my research is to determine the effect of monetary policy on homeownership. Since the model allows for exogenous changes to monetary policy (as discussed in Section 2.2), I introduce a monetary policy shock into the model and study how households respond with respect to their homeownership decisions.

The monetary policy shock is first introduced into the estimated VAR which creates an impulse response function across interest rates, aggregate income and house prices. The responses of the aggregate states in the VAR are then discretised, enabling households to form expectations over their path. The impulse response function that is fitted by the discretisation algorithm in response to a one standard deviation unanticipated contractionary monetary policy shock is illustrated in Figure 3. It shows interest rates rising by 12 basis points, aggregate income decreasing by 0.05 percent, and house prices falling by as much as 0.25 percent.

To obtain my results, I input these fitted impulse responses into the structural model and have households respond to these changes in the aggregate state variables. Changes in interest rates and house prices affect all households in the model equally, whereas shifts in aggregate income only impact working-age households.[13] This is because the main source of income for retirees is unlikely to be labour income and therefore, their income not impacted by changes in aggregate demand from a monetary policy shock.

This impulse response is then decomposed by transmission channel. To do this, I feed only the discretised impulse response of one aggregate state variable at a time into the structural model. This enables me to isolate the effect of each transmission channel of monetary policy. It should be noted that this impact includes the direct movement of the aggregate state variable

[13] Although younger and lower income households are likely to have steeper falls in income, I abstract from this earnings heterogeneity channel of monetary policy for model tractability.

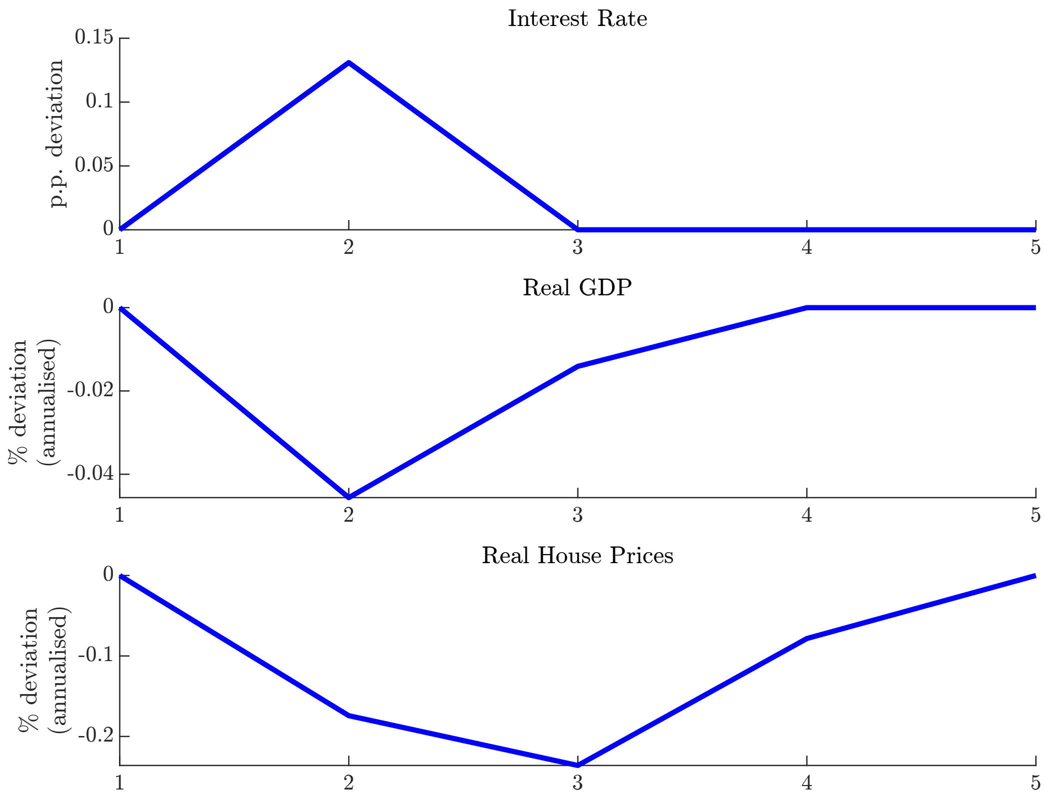

Figure 3: Response of aggregate state variables to a one standard deviation unanticipated contractionary monetary policy shock

and the change in expectations by households from being in a different joint aggregate state. Therefore, the decomposition holds the aggregate states constant but not households expectations over the evolution of the aggregate states. Finally, I study the cross-sectional impact of monetary policy by decomposing the aggregate response by age and income quintile.

All impulse responses are calculated as deviations from the stochastic steady state. This is the counterfactual world in which households faced the same idiosyncratic income shocks and there was no movement in the aggregate states, but where households still form expectations of the likely evolution of the aggregate states. Thus, the responses isolate the impact of monetary policy.

4.1 Aggregate Responses to Monetary Policy Shock

Figure 4 displays the path of the endogenous variables, including homeownership, mortgagor, outright homeownership, consumption, loan-to-value ratio of borrowers and net worth to the exogenous movement of the aggregate states as seen in Figure 3.

In response to a one standard deviation contractionary monetary policy shock, the model shows a small positive impact on homeownership, increasing by a little over 0.10 percentage points. However, as seen in panel (a), this increase is not immediate and slowly returns to its steady state value as the shocks dissipate. As homeownership increases in response to a tightening of monetary policy, this suggests that the house price channel must be dominating. I explore this further in Section 4.2.

Among the different housing tenure types, panels (b) and (c) show there is a movement out of indebted homeownership into outright homeownership. The magnitude of this movement is approximately four times the overall impact on the total homeownership rate. To understand this movement among homeowners, it is best to study the cross-sectional effect. This is left to Section 4.3. The sum of the homeowner with a mortgage and outright panels at each point in time give the total homeownership impulse response.

Despite the question of interest being related to housing, the model is also capable of studying the impact of monetary policy on demand and other key macroeconomic aggregates. It finds that there is a contemporaneous drop in consumption by 0.09 percent, though this effect only lasts for one year, as seen in panel (d).

The mean loan-to-value ratio for homeowners rises by as much as 0.12 percentage points (panel (e)), whereas the mean net worth of all households falls by almost 0.25 percent (panel (f)). The greatest changes in loan to value ratio and net worth occur in the same period when house prices are the lowest and when the two other channels have largely dissipated, suggesting that changes in house prices are driving these movements. Both variables

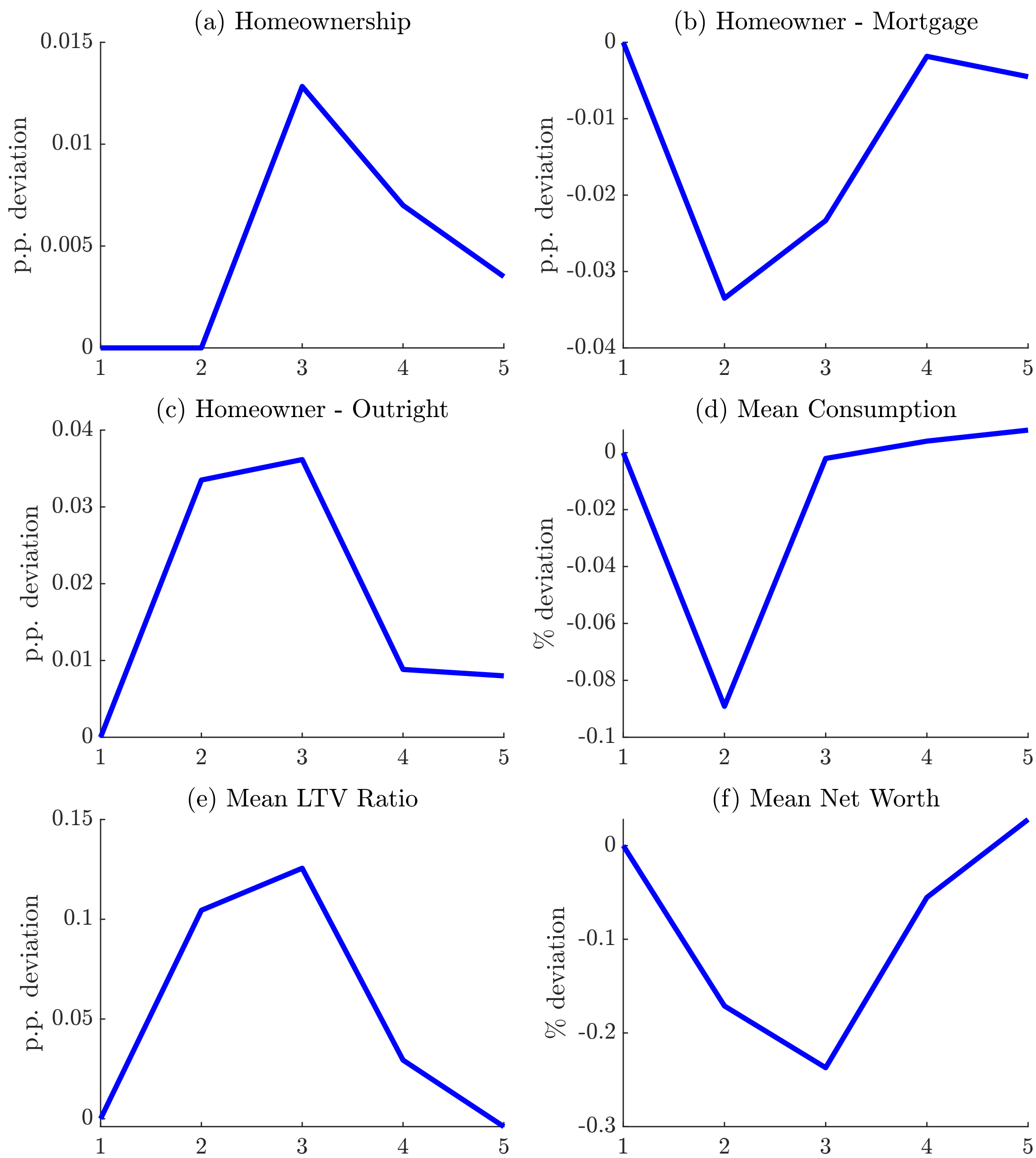

Figure 4: Aggregate Impulse Responses

Note: The mean LTV ratio is calculated among mortgagors only.

quickly return to steady state after about two years from the peak of their respective responses.

4.2 Decomposition by Transmission Channel

Figure 5 illustrates the effect of monetary policy via each transmission channel on the endogenous variables of interest. I focus on each variable, reviewing every channel in turn.

Panel (a) decomposes the overall response of homeownership to a monetary policy shock by transmission channel. Higher interest rates alone (red dashed line), lead to a decline in the overall homeownership rate by about 0.004 percentage points, and this effect occurs in the period of the shock. This is because a rise in interest rates restrains the capacity of prospective homebuyers to borrow for housing, preventing them from entering the housing market had they not been subject to a reduction in their borrowing power. As interest rates return to steady state, so does homeownership, but not before up-ticking slightly as greater interest received on savings helps some marginal homebuyers achieve their downpayment requirement earlier. If the aggregate income channel (yellow dot-dashed line) is only active, this results in a similar contemporaneous fall in homeownership as if interest rates had only shifted. This should be expected, as lower incomes makes it more difficult to reach the deposit required for a home purchase. Although aggregate income recovers slightly in the period after the shock (as per panel (b) of Figure 3), homeownership remains subdued, as some households still face lower incomes, while others are still catching up on saving for their deposit. In the case of the house prices channel (green dotted line) being only in effect, there is a positive immediate impact on homeownership; rising by as much as 0.12 percentage points in the period after the shock. This is as expected as lower house prices reduces the cost of entry into the housing market. As house prices return to steady state, so does the homeownership rate.

Putting this altogether, it becomes clear why there is no contemporaneous effect of homeownership to a monetary policy shock. In the period of the shock when all aggregate variables have shifted, the effect of each transmission channel on homeownership effectively cancels one another out. As the

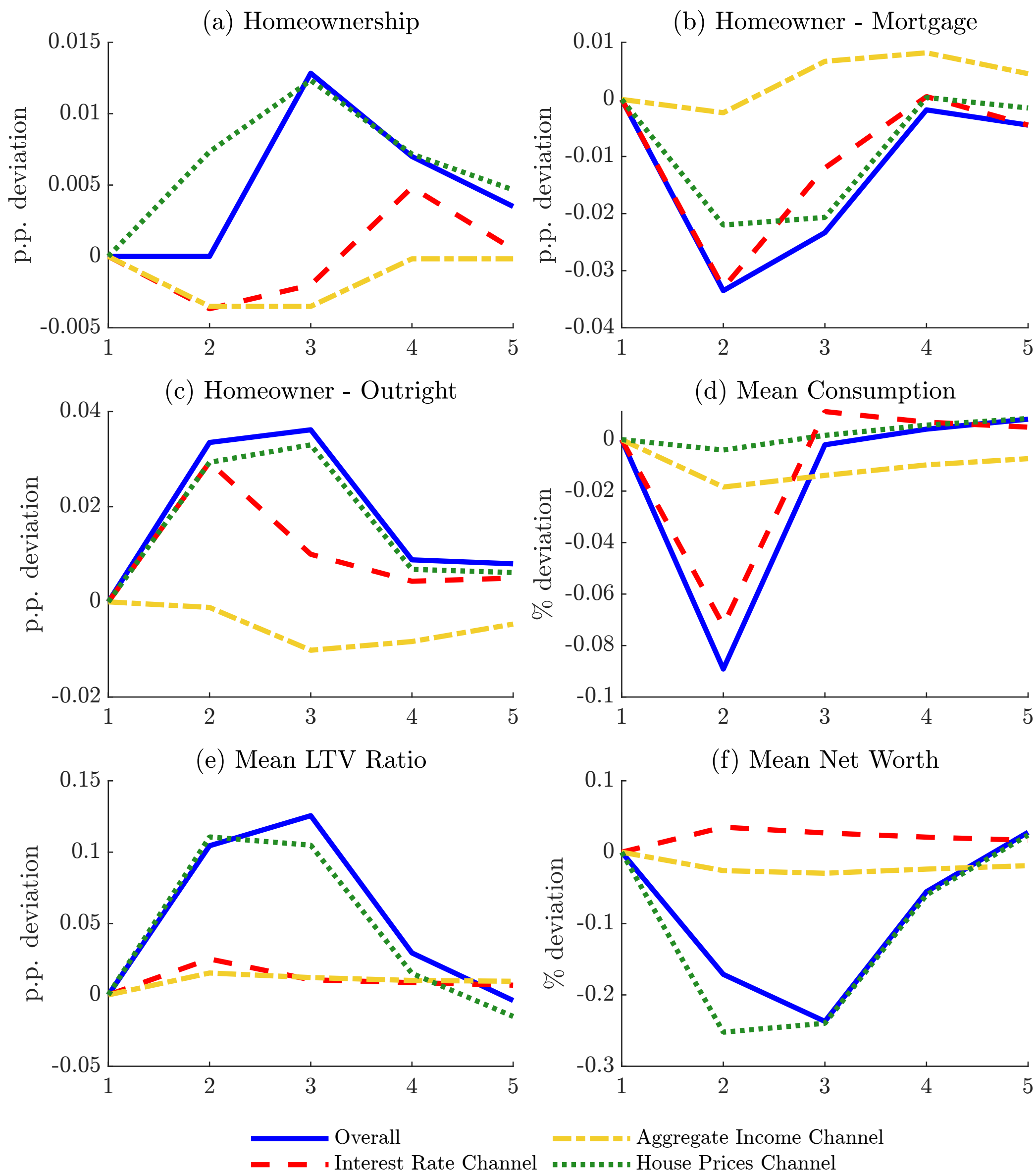

Figure 5: Impulse Responses by Transmission Channel

Note: The mean LTV ratio is calculated among mortgagors only.

interest rate and aggregate income channels are the first to dissipate, this leaves the rest of the aggregate response to trace out the impulse response of the house prices channel. This is also true for the different classes of homeownership (with and without a mortgage) as well as for the mean LTV ratio of borrowers and mean net worth, as I discuss below.

Panels (b) and (c) provide a more nuanced insight into the how the homeownership response evolves, by transmission channel. Greater interest rates by themselves raise the outright homeownership rate, whilst there is a fall in the number of mortgagors. However, this decrease in homeowners with a mortgage is not completely offset by higher outright homeownership, leading to a decline in the overall homeownership rate, as discussed above. This means interest rates must be having separate effects on housing tenure. The first is at the intensive margin wherein higher rates increase mortgage servicing costs, which existing homeowners avoid by paying off their loan faster, leading to more outright homeowners moving from homeownership with a mortgage. The second is the fall in the borrowing bower of prospective homeowners, which is responsible for the observed decline in the overall homeownership rate. With respect to the aggregate income channel, lower incomes make reaching a deposit more challenging for prospective homeowners, as the fall in overall homeownership is mainly due to a decrease in the number of mortgagors. However, over time, reduced incomes also mean less funds are available to existing homeowners to pay off their mortgage, leading to a drop in outright homeownership, as more homeowners stay with a mortgage. Within the two types of homeownership, lower house prices also cause a movement out of holding a mortgage and into outright homeownership. By its own, it is difficult to think of a plausible explanation, but this becomes clearer once the cross-sectional effect is studied in Section 4.3.

Panels (e) and (f) are useful for studying the impacts on borrowing and savings behaviours, addressing how each transmission channel is related to wealth. All else equal, higher interest rates slightly raise the loan-to-value ratio of borrowers. This is intertwined with the movement of many mortgagors into outright homeownership; only those with the lowest mortgage values (and hence, lowest LTV ratios) can make this jump. This means the remaining mortgagors have a higher average LTV ratio. Higher interest rates also increase the rate of return on saving, leading to a slightly higher average net worth across all households. The mean LTV ratio of borrowers barely responds to the income shock, whereas average net worth is slightly lower as households have less funds to funnel into savings. In contrast, most of the response in the mean LTV ratio and mean net worth is driven by changing house prices. Lower house prices increase the leverage of existing homeowners and reduce mean net worth since housing is a major component of households' stock of wealth.

Looking at consumption in panel (d), we can see that the overall impulse response, follows a very similar shape to the response in which only interest rates change. This suggests that most of the consumption response is driven by the interest rate channel. This contrasts with the dissimilar shapes of the interest rate only channel and overall impulse responses for homeownership. This suggests that homeownership and consumption are affected by different transmission channels of monetary policy. The aggregate income channel has some impact on consumption, but a substantially less effect than interest rates.

Back of the envelope calculations of the marginal propensity to consume (MPC) out of income in the model is 34 cents in the dollar, which is lower than the estimate of 50 cents in the dollar given by May, Nodari, and Rees (2020) for Australian data. Consumption is also subject to a small wealth effect, as a result of falling house prices. The marginal propensity to consume out of housing wealth in the model is about 2.12 cents in the dollar. This is consistent with empirical estimates for Australia, such as those given by May, Nodari, and Rees (2020), Dvornak and Kohler (2007) and Atalay, Whelan, and Yates (2016), which are between 2 and 3 cents in the dollar. Although, consumption is not the main focus of this paper, it is the most frequently studied response in the literature and for this reason, I reserve further discussion for Section 4.4.

4.3 Cross-sectional Responses to Monetary Policy Shock

Figure 6 displays the impulse responses to a one standard deviation unanticipated contractionary monetary policy shock by age, when all transmission channels are in operation. Households are divided into four age groups of equal size, with the eldest group (aged 66-80), wholly consisting of retirees.

As illustrated in panel (a) of Figure 6, most of the small positive effect of homeownership is largely driven by older working-age households (aged 51-65). These households move from renting into homeownership with a mortgage, as per panels (b) and (c). The reason why older working age households make up the bulk of the impact and not younger households is likely twofold. Firstly, elder working-age renters are closer to the margin of homeownership than their younger counterparts, as they have greater incomes and savings. As the effects of the monetary policy shock on the aggregate states are small, this is important as only the most marginal households (i.e., older working-age) are pushed into homeownership. A second related reason is due to lifecycle dynamics. At older ages, most households have entered the housing market and those that do not, do so by choice. Contrastingly, for younger households, they are more constrained and simply do not have the minimum downpayment, so changes to the macroeconomic environment, especially when they are small, do not help them reach the required deposit.

Retirees face no overall change to their total homeownership rate, as seen in panel (a). However, they account for essentially all the movement out of being mortgagors and into outright homeownership (see panels (b) and (c)). This is due to the bequest motive, which strengthens in later life. In the model, households save for bequests, which is the sum of housing wealth and liquid assets. Specifically, housing wealth is defined at current prices, so if house prices fall, this reduces household wealth and the value of the bequest. To compensate, households save more, paying down more of their mortgage,

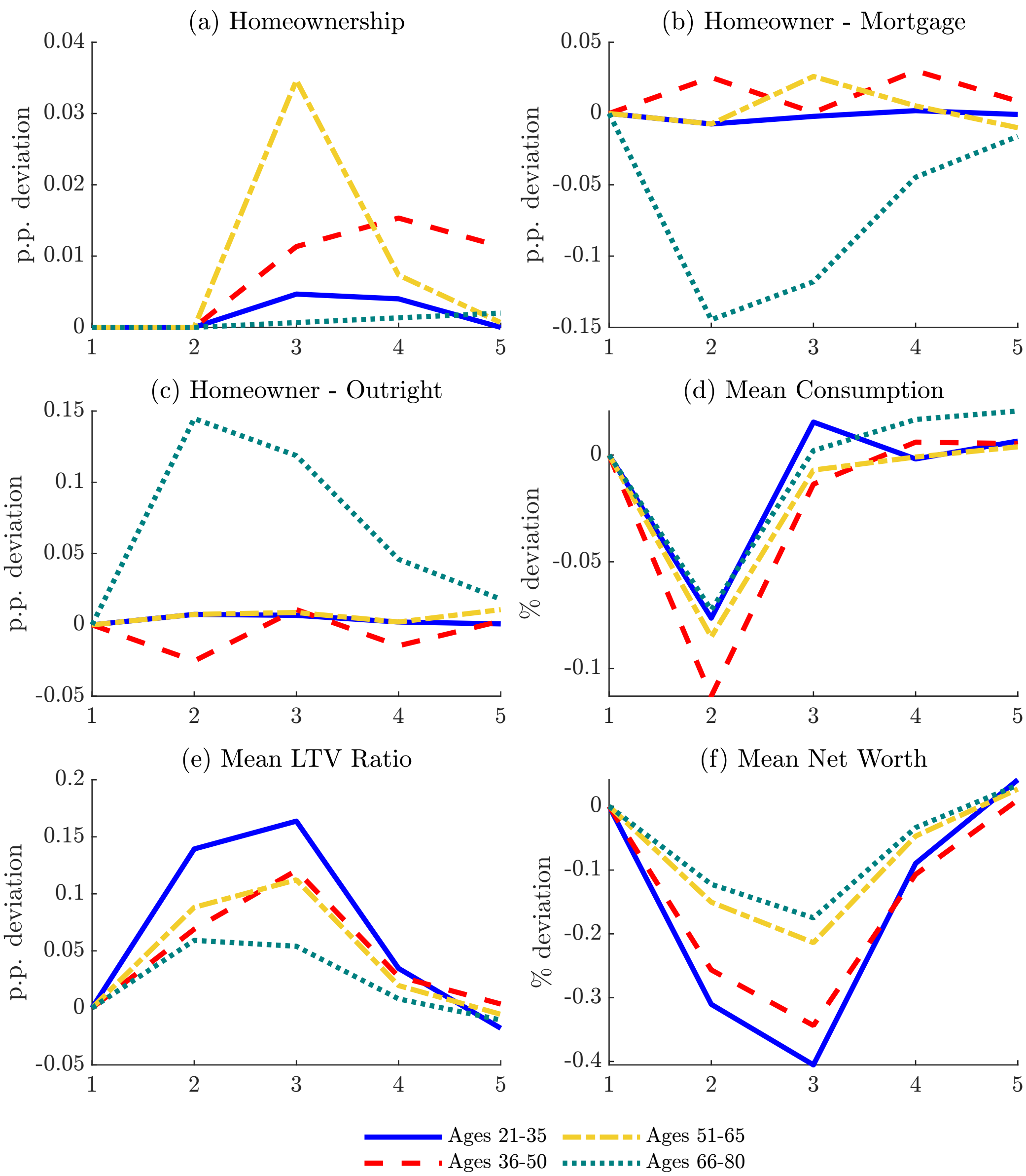

Figure 6: Impulse Responses by Age Group

Note: The mean LTV ratio is calculated among mortgagors only.

with some of them paying it off entirely and becoming outright homeowners. The magnitude of this effect is large relative to the response in the overall homeownership rate. I suspect this is being overestimated as the model has too many mortgagors and too few outright homeowners beyond the age of 60 compared with the data, as illustrated in Figure 2, panels (b) and (c).

As per the prior decomposition exercise (Figure 5), changes in house prices have the greatest influence over the mean LTV ratio of borrowers and the mean net worth of households, as shown in panels (e) and (f), respectively. As a result, households who are most leveraged will have the most sensitive response to both these variables. As young households are the most leveraged with the greatest loan balances, the average LTV ratio of their borrowers will rise the most, compared to older groups. Similarly, since most of their wealth is tied up in housing, younger households face the sharpest falls in their net worth as house prices and therefore, the value of their housing wealth falls. The impact is less pronounced for older households as they are less leveraged and have built up another source of wealth from their stock of savings.

Panel (d) reveals that middle-aged households face the steepest decline in consumption due to tightening monetary policy. Using prior analysis which shows that changes in interest rates have the strongest sway over consumption, mortgagors are allocating funds away from consuming to pay higher interest on their mortgage. Most of these mortgagors are middle-aged households. This also explains why the youngest and oldest households have a less sensitive response, since the majority are renters and outright homeowners, respectively. A further discussion can be found in Section 4.4.

Age is not the only dimension of heterogeneity that the model is capable of exploring. I also decompose the impulse responses by income quintile as shown in Figure 7. This is useful as homeownership decisions vary depending on an individual's income. A household's position in the income distribution is also likely to be linked with their age, so this cross-sectional examination complements that above. For this analysis, I compute income quantiles at every time period in the model.[14]

[14] As a result there are some compositional changes between the quantiles across the time

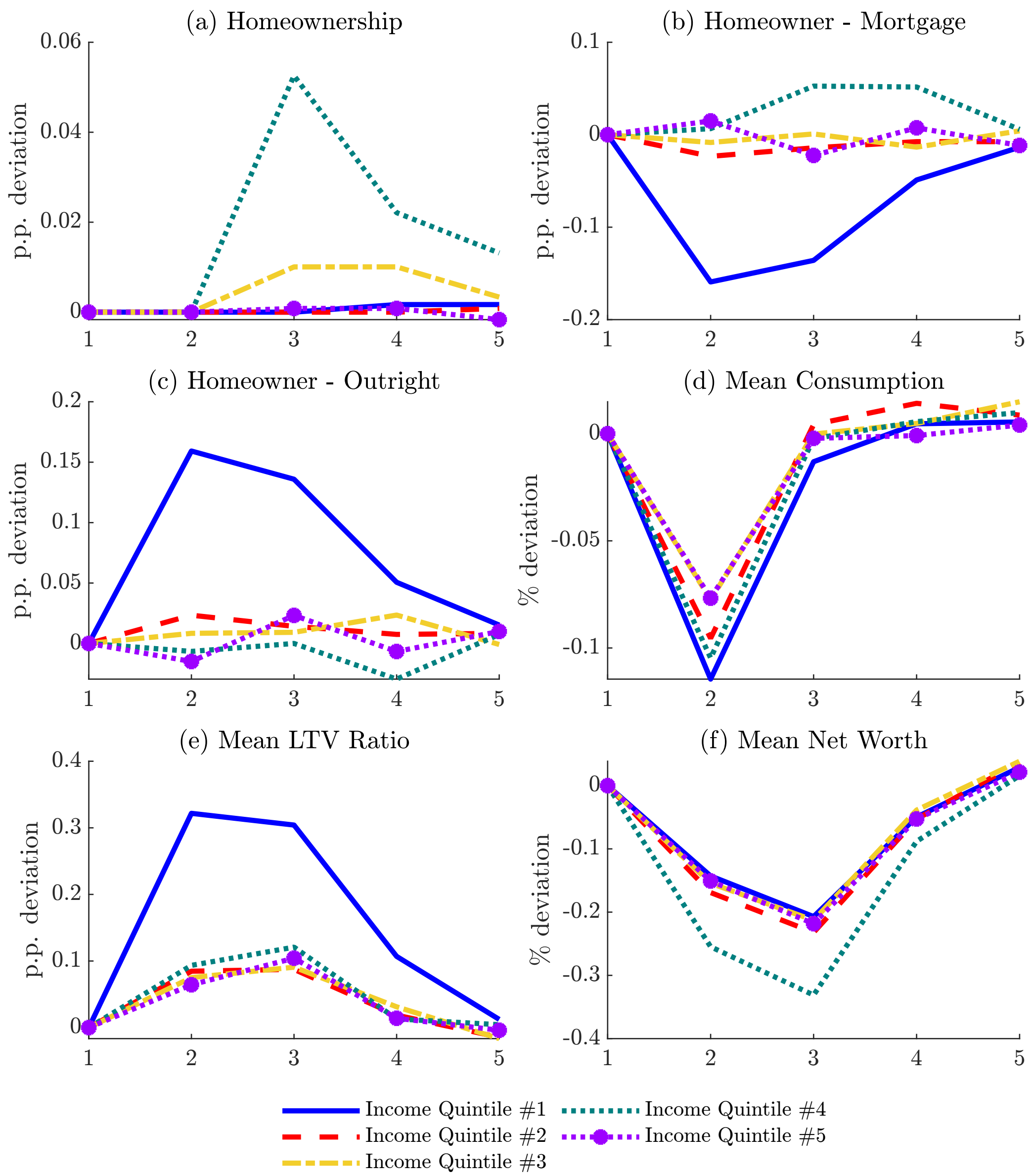

Figure 7: Impulse Responses by Income Quintile

Note: The mean LTV ratio is calculated among mortgagors only.

periods a monetary policy shock occurs. This is because the aggregate income transmission channel only affects working-age households. However, as households cannot choose their

As per panel (a), changes to the homeownership rate are entirely driven by households in the upper-middle part of the income distribution. Since households at the top quintile are already homeowners, the most marginal households are those in the quintile below, as they have the income necessary to exploit small changes in economic conditions. Households in the third- and fourth-income quintiles are also the older working age households, so this corroborates the discussion earlier. Similarly, as seen in panels (b) and (c), the exodus of mortgagors becoming outright homeowners is driven by retirees, who would be in the lowest income quintile.

Looking at panel (e), the LTV ratio among borrowers rises the most for the lowest income households as these would include young households who are the most leveraged. Households in the fourth income quintile incur the steepest fall to their net worth, as illustrated in panel (f). This is because they are also the group that become homeowners. As house prices fall, the value of their house and hence wealth, falls more than in the counterfactual case in which they would have otherwise saved in liquid assets had they not become homeowners.

As for consumption in panel (d), its response is strongest among households in the lowest part of the income distribution. These poorer households are also more likely to be young renting households or retirees who are liquidity constrained and thus, cannot smooth consumption. In the case of the former, this is due to restrictions against unsecured borrowing for renters, whereas for the latter, older households cannot refinance nor become a mortgagor again. High income households can draw on their savings to continue consuming, so their contemporaneous response is about two-thirds the magnitude of the lowest income group.

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income (neither the deterministic lifecycle component or their stochastic idiosyncratic component), self-selection is not present. Regardless, the compositional changes are likely to be small.

4.4 Consumption Responses by Transmission Channel and Age

In this section, I take a closer look at the response of consumption in my model to a monetary policy shock. In particular, I examine the contemporaneous response of consumption and decompose this by transmission channel and age, as seen in Figure 8. Despite mainly focusing on a homeownership channel throughout the paper, it appears that there are implications for consumption through changes in homeownership decisions. This analysis will seek to connect my thesis to a literature examining the interplay between inequality and monetary policy, that primarily focuses on the transmission to aggregate demand. I draw on two prominent papers in this area, Auclert (2019) and Kaplan, Moll, and Violante (2018) to serve as a counterpoint to my analysis. Both papers undertake a decomposition exercise as I do.

Panel (a) of Figure 8 illustrates the dispersion in the aggregate response to consumption by age which was first detailed in Figure 4. Although, the aggregate response is a fall of 0.09 percent, for some cohorts, namely middle-aged households, this effect is stronger, with their consumption decreasing by 0.15 percent. To understand why, I decompose the consumption responses by transmission channels, first seen in Figure 5, by age.

As foreshadowed earlier in Section 4.2, the interest rate channel has the greatest impact on consumption. Indeed, panel (b) takes a very similar shape to the consumption response by age when all three channels are active. The curvature of the histogram can be explained by the level of exposure to mortgages among age groups. This is because higher interest rates raise the cost of servicing a mortgage, leading to an allocation away from consumer spending. Young and old households have the least sensitive response to interest rate changes, as the majority of them are renters and outright homeowners, respectively. In fact, given they more likely to be savers, a higher rate of return on their liquid assets has an income effect for this group, fuelling consumption and offsetting some of the negative response. Middle-aged households are not

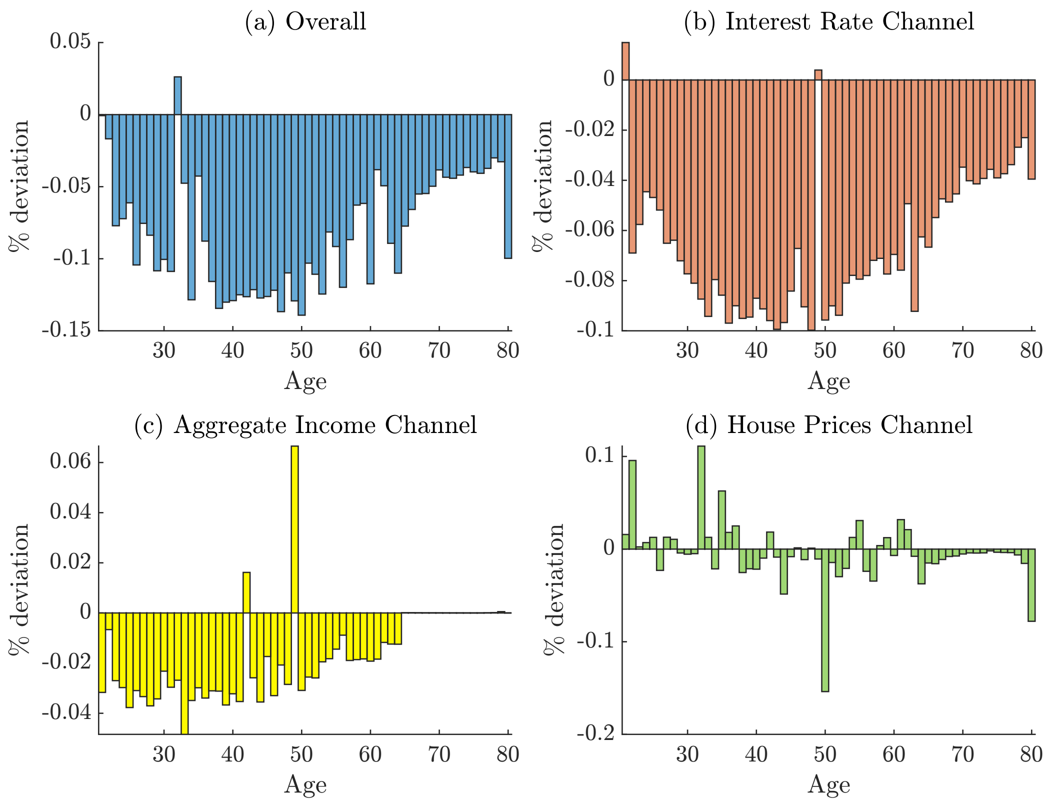

Figure 8: Contemporaneous response of mean consumption to a one standard deviation unanticipated contractionary monetary policy shock, decomposed by transmission channel and age

only the group with the highest proportion of mortgagors, but they are also relatively leveraged; having high LTV ratios. As a result, increases to their mortgage repayments are steeper, compounding their fall in consumption.

Panel (c) unpacks how consumption changes if only aggregate income shifts. As retirees are unaffected by changes to aggregate income, they do not alter their consumption choices. For working age households, lower incomes reduces funds available for consumption, leading to its decline. These falls are strongest for younger and middle-aged households as they are constrained and cannot borrow to smooth consumption. In the case of the former, the majority of young households are renters and are restricted from engaging in unsecured borrowing in the model. For the latter, middle-aged households are mainly relatively leveraged mortgagors who would struggle to borrow further against their property. In the ages prior to retirement, the effect of the aggregate income channel drops off as households pay off their mortgage and build savings to smooth consumption.

The response of consumption to the movement in house prices is less straightforward to understand, as panel (d) illustrates. In Section 4.2, the model found that falling house prices exhibit a weak negative effect on consumption, but clearly this is quite heterogeneous among household cohorts. For young households, a decrease in house prices tends to have a positive effect on consumption. This is because many of them are moving into homeownership and would have entered the housing market, regardless of the change in house prices. Lower house prices simply leaves more leftover funds available for consumption. Middle-aged households consumption responses are broadly negative for two reasons. First, as the majority of them are homeowners, they are subject to wealth effects associated with the falling value of their property. Second, lower house prices pushes some households into homeownership, where the funds allocated to the purchase of a home, come at the expense of higher consumption had they continued to rent in a world in which house prices remained constant. As for retirees, since they do not move into or out of homeownership (see Figure 6), and are mostly homeowners, their negative consumption response is due to a wealth effect. However, this effect is quite weak and aligns with research by Buiter (2008) as housing wealth is illiquid and such changes are typically not realised unless the house is sold. The exception to this is at the final age of life (age 80), where the consumption response is the strongest among retirees, due to the bequest motive. As households die with certainty and housing is a component of bequests, lower house prices reduce housing wealth and to compensate, these households save more and consume less to offset losses in the value of their bequest.

My results are related with those of Kaplan, Moll, and Violante (2018) who find that the illiquid assets (in my case, housing specifically) held by households is important for the transmission of monetary policy through to consumption. Their paper also decomposes the impact of monetary policy by interest rates and incomes. However, while they find that the income channel is responsible for the majority of the consumption response, I obtain the opposite finding. This is likely due to two key differences between the models. First, Kaplan, Moll, and Violante offer a more elaborate treatment of illiquid assets which is important since their income effect is mainly driven by hand-to-mouth households. Second, their model also incorporates fiscal policy, so household incomes are impacted by changes to government transfers. On the other hand, my analysis is similar to Auclert (2019) who finds the redistributive effects of monetary policy has aggregate impacts on consumption. In my case, the impact of monetary policy on which households become homeowners is important to consider, as the purchase of housing crowds out consumption expenditure in the the period of the transaction. This can lead to effects on aggregate consumption.

5 Conclusion

In this paper, I study the impact of monetary policy to homeownership. I do this by constructing a partial equilibrium heterogeneous agent OLG model calibrated to the Australian economy. This model characterises the economy with aggregate states, allowing household responses to an exogenous monetary policy shock to be studied. In this setup, households retain consistent expectations over the evolution of the aggregate states that is informed by an estimated time-series model for Australia. Households respond to the transitory movements in interest rates, aggregate income and house prices arising from a monetary policy shock and I study their effect in aggregate, by transmission channel, and by age and income.

I find that tighter monetary policy appears to have a small positive effect on homeownership. The effect of house prices matters more than changes in interest rates and income, when examining the impact of a contractionary monetary policy shock on homeownership. Older working age households are documented to benefit the most from these changes in economic conditions. In the context of the current monetary tightening cycle in Australia, this suggests that policymakers should not be too worried about adverse effects on homeownership rates.

Despite fitting the lifecycle profile of key variables reasonably well, the model is subject to some limitations. First, monetary policy operates over the short term, so having the model at a quarterly frequency, rather than annual, may provide a richer analysis. Second, since there is only one non-zero house size available for purchase, the model is mainly limited to studying homeownership decisions at the extensive margin. Studying homeownership responses at the intensive margin, would provide a better picture of households' upsizing/downsizing and refinancing decisions. Similarly, to maintain model tractability, household's liquid savings and mortgage balances are combined into one net asset quantity. Splitting this setup, would allow an analysis of how household savings and their interaction with housing decisions respond to monetary policy. Finally, future work may consider studying the impact of macroprudential policies on homeownership. Such a suite of policies has more recently been used by policymakers to target the housing market and promote financial stability. Studying the effect of changing LTV, PTI (payment-to-income) and DTI (debt-to-income) ratios is possible with similar models. These are potential pathways for further research.

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6 Appendix

6.1 VAR Implementation

As detailed in Section 2.2, 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:

$$\Delta S_t = A \Delta S_{t-1} + u_t$$

where $S_t = \{r_t, \log(\gamma_t), \log(P_{ht})\}$ is the vector of aggregate states. As discussed earlier, since the policy interest rate is endogenous, this is replaced with a monetary policy shock series from Beckers (2020). 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 lower triangular:

$$B = \begin{pmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{pmatrix}$$

This identifying assumption enables shocks to monetary policy to contemporaneously impact all the aggregate state variables. This is a plausible assumption to make, as changes to monetary policy affect household's expectations about the future of the economy, thereby shaping their decisions today, even if the direct change of interest rates is not immediately passed through. As B is lower 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 $Q = \Delta S$. This substitution is made for ease of notation. Although the variance-coviance matrix of shocks ε_t is diagonal, Tauchen (1986) can only discretise VAR's of 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:

$$
\begin{aligned}
Q_t &= Qz_{t-1} + B\varepsilon_t \\
\implies B^{-1}Q_t &= B^{-1}AQ_{t-1} + B^{-1}B\varepsilon_t \\
\implies B^{-1}Q_t &= B^{-1}AQ_{t-1} + \varepsilon_t \\
\implies B^{-1}Q_t &= B^{-1}ABB^{-1}Q_{t-1} + \varepsilon_t \\
\implies x_t &= \rho x_{t-1} + \Psi_t
\end{aligned}
$$

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

6.2 Model Computation

As the household's decision problem does not admit an analytical solution, the model is solved numerically in MATLAB. Being a lifecycle model, it is solved using backward induction from the final age of life. At every age, the value functions for renting and owning a home are computed, and the overall policy function is given by comparing these two functions. Each of the value functions are solved on a discrete grid, for the state variables: net liquid assets, owner-occupier housing stock, idiosyncratic income and the aggregate states.

There are 180 grid points for liquid assets, which are logarithmically spaced on the negative side, and linearly spaced among positive balances. The idiosyncratic income state is discretised into 7 states, using the Rouwenhorst (1995) method. The aggregate states are obtained from estimating a VAR, as described in Section 2.2 and discretising it using the method of Tauchen (1986), as implemented by the procedure outlined in Section 6.1. Discretising both these processes yields separate transition probability matrices. To construct a joint probability transition matrix, the Kronecker product between the separate matrices is taken, enabling households to form expectations over idiosyncratic income and the evolution of the aggregate states. Linear interpolation is used to obtain choices between grid points.

Taking the idiosyncratic income and aggregate states as given and having these expectations, households solve their decision problem. As the budget constraint is solved for the level of consumption, households choose only their level of liquid assets, housing tenure type and level of housing services.

There are 60 cohorts (age groups) of households which are present in the model, with 10,000 households in each cohort. Once the model is calibrated in its stochastic steady state, I feed a path of interest rates, aggregate income and house prices arising from a monetary policy shock. Given their prior liquid asset and housing choice, as well as the realisation of their idiosyncratic component of income and realised aggregate state variables, households make their consumption, saving and housing choices. Their responses are then observed and reported.