An Overlapping Generations Model of Housing Tenure and House Prices in the UK

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Working Paper No. 007 March 2026

EMAP Working Paper Series

Queen Mary
University of London

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September 2025

1 Non-Technical Executive Summary

The question of house prices, rental prices, and tenure distribution are all enormously significant for both the Department for Work and Pensions (DWP) and wider government. Tenure distribution refers to the proportion of households in either owner-occupied housing, the private rented sector (PRS), or the social rented sector (SRS) housing at any given time. The DWP spends over £30 billion annually on housing support for low-income households, with this amount set to increase significantly in the future. The level at which current housing support is set means that many renters' rental costs are substantially higher than the housing support they receive.

Many factors can affect both prices and tenure distributions. Previous research has shown that economic growth, interest rates, housing supply, mortgage availability, population changes, and shifts in the way households are formed can all influence the price of housing and tenure distributions. The DWP currently forecasts the future expected costs associated with housing support, but it doesn't explicitly account for how all of these factors may change in the future and how they might affect the number of people eligible for housing support. MHCLG, who lead on housing policy, do not forecast prices or tenure distributions.

This paper develops an economic model as a tool to explore the relationship between interest rates, mortgage availability and house prices and tenure distributions, with a focus on the share between owner-occupied housing and PRS housing. The purpose of this work is not to produce a detailed forecast, but rather to explore the extent to which interest rates and mortgage conditions can influence the housing market. The findings can then be used to inform strategic thinking around housing both within DWP and across government more widely. For example, due to the high inflation post-COVID, interest rates were raised. This model can shed insight into how that might affect house and rental prices, which in turn has implications for DWP's housing welfare policy.

This research finds that interest rates have an inverse relationship with house prices; as interest rates go up, house prices go down. On the other hand, interest rates have a relatively weak effect on rental prices. The research also finds that increased mortgage availability increases housing wealth inequality; as owner-occupier mortgages and buy-to-let mortgages allow for greater borrowing, the findings suggest a relatively small proportion of the population ends up owning a large proportion of the total housing stock.

2 Introduction

Real house prices and rental prices[1] in the UK have increased massively over the last 40-50 years (Figure 1). Historically, housing has undergone boom-and-bust cycles, whereby increases in house prices have generally been followed

[1] In this paper, rental prices refer to prices in the private rented sector unless explicitly stated otherwise.

by 'resets', which reduced prices relative to incomes. However, since the mid-90s, the UK has seen an unprecedented housing price boom. The increase has outpaced any gains in median wage growth, productivity, and GDP per capita. Similar trends have been observed to varying extents across many other developed countries (Mumtaz and Sustek, 2023). There are a range of factors which are put forward for this price growth in the UK, including the fall in interest rates, credit liberalisation, supply constraints, demographic shifts, and specific policy interventions such as Right to Buy.
Housing plays a distinct role in our economy as it provides a housing service to its occupier as a consumption good, whilst also acting as an investment vehicle through potential price appreciation and rental income; most other investment goods provide no utility to the investor beyond the promise of future returns. Across a large part of the housing quality and size distribution, demand for housing is reasonably price-inelastic, due to the necessity of having at least some basic form of shelter to survive. Therefore, shocks to the user cost of housing, credit availability, and supply conditions can all have significant effects on house prices, tenure distributions, and social welfare.

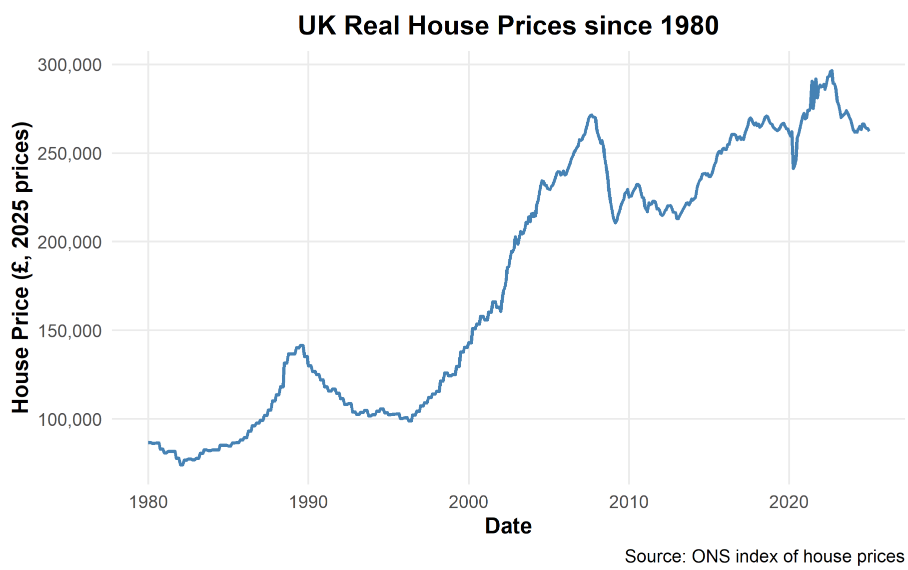

Figure 1: *Real house prices have almost tripled since 1980.*

Over the same period that house prices have increased, there have been significant changes in tenure distribution (Figure 4). Owner occupancy rates peaked at 71% in 2003 but have since fallen to 65%. At the age of 27, those born in the late 1980s had a home ownership rate of 25%, compared with 43% for those born just ten years earlier (in the late 1970s) (Cribb and Hood, 2018). The social rented sector (SRS) made up a third of UK housing in the late 1970s but now represents just 16% of tenures, whereas the private rented sector (PRS) makes up 19% of tenures, having been closer to 12% in 1980 (MHCLG, 2025). The decrease in SRS can be attributed to the right-to-buy scheme introduced in 1980.

For some households, the sustained increase in house prices has resulted in huge windfall gains, which has driven a significant proportion of intergenerational inequality and resulted in a decline in the number of young households owning their own homes. Regional variations in house price growth have meant that London and the south-east are particularly unaffordable. And whilst housing wealth explains a significant proportion of intergenerational inequality, it is also likely a key driver of intragenerational inequality by creating a significant divide between those who inherit housing wealth and those who do not (Financial Times, 2024). High house prices may also affect productivity growth by restricting mobility in the labour market (Alma Economics, 2025) and by crowding out investment in more productive capital (Bezemer, Grydaki, and Zhang, 2016).

Rental prices have also increased over the last 40-50 years, albeit at a slower rate than house prices. Figure 3 shows that since 1980, the ratio of average house price to average rent price has almost doubled, showing that prices have risen faster than rents. However, in recent years, rent price inflation has been high; it was 6.7% in the 12 months to June 2025, with the rental inflation rate peaking at 9.1% in March 2024 since the period of high inflation post-COVID. In June 2025, house price inflation was at 3.9%, significantly lower than rental price inflation. This sustained high rental price inflation compared with house price inflation over the last two and a half years has acted to somewhat reverse the trend of declining rental yields (ONS, 2025b).

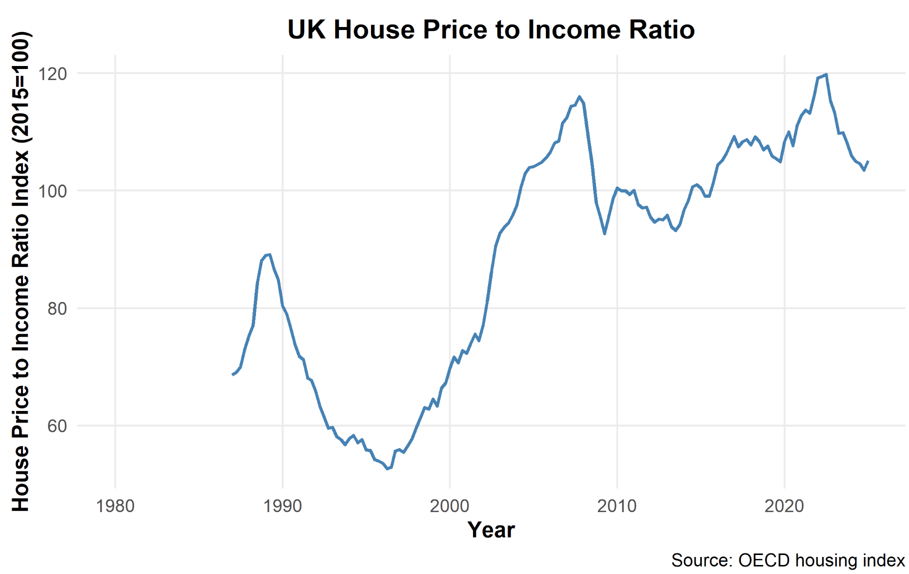

Figure 2: *Mean house price to income ratios have increased significantly since 1987 (Indexed to equal 100 in 2015).*

Over the last 40 years, government policy to support low-income households with their housing costs has shifted substantially from supply-side subsidies to demand-side subsidies. In 1975, 82% of government housing support expenditure was supply-side; by 2022, there had been a complete reversal, with 88% of housing support expenditure being demand-side subsidy. The Department for Work and Pensions' (DWP) expenditure on housing support was over £31 billion in the 23/24 financial year, compared to under £5 billion in the late 1970s (Gibb, 2024). Meanwhile, the social rented sector (SRS) construction, which peaked at over 300,000 council-built dwellings per year between the 1950s and 70s, has fallen to much lower levels, at a rate of approximately 10,000 per year (Hill, 2022).
The sustained increase in housing costs, particularly rents, and shifts in tenure distributions have significant fiscal implications for the DWP, specifically in the context of housing support and welfare. 38% of tenants in the private rented sector receive housing support from the DWP (IFS, 2023); whilst increases in the number of households living in the PRS would not necessarily mean more households in receipt of housing benefits, if low-income households who might have previously been owner-occupiers become private renters, then this could be the case. Even without increased caseload, high rental inflation has meant that sporadically uprated Local Housing Allowance (LHA) is only sufficient to cover a small proportion of new listed rental properties in the PRS (Crisis, 2025).

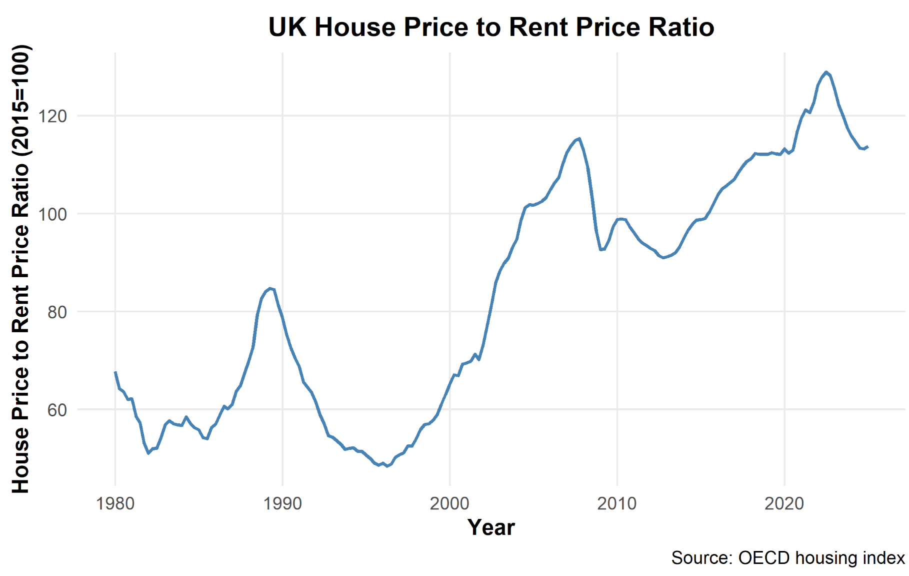

Figure 3: *The ratio of mean house prices to mean rents has increased significantly since 1980. Whilst rental prices have increased, house prices have increased at a higher rate, meaning rental yields have decreased since 1980 (Indexed to equal 100 in 2015).*

The DWP, using statistical models, creates forecasts for tenure distributions, using a range of different external information (e.g., the OBR's rental inflation forecast)and internal information to forecast long-term housing support expenditure. MHCLG, who lead on housing policy, do not currently forecast tenure distributions, house prices or rental prices. The aims of this paper are to introduce a structural model which allows for exploration of the macroeconomic determinants of house prices, rental prices and tenure distributions. The model developed is a partial equilibrium model in housing markets, with exogenous interest rates and housing supply. The aim of this work is not to produce a detailed forecast for future housing support expenditure, but rather to present a framework and modelling approach that can inform the strategic thinking around long-term housing support forecasts as well as wider housing policy.

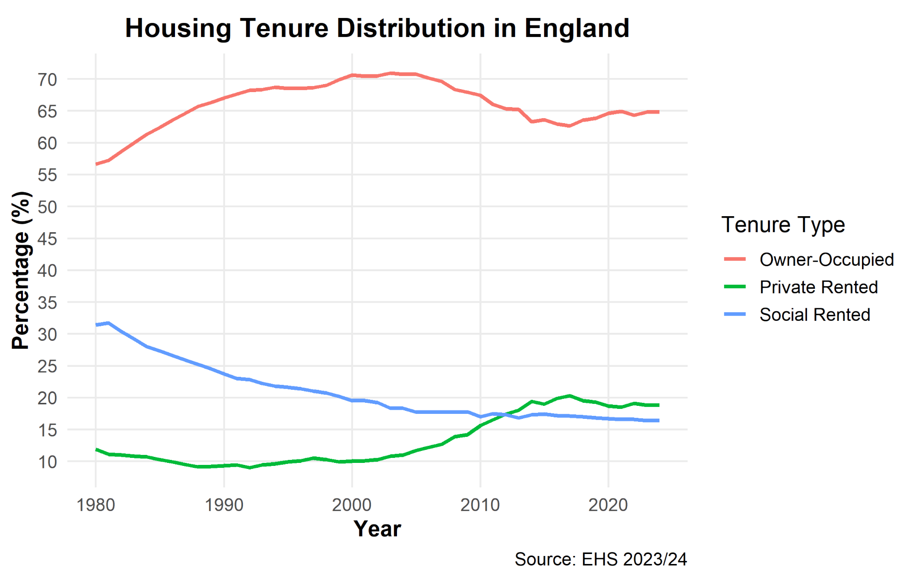

Figure 4: *The distribution of housing tenure over time.*

In this paper, a two-generation overlapping generations (OLG) model incorporating a composite consumption good and housing is developed to explore the impact of interest rates and mortgage credit conditions on house prices, rental prices, and tenure distribution between the PRS and owner-occupancy. We will start by briefly reviewing the existing research on the drivers of historical changes in house and rental prices and tenure distribution in the UK. Following this, we will go ahead and outline the research methodology in detail, including justifying the model structure, its scope, and explicitly stating any assumptions and limitations of the model. We will then develop the mathematical structure of the model and define the equilibrium conditions that allow the model to be solved for equilibrium prices and tenure distributions. We will then calibrate the model, using a range of data sources to choose the relevant parameters for the model. Following this, a series of experiments are run to consider the impact

of changes in mortgage credit conditions and changes in interest rates on house and rental prices and tenure distributions. An amendment to the initial model is then proposed and solved.
The model outputs will then be discussed, particularly in the context of the DWP and wider government's housing agenda, and how it can inform strategic thinking and decision-making. Finally, to qualify the results, a critical appraisal of the model's limitations and possibilities for further development will be discussed.

3 Literature Review

Extensive academic research has examined the trends in house prices and in tenure distribution in the UK in the recent past. Research suggests that house price growth over the past 40 years has been influenced by the long-term decline in interest rates, credit liberalisation, tight housing supply, rising incomes and inequality, demographic pressures, government policies (such as Right to Buy and Help to Buy), and growing demand for housing as an investment asset.
Miles and Monro (2019) develop an equilibrium model of housing incorporating the user cost of housing for owner-occupiers to explore the impact of the secular decline in interest rates seen since the 1980s on house prices in the long run. They find that the decrease in interest rates caused approximately a doubling in house price increases in the UK. In contrast, as argued by Ryan-Collins (2024), Germany saw a similar decline in interest rates but did not see substantial increases in house prices.
Ryan-Collins (2024) argues that the financialisation of housing in the UK has contributed towards a significant proportion of the increase in house prices. He argues that the relaxation of mortgage constraints for both owner-occupiers and buy-to-let landlords since the 1980s led to a substantial increase in mortgage credit, which stimulated increased demand from both owner-occupiers and landlords in a supply-constrained environment, leading to increased prices.
Research has also shown that the surge in credit did not lead to a commensurate increase in housing supply. The question of why supply has been so unresponsive is also well researched, with regulatory constraints such as planning restrictions often cited as creating an artificial scarcity of developable land. There is research that suggests causal evidence for this (Kohl, 2019), and the authors claim that prices would have been about 35% lower in 2008 with fewer planning restrictions. The broad consensus view of a very low supply elasticity means that demand increases mainly translate into higher prices rather than increased supply.
Some changes in the housing market were likely the result of shifts in the regulatory environment. The PRS has more than doubled its share since 1990, and it is strongly linked to regulatory reform; the Housing Act 1988 introduced assured shorthold tenancies and ended rent controls on new lettings, which is widely credited as making landlordism more attractive. Buy-to-let mortgages were first introduced in the UK in the late 1990s, facilitating further expansion of the PRS by increasing credit availability. Another factor is the tax envi-

ronment: owner-occupiers used to benefit from mortgage interest tax relief and continue to benefit from tax-free capital gains on primary residences, whereas landlords face taxes on rental income, and any houses that aren't the owner's primary residence face a capital gains tax when sold.

Demographic shifts and household formation can also affect prices by changing the distribution of the number of people living in each housing unit. Research using OLG models has shown that strong household formation rates can sustain real house price growth even as society ages and that longer life expectancy and immigration can also play a role (Day, 2018).

Whilst the question of house prices and tenure distributions has been widely explored, there has been limited research on the questions around rental prices in the PRS and the responsiveness of the sector to macroeconomic variables. In the next section, we will outline the approach taken in this paper to model a system where agents are able to make decisions around their housing tenure.

4 Methodology

In this section, we outline the approach taken to develop an OLG model that incorporates housing and a separate composite consumption good. We assume that agents in the model can be in precisely one of three states: landlords, owner-occupiers, or renters. Landlords purchase housing to live in and also buy further housing to rent out to renters, owner-occupiers purchase housing only to live in, and renters rent out housing services from landlords.

OLG models are a commonly used foundational model in macroeconomics that allow for analysis of intertemporal decision-making by agents. OLG models are built on microfoundations, explicitly modelling individuals' utility-maximising decisions over finite lifetimes. Through these decisions, agents influence prices, causing all markets to clear.

In OLG models, time is discrete, and in each time period, a new generation of agents is born. Each generation can live for two or more time periods; in this paper, we set it such that agents live for two periods (they are labelled 'young' in the first period and 'old' in the second period of life). As a result of this, there always exists a mix of young and old agents in the economy at any given time. Young agents work to earn income, and old agents receive income through investment decisions made when they were young.

Typically, OLG models use a single 'representative agent' whose behaviour is meant to capture the aggregate behaviour of the entire economy - this often allows for analytical tractability. However, we introduce heterogeneity within the population, as without heterogeneity, all agents would be identical and therefore make identical decisions with respect to housing and consumption (all would be owner-occupiers with no rental market). We introduce heterogeneity into the population by following the approach of Greenwald and Guren (2021). To implement this heterogeneity, agents receive an additional service flow which is equal to a proportion of the house price ($\alpha p_t H_t^o$) for any owner-occupied housing and a proportion of the rental price ($\gamma q_t H_t^q$) for any housing rented out as a landlord (the additional service flow can be positive or negative), which is added to agents' first period budget constraint. As discussed in Greenwald and Guren (2021), this heterogeneity in owner-occupancy service flow can be interpreted as the ability to save for a deposit, subjective value assigned to owner-occupied housing, or household composition. The heterogeneity in landlord service-flow can be interpreted as both the suitability of specific different properties to be rented, as well as the landlord's ability to save for a deposit for a rental property. Heterogeneity within properties' suitability for renting may be due to factors such as geographical location (a flat in a city may be far easier to let out compared to a rural detached house).

There are some key differences in this paper's work as compared to Greenwald and Guren (2021). Primarily, they assume that landlords only sell housing services to renters and do not consume housing services themselves; they treat landlords as institutional investors who can choose a level of investment in the housing market and other markets. This is a key difference to our model, where we assume that landlords are also owner-occupiers - this is a deliberate choice to mirror the fact that the majority of landlords in the UK own relatively few properties (and would therefore not be well classified as institutional investors), recent research shows 45% of landlords hold just one property and a further 37% hold between two and four (Savills UK, 2025). Secondly, their main model assumes that landlords are not credit-constrained (although they do also briefly explore the case of credit-constrained households) and therefore not impacted by credit shocks, whereas we assume that landlords are credit-constrained. Additionally, they assume that there is a population of unconstrained savers in the economy who also own housing and are able to absorb some of the changes in demand from borrowers caused by credit shocks - we do not incorporate this agent type into our model. Finally, they assume that landlords do not receive labour income and receive the entirety of their income through either housing or other investments. In contrast, in our model, landlords do receive labour income.

More broadly, several simplifying assumptions are adopted to maintain model parsimony. Firstly, we make the standard assumptions under neoclassical economics whereby agents make decisions that maximise their utility under a set of budget constraints. We are therefore assuming that agents are self-interested, although the second-period consumption can be interpreted as also assigning some utility in leaving a bequest to later generations; this interpretation has no impact on the mechanics of the model.

We assume that agents choose a housing tenure when young and remain in this tenure for their entire life. We also assume that agents who purchase housing face a fixed-rate mortgage over their lifespan (at a mortgage rate that they are aware of when young), as this is a necessary assumption for a two-period OLG model. Whilst many countries do have fixed-rate mortgages, most mortgages in the UK are adjustable-rate mortgages, so in reality, people who choose to purchase houses are not in fact making decisions with perfect information about the future interest rates on their mortgages. There is evidence to suggest that the decline in real interest rates in the UK over the past 40 years (reversed slightly over the last three years) was unanticipated; in other words people thought interest rates would remain roughly at the level they were at any time in the past and the decline in interest rates was only priced into the cost of housing at the time it occurred (Miles and Monro, 2019).

We assume that all real interest rates are determined exogenously. Renters, who save through non-housing investment when young, purchase UK government gilts when young that provide a return with an interest rate r_1 when old. Owner-occupier mortgages face an interest rate of r_2 and buy-to-let mortgages face an interest rate of r_3. We set $r_1 < r_2 < r_3$ to reflect the fact that gilts provide a lower return due to the very low risk nature compared to owner-occupancy mortgages, where there is a risk of default, and buy-to-let mortgages face a higher rate than owner-occupancy mortgages due to the uncertainty associated with rental income. In the model, we assume that agents are borrowing or saving with an external institution (such as a government) which can provide loans or accept deposits at set interest rates.

We also make assumptions around agents' predictions for next period house prices, and explore how sensitive tenure distribution and house prices are to these expectations. We assume that agents have extrapolative expectations and expect house prices to increase at a similar rate to the past. Agents in the model make utility-maximising decisions around their housing tenure when young, which are informed by their expectation of future house prices, without actually knowing what the house price in the next period is. The model could have been structured such that house prices in the next period are entirely deterministic (whereby all agents are fully aware of all other agents' utility functions); however, such a model formulation was not deemed to reflect how agents actually make decisions around housing tenure accurately.

We further assume that movement of the housing stock between different tenures is frictionless (i.e., any changes in exogenous parameters that result in a shift in demand for the different tenures can costlessly result in a change in the tenure distribution), and we similarly set all transaction costs to be zero. Housing is also modelled as a continuous consumption good, when in actual fact housing is discrete in nature (e.g., one cannot generally purchase half of a flat to live in). The overall housing supply can therefore be interpreted as the aggregate quality-adjusted amount of housing stock in square metres available, with agents making individual decisions over a continuous spectrum around how many square metres they want to consume (or rent out).

We also assume that housing supply is exogenous, which likely holds well in the short run. This is equivalent to saying that the price elasticity of supply is equal to zero. There is evidence for this; the Barker Review (2004) commissioned by the UK government found that private house building had occurred at a much slower rate when compared to other European countries, despite increasing house prices. Furthermore, research has shown that average floor space per person rose negligibly in the UK from $34.8\,\text{m}^2$ per person in 1996 to $38.1\,\text{m}^2$ per person in 2018, suggesting there has been little increase in the housing stock on a per capita basis (GLA, 2021). Even in the longer run, the supply of housing (30.5 million dwellings) is relatively large compared to even ambitious house building programmes (such as the 1.5 million net additional homes hoped for by the current government, which would increase the size of the housing stock by less than 5%.

We further assume that owner-occupiers and landlords only save through their housing purchases. In the UK, net property wealth has come to become the largest source of household wealth (ONS, 2025a). We also assume that those who rent housing to live in are unable to become landlords themselves, as only 5% of renters in the UK have any property wealth (ONS, 2025a).

We initially assume that all owner-occupiers and landlords borrow at the maximum amount they can, constrained only by loan-to-value ratios of ϕ_o and ϕ_q, respectively.

We abstract away from any taxation on property purchase or any income source, including rental income.

Finally, as discussed briefly in the introduction, we do not consider SRS housing in our model, as this allows for a more parsimonious model construction. This is justified because a large proportion of the population is ineligible for social housing or on very long waiting lists. The SRS also has regulated rents, and occupants in the SRS typically remain in the same tenure for a long time. It is therefore not subject to the same market dynamics as the rest of the housing market, and can be considered to be sufficiently segmented from the rest of the housing market for the purposes of this paper.

5 Model

This section introduces the mathematical framework of the OLG model that is used to explore the dynamics of tenure distribution and prices.

Outlined below are the symbols and descriptions for all the parameters used in the model:

Symbol	Description
H_t^o	Housing demand owner-occupiers
H_t^l	Housing demand landlords (as owner-occupiers)
H_t^q	Housing supply landlords (to renters)
H_t^r	Housing demand renters
α	Surplus from owner-occupancy
γ	Surplus from housing investment (to rent out)
δ	Housing depreciation
ϕ_o	Loan to house value ratio (owner-occupancy)
ϕ_q	Loan to house value ratio (housing to rent out)
p_t	Price of purchasing housing
p_{t+1}	Expected next period house price
q_t	Aggregated price of renting housing
n	Population size
$\hat{H}$	Housing supply
r_1	Interest rate on government gilts
r_2	Interest rate on owner-occupier mortgages
r_3	Interest rate on buy-to-let mortgages
s_t	Renter savings when young

Table 1: *Model symbols and their meanings*

All agents have the following utility function, where $c_{1,t}$ $c_{2,t+1}$ represent composite consumption goods whilst young and old respectively and H_t^j represents housing goods:

$$U = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H_t^j)$$
$$where\ j \ \epsilon \ \{o, r, l\}$$

This utility function satisfies $\frac{dU}{dc_{1,t}}, \frac{dU}{dc_{2,t+1}}, \frac{dU}{dH_t^j} > 0$ and $\frac{d^2U}{dc_{1,t}^2}, \frac{d^2U}{dc_{2,t+1}^2}, \frac{d^2U}{dH_t^{j2}} < 0$ (i.e., non-satiety across all three goods alongside diminishing marginal utility).

5.1 Owner Occupiers

First, the owner-occupier problem will be considered. Owner-occupiers have the following utility function:

$$U = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H_t^o)$$

So the maximisation problem can be written as:

$$\max_{c_{1,t},\, c_{2,t+1},\, H_t^o} \{\log(c_{1,t}) + \beta \log(c_{2,t+1}) + \theta \log(H_t^o)\} \tag{1}$$

and they face the following budget constraints:

$$\underbrace{c^i_{1,t}}_{\substack{\text{Consumption}\\ \text{when young}}} = \underbrace{w_t}_{\text{Income}} + \underbrace{\alpha^i p_t H^{oi}_t}_{\substack{\text{Owner}\\ \text{surplus}}} - \underbrace{p_t H^{oi}_t}_{\substack{\text{Purchase}\\ \text{price}}} + \underbrace{l^{oi}_t}_{\text{Mortgage}} - \underbrace{\delta p_t H^{oi}_t}_{\text{Depreciation}} \tag{2}$$

$$\underbrace{c^i_{2,t+1}}_{\substack{\text{Consumption}\\ \text{when old}}} = \underbrace{p_{t+1} H^{oi}_t}_{\substack{\text{Return on}\\ \text{housing}}} - \underbrace{(1+r_2) l^{oi}_t}_{\substack{\text{Mortgage}\\ \text{repayment}}} \tag{3}$$

$$l^{oi}_t = \underbrace{\phi_o p_t H^{oi}_t}_{\substack{\text{Loan-to-value}\\ \text{ratio}}} \tag{4}$$

The superscript i denotes the variables that are specific to individuals (as there is heterogeneity within the population in the consumption over both periods and housing decisions). However, to simplify the notation, from this point on in the paper, the i terms are dropped; nonetheless, any equations will still represent individual-specific solutions. The above budget constraints can then be written as:

$$c_{1,t} = w_t + \alpha p_t H^o_t - p_t H^o_t + l^o_t - \delta p_t H^o_t \tag{5}$$

$$c_{2,t+1} = p_{t+1} H^o_t - (1+r_2) l^o_t \tag{6}$$

$$l^o_t = \phi_o p_t H^o_t \tag{7}$$

The Lagrangian can be written as:

$$\begin{aligned}\mathcal{L} = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H^o_t) \\ + \lambda[-c_{1,t} + w_t + (\alpha p_t - p_t + \phi_o p_t - \delta p_t) H^o_t] \\ + \mu[-c_{2,t+1} + (p_{t+1} - (1+r_2)\phi_o p_t) H^o_t]\end{aligned} \tag{8}$$

Take first order conditions:

$$\frac{1}{c_{1,t}} - \lambda = 0 \tag{9}$$

$$\frac{\beta}{c_{2,t+1}} - \mu = 0 \tag{10}$$

$$\frac{\theta}{H^o_t} + \lambda[\alpha p_t - p_t + \phi_o p_t - \delta p_t] + \mu[p_{t+1} - (1+r_2)\phi_o p_t] = 0 \tag{11}$$

We can then arrive at the optimal conditions:

$$\boxed{c^*_{1,t} = \frac{w_t}{1+\theta+\beta}} \tag{12}$$

$$\boxed{c^*_{2,t+1} = \frac{(\theta+\beta)w_t}{1+\theta+\beta}\left(\frac{p_{t+1}-(1+r_2)\phi_o p_t}{(1-\phi_o)p_t - \alpha p_t + \delta p_t}\right)} \tag{13}$$

$$\boxed{H^{o*}_t = \frac{(\theta+\beta)w_t}{(1+\theta+\beta)[(1-\phi_o)p_t - \alpha p_t + \delta p_t]}} \tag{14}$$

5.2 Landlords

The second type of agent are landlords, who purchase housing to live in as owner-occupiers but also purchase further housing to rent out to renters.
They have the following utility function where H^l_t is the housing they purchase to live in themselves.

$$U = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H^l_t) \tag{15}$$

So the maximisation problem can be written as:

$$\max_{c_{1,t},\, c_{2,t+1},\, H^l_t,\, H^q_t} \left\{\log(c_{1,t}) + \beta\log(c_{2,t+1}) + \theta\log(H^l_t)\right\} \tag{16}$$

These are the budget constraints over both periods:

$$\begin{aligned} c_{1,t} = \underbrace{w_t}_{\text{Income}} + \underbrace{\alpha p_t H^l_t}_{\text{Owner surplus}} - \underbrace{p_t H^l_t}_{\text{Purchase Price}} + \underbrace{\gamma q_t H^q_t}_{\text{Landlord surplus}} + \\ \underbrace{l^l_t}_{\substack{\text{Owner-occupier}\\ \text{mortgage}}} + \underbrace{l^q_t}_{\substack{\text{Buy-to-let}\\ \text{mortgage}}} - \underbrace{p_t H^q_t}_{\text{Purchase Price}} - \underbrace{\delta p_t H^l_t}_{\text{Depreciation}} - \underbrace{\delta p_t H^q_t}_{\text{Depreciaton}} \end{aligned} \tag{17}$$

$$c_{2,t+1} = \underbrace{p_{t+1}H^l_t}_{\substack{\text{Income from}\\ \text{selling house}}} - (1+r_2)l^l_t - (1+r_3)l^q_t + p_{t+1}H^q_t + \underbrace{q_t H^q_t}_{\text{Rental income}} \tag{18}$$

Where mortgages received when young are constrained by the following loan-to-house value ratios:

$$l^l_t = \phi_o p_t H^l_t \tag{19}$$

$$l^q_t = \phi_q p_t H^q_t \tag{20}$$

and

$$H_t^q \geq 0 \tag{21}$$

Here, q_t is the aggregated rental price over an agent's lifetime. As w_t also represents aggregated income over an agent's lifetime, q_t can straightforwardly be interpreted as the proportion of an agent's income spent on renting housing services. The other terms are equivalent to those used in the owner-occupier case.
The $c_{1,t}$, $c_{2,t+1}$, and H_t^l will by definition be positive as the utility function is defined through a linear combination of the log of these terms. The H_t^q term does not appear in the utility function, so this constraint needs to be stated explicitly.

Substituting the constraints on the loan value into equations 17 and 18 gives the following:

$$c_{1,t} = w_t + (\alpha p_t - p_t + \phi_o p_t - \delta p_t)H_t^l + (\gamma q_t - p_t + \phi_q p_t - \delta p_t)H_t^q \tag{22}$$

$$c_{2,t+1} = (p_{t+1} - (1 + r_2)\phi_o p_t)H_t^l + (p_{t+1} - (1 + r_3)\phi_q p_t + q_t)H_t^q \tag{23}$$

We can define a new set of constants as follows to simplify the above budget constraints:

$$A_l = \alpha p_t + (\phi_o - 1)p_t - \delta p_t \tag{24}$$

$$A_q = \gamma q_t + (\phi_q - 1)p_t - \delta p_t \tag{25}$$

$$B_l = p_{t+1} - (1 + r_2)\phi_o p_t \tag{26}$$

$$B_q = p_{t+1} - (1 + r_3)\phi_q p_t + q_t \tag{27}$$

$$D = A_l - \frac{A_q B_l}{B_q} \tag{28}$$

We consider the case where the $H_t^q \geq 0$ constraint is non-binding, i.e., $H_t^q > 0$. When $H_t^q = 0$, the problem collapses to the owner-occupiers' maximisation problem, which was solved in the previous section. This gives the following Lagrangian:

$$\mathcal{L} = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H_t^l) \tag{29}$$
$$+\lambda[-c_{1,t} + w_t + A_l H_t^l + A_q H_t^q] \tag{30}$$
$$+\mu[-c_{2,t+1} + B_l H_t^l + B_q H_t^q] \tag{31}$$

Solve for $c_{1,t}, c_{2,t+1}, H_t^l, H_t^q$ by taking first order conditions:

$$\frac{\partial \mathcal{L}}{\partial c_{1,t}} = \frac{1}{c_{1,t}} - \lambda = 0 \tag{32}$$

$$\frac{\partial \mathcal{L}}{\partial c_{2,t+1}} = \frac{\beta}{c_{2,t+1}} - \mu = 0 \tag{33}$$

$$\frac{\partial \mathcal{L}}{\partial H_t^l} = \frac{\theta}{H_t^l} + \lambda A_l + \mu B_l = 0 \tag{34}$$

$$\frac{\partial \mathcal{L}}{\partial H_t^q} = \lambda A_q + \mu B_q = 0 \tag{35}$$

And the budget constraints are:

$$c_{1,t} = w_t + A_l H_t^l + A_q H_t^q \tag{36}$$

$$c_{2,t+1} = B_l H_t^l + B_q H_t^q \tag{37}$$

From the first two derivatives of the Lagrangian:

$$\frac{1}{c_{1,t}} - \lambda = 0 \quad \Rightarrow \quad c_{1,t} = \frac{1}{\lambda} \tag{38}$$

$$\frac{\beta}{c_{2,t+1}} - \mu = 0 \quad \Rightarrow \quad c_{2,t+1} = \frac{\beta}{\mu} \tag{39}$$

Substitute the expressions for λ and μ into equation 35:

$$\frac{A_q}{c_{1,t}} + \frac{\beta B_q}{c_{2,t+1}} = 0 \Rightarrow \frac{c_{2,t+1}}{c_{1,t}} = \frac{-\beta B_q}{A_q} \tag{40}$$

From 34:

$$\frac{\theta}{H_t^l} + \frac{A_l}{c_{1,t}} + \frac{\beta}{c_{2,t+1}} B_l = 0 \tag{41}$$

From 41, using the ratios of consumption over both periods (equation 40):

$$\frac{\theta}{H_t^l} + \frac{A_l}{c_{1,t}} + \beta B_l \left(\frac{-A_q}{\beta B_q c_{1,t}} \right) = 0 \tag{42}$$

$$c_{1,t} = \frac{-H_t^l D}{\theta} \tag{43}$$

From 37 using 40:

$$\frac{-\beta B_q}{A_q} c_{1,t} = B_l H_t^l + B_q H_t^q \tag{44}$$

Using 43:

$$\frac{-\beta B_q}{A_q}\frac{-H_t^l D}{\theta} = B_l H_t^l + B_q H_t^q \tag{45}$$

$$H_t^q = \left[\frac{-B_l}{B_q} + \frac{\beta D}{A_q\theta}\right] H_t^l \tag{46}$$

From 36 using 43 and 46:

$$\frac{-H_t^l D}{\theta} = w_t + H_t^l A_l + A_q\left[\frac{-B_l}{B_q} + \frac{\beta D}{A_q\theta}\right] H_t^l \tag{47}$$

$$\boxed{H_t^{l*} = \frac{-\theta w_t}{D(1+\beta+\theta)}} \tag{48}$$

From 43 sub in 48:

$$\boxed{c_{1,t}^* = \frac{w_t}{1+\beta+\theta}} \tag{49}$$

From 40 using 49:

$$\boxed{c_{2,t+1}^* = \frac{-B_q\beta w_t}{A_q(1+\beta+\theta)}} \tag{50}$$

From 46 using 48:

$$\boxed{H_t^{q*} = \left[\frac{B_l}{B_q D} - \frac{\beta}{A_q\theta}\right]\left[\frac{\theta w_t}{(1+\beta+\theta)}\right]} \tag{51}$$

For the constraint on housing purchased to rent out to be non-binding, certain conditions must hold. From equation 50 we can see that B_q and A_q must be of opposite signs to ensure that $c_{2,t+1} > 0$, and from equation 48 we can see that D must be negative to ensure that $H_t^l > 0$. Additionally, the first bracketed term in the expression above for H_t^{q*} must be greater than zero.
If none of these conditions hold, the agent will not choose to purchase housing to rent out. Instead, they will either only purchase housing to live in or opt not to buy housing and instead live in rented housing.

5.3 Renters

Renters do not purchase housing, but rather rent housing services from landlords.
They have the following utility function:

$$U = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H_t^r) \tag{52}$$

So the maximisation problem can be written as:

$$\max_{c_{1,t},\, c_{2,t+1},\, H_t^r} \{\log(c_{1,t}) + \beta \log(c_{2,t+1}) + \theta \log(H_t^r)\} \tag{53}$$

We assume that renters purchase gilts in lieu of housing as an investment which provides a return with interest rate r_1 when old. They also face a rental cost of q_t. This leads to the following budget constraints:

$$c_{1,t} = w_t - q_t H_t^r - s_t \tag{54}$$

$$c_{2,t+1} = (1 + r_1)s_t \tag{55}$$

$$s_t \geq 0 \tag{56}$$

This gives the following Lagrangian:

$$\begin{aligned}\mathcal{L} = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H_t^r) \\ + \lambda[-c_{1,t} + w_t - q_t H_t^r - s_t] \\ + \mu[-c_{2,t+1} + (1 + r_1)s_t]\end{aligned} \tag{57}$$

To solve for optimal $c_{1,t}, c_{2,t+1}, H_t^r, s_t$ take first order conditions:

$$\frac{1}{c_{1,t}} - \lambda = 0 \tag{58}$$

$$\frac{\beta}{c_{2,t+1}} - \mu = 0 \tag{59}$$

$$\frac{\theta}{H_t^r} - \lambda q_t = 0 \tag{60}$$

$$-\lambda + \mu(1 + r_1) = 0 \tag{61}$$

We then arrive at the following solution:

$$\boxed{c_{1,t}^* = \frac{w_t}{1 + \beta + \theta}} \tag{62}$$

$$\boxed{c_{2,t+1}^* = \frac{\beta(1 + r_1)w_t}{1 + \beta + \theta}} \tag{63}$$

$$\boxed{s_t^* = \frac{\beta w_t}{1 + \beta + \theta}} \tag{64}$$

$$\boxed{H_t^{r*} = \frac{\theta w_t}{q_t(1 + \beta + \theta)}} \tag{65}$$

5.4 Equilibrium Conditions

To solve for the price of housing p_t and the rental price q_t, we solve numerically the two equilibrium conditions; the demand across all agents for housing to live in must equal the total supply of housing, and the demand across all agents for rented housing must equal the supply of rented housing by landlords. The supply of housing is assumed to be exogenous.
Denoting the aggregate demand from owner-occupiers, landlords (for living in themselves), renters, and landlord supply as D_o, D_l, D_r, S_q respectively, we can write the equilibrium condition as follows:

$$D_o + D_l + D_r = \hat{H} \tag{66}$$

$$D_r = S_q \tag{67}$$

Labelling the population of owner-occupiers, landlords, and renters as P_o, P_l, P_r respectively, we also have the condition:

$$P_o + P_l + P_r = n \tag{68}$$

There exist threshold γ and α pairwise combinations at which agents may be indifferent between any two of the three possible states at a given house price and rental price (e.g., there exists an α value at which an agent would be indifferent between renting and being an owner-occupier). However, there exists no closed-form solution for either of the other two boundaries that the landlord makes with owner-occupiers or renters. As the landlord utility is a function of both γ and α, the threshold between either the landlord or renter state would now be a curve in the (α, γ) space, rather than a single point.
Therefore, to get the demand for housing each agent we integrate the demand function for each agent type over the domain of the α and γ distributions, using an indicator function which only equals one when the utilty of the respective agent is greater than the utility of either of the two agents at a given price level, and zero otherwise. This leads to the following expressions for housing demand across each of the groups:

$$D_l(p_t, q_t) = \int_{\alpha_{min}}^{\alpha_{max}} \int_{\gamma_{min}}^{\gamma_{max}} nH_t^l \cdot \underbrace{\mathbf{1}\left(U_l > U_o \,\&\, U_l > U_r\right)}_{\text{Indicator Function}} \; \underbrace{f_\gamma(\gamma) f_\alpha(\alpha)}_{\substack{\text{Distribution of} \\ \alpha \text{ and } \gamma}} \; d\alpha d\gamma \tag{69}$$

$$D_o(p_t, q_t) = \int_{\alpha_{min}}^{\alpha_{max}} \int_{\gamma_{min}}^{\gamma_{max}} nH_t^o \cdot \mathbf{1}\left\{U_o > U_l \,\&\, U_o > U_r\right\} f_\gamma(\gamma) f_\alpha(\alpha) d\alpha d\gamma \tag{70}$$

$$D_r(p_t, q_t) = \int_{\alpha_{min}}^{\alpha_{max}} \int_{\gamma_{min}}^{\gamma_{max}} nH_t^r \cdot \mathbf{1}\left\{U_r > U_o \,\&\, U_r > U_l\right\} f_\gamma(\gamma) f_\alpha(\alpha) d\alpha d\gamma \tag{71}$$

$$S_q(p_t, q_t) = \int_{\alpha_{min}}^{\alpha_{max}} \int_{\gamma_{min}}^{\gamma_{max}} nH_t^q \cdot \mathbf{1}\left\{U_l > U_r \;\&\; U_l > U_o\right\} f_\gamma(\gamma) f_\alpha(\alpha) d\alpha d\gamma \quad (72)$$

By substituting these conditions into the equilibrium conditions (68 and 67) defined above, we can solve numerically for the optimal house price level, rental price, and tenure distributions. This approach means we are solving the model statically, rather than dynamically. Whilst agents are forward-looking, this approach will give us an idea of a snapshot equilibrium (for prices and tenure distributions) at a point in time, but will not show how a trajectory of how prices or tenures shift over time. It will, however, allow for comparative statics of endogenous variables' long-run response to changes in any exogenous parameters.

We can also calculate the population living in each tenure type by the following, which are equivalent to the above integrals with the housing demand removed:

$$P_o(p_t, q_t) = \int_{\alpha_{min}}^{\alpha_{max}} \int_{\gamma_{min}}^{\gamma_{max}} n \cdot \mathbf{1}\left\{U_o > U_l \;\&\; U_o > U_r\right\} f_\gamma(\gamma) f_\alpha(\alpha) d\alpha d\gamma \quad (73)$$

$$P_r(p_t, q_t) = \int_{\alpha_{min}}^{\alpha_{max}} \int_{\gamma_{min}}^{\gamma_{max}} n \cdot \mathbf{1}\left\{U_r > U_o \;\&\; U_r > U_l\right\} f_\gamma(\gamma) f_\alpha(\alpha) d\alpha d\gamma \quad (74)$$

$$P_l(p_t, q_t) = \int_{\alpha_{min}}^{\alpha_{max}} \int_{\gamma_{min}}^{\gamma_{max}} n \cdot \mathbf{1}\left\{U_l > U_r \;\&\; U_l > U_o\right\} f_\gamma(\gamma) f_\alpha(\alpha) d\alpha d\gamma \quad (75)$$

It is therefore essential to distinguish between the *tenure demand* and the *tenure population* across the different tenures. As prices vary, agents vary in how much housing they choose to consume. For example, a scenario could arise where owner-occupiers only make up 10% of the population but consume 20% of the housing in the economy; or a scenario may arise where owner-occupiers are 10% of the population but consume only 1% of the housing.

5.5 Model Calibration

As the two-generation OLG model represents a typical human lifespan, we assume the time gap between being 'young' and being 'old' to be thirty years. This reflects the fact that most people enter the workforce and make decisions around home ownership in their mid to late twenties, and exit the workforce approximately thirty years later. Therefore, any parameters, such as interest rates, that are typically set at annual rates, need to be uprated to reflect the aggregate effect over 30 years.

A set of parameters values are chosen to mirror housing market conditions in the UK over the past 30-40 years. We then consider the effect of changing specific parameters (e.g., the impact of an increase in interest rates).

$\boldsymbol{r_1}$**:** The real interest rate on a 'risk-free' asset, assumed to be a UK government bond. This is set at an annual value of 2%. This is based on cross-comparison of different sources of information to estimate the average real interest rate of long-term UK government gilts over the past 50 years (Bleaney, 2025).
$\boldsymbol{r_2}$**:** The real interest rate on owner-occupier mortgages. This is greater than the interest rate on government bonds, to reflect the fact that mortgage holders face some likelihood of default, unlike gilts. Commercial banks price this into the interest rates they offer for mortgages. A cross-comparison of different sources over the last 50 years suggests an average annual real interest rate of 2.5%, which equates to a wedge between mortgages and long-term gilts of approximately 0.5% (Bank of England, 2025).
$\boldsymbol{r_3}$**:** The real interest rate on buy-to-let (BTL) mortgages. Mortgage costs are typically higher for BTL properties. This is because lenders perceive BTL as riskier than owner-occupier mortgages, as the rental income stream is not guaranteed if tenants default on their rental payments or the property is left vacant. The real annual interest rate on BTL mortgages is set at 3.5%.
$\boldsymbol{\theta}$**:** The utility weight on housing is set at 0.2, as in Davis and Ortalo-Magné (2011).
$\boldsymbol{\beta}$**:** The utility weight on the second period of consumption is set to an annualised rate of 0.97, and aggregated over thirty years.
$\boldsymbol{p_{t+1}}$**:** The expected next period house price. This is set at twice the current period house price, to reflect the fact that house prices have increased significantly in the past, and we are modelling a scenario in which we assume the population has extrapolative expectations; in other words, that they expect future house prices to increase at a similar rate to in the past.
$\boldsymbol{\phi_o}$**:** This is set to match the mean mortgage-to-house value ratios for first-time buyers. This gives a value of 73% based on the latest Nationwide yearly report (Nationwide, 2025).
$\boldsymbol{\phi_q}$**:** This is set to match the mean mortgage-to-house value ratio for buy-to-let landlords. This gives a value of 63%.
$\boldsymbol{\delta}$**:** The depreciation rate of housing. An annual value of 1% of the house value is used, in line with extensive academic research (Wilhelmsson, 2008)
$\boldsymbol{w_t}$ **:** This is normalised to a value of one.
$\boldsymbol{\hat{H}}$**:** This is normalised to a value of one.
n: This is normalised to a value of one. By setting n and $\hat{H}$ to one, the price of purchasing housing and renting housing can straightforwardly be interpreted as a proportion of agents' income spent on housing.
$\boldsymbol{f_\alpha(\alpha), f_\gamma(\gamma)}$**:** The distribution of owner-occupancy surplus flow and the distribution of landlord surplus flow. We assume these are uniformly distributed. We calibrate the distributions such that solving the equilibrium conditions 68 and 67 results in a tenure distribution that is approximately equal to the latest EHS, where the ratio of renters to owner-occupiers is approximately $1:3$. This gives distributions of $f_\alpha \sim Uniform(-0.18, 0.14)$ and $f_\gamma \sim Uniform(-0.65, 0.15)$. f_α and f_γ we assume are entirely independent such that $corr(\alpha, \gamma) = 0$.

6 Results

We run a series of experiments to explore the impact of variations in the interest rates and loan-to-value ratios on tenure distributions, house prices, and rental prices. We solve the equilibrium condition as described in 68 and 67 to find the equilibrium prices and tenures.

To find the equilibrium prices, we used an iterative grid search algorithm that initially searches over a wide range of p_t and q_t values with coarse spacing, and iteratively narrows the search range by identifying the points that minimise a distance metric. More efficient numerical solvers, such as the Newton-Raphson method, which requires continuously differentiable functions, were not appropriate because demand discontinuities exist across the α, γ space as agents switch between the three tenure types. We calculated the demand and supply integrals using the adaptIntegrate package in R, which uses a cubature rule to approximate the integral and the associated error. In addition to this, we also calculated the integrals using a Monte-Carlo algorithm to check the outputs from the adaptIntegrate algorithm. Due to the computational expense of solving the equilibrium conditions, the experiments are run over a relatively coarse grid for both the interest rate and loan-to-value ratios; this means it may look as though there are sharp discontinuities in some of the results.

Firstly, we consider the impact of varying the real interest rate on government gilts. We assume that any increases or decreases in the gilt yield are passed through proportionally onto mortgages for owner-occupiers and buy-to-let mortgages. Whilst varying the interest rate, we keep all other variables constant at the values outlined in the previous section.

As can be seen in Figure 5, increasing the interest rate on gilts from 1% to over 2% leads to a significant decrease in the housing price, from approximately 60% of lifetime income to just over 20% of lifetime income. This is because increasing the interest rate leads to an increase in the cost of servicing mortgage debt. Meanwhile, the rental price increases up to a gilt yield of approximately 1.75% and then starts to decrease. The price increase is caused by more agents choosing to be renters as mortgage debt costs increase, whilst the return on government gilts increases. However, after a certain point, the rental price decreases as the decreasing price of purchasing housing dominates the increasing demand from renters. Overall, the price of housing and the price of renting also converge, which is equivalent to a decreasing rental yield. At the highest interest rate we consider, the rental price and house price are almost the same.

The tenure distributions show that, everything else being equal, at the lowest interest rate, all agents choose to be owner-occupiers. As the interest rate increases, owner-occupancy rates decrease, and more agents choose to be landlords and renters. The overall owner-occupancy rate (one minus renter population) decreases from 100% to approximately 40% at the highest interest rate. It can also be seen that the renter population curve increases at a faster rate than the renter demand curve, showing that although renters make up a large portion of the population at high gilt rates, they consume relatively little housing per agent. Meanwhile, landlords make up less than 40% of the population at the highest interest rate but use (as owner-occupiers) more than 55% of the housing stock.

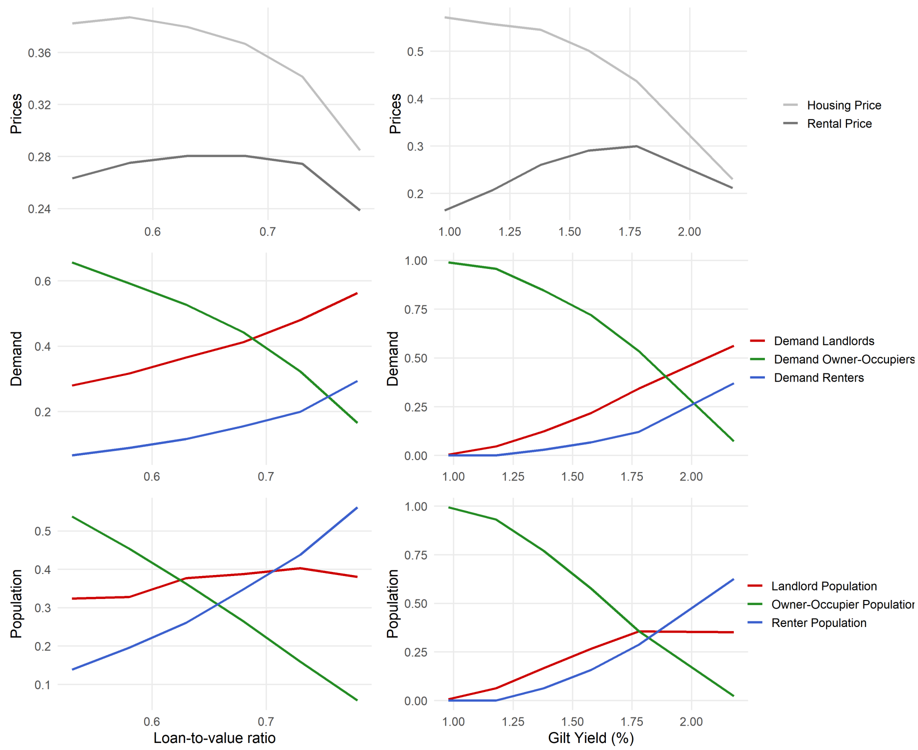

Figure 5: *The effect of (a) varying mortgage loan-to-value ratios on equilibrium housing and rental prices, demand across agent type, and population across agent types and (b) varying interest rates on equilibrium housing and rental prices, demand across agent types, and population across agent type. The landlord demand refers to the landlord's demand for housing to live in. By definition, at equilibrium, landlord supply equals the renter demand. Prices are relative to lifetime earnings.*

We also conduct experiments to investigate the effect of changing the mortgage-to-value ratio. We consider the impact of simultaneously changing the owner-occupancy and buy-to-let mortgage rate by ±10% from the average values of 73% and 63% we chose in the previous section. This might occur in a scenario where financial regulations around mortgages are either tightened or eased.

In Figure 5, we can see that increasing ϕ_o and ϕ_q initially leads to a slight increase in house prices, but then quickly results in a decrease in house prices. Meanwhile, rental prices increase marginally over initially, but then also decrease at high ϕ_o and ϕ_q values. The decrease in house prices at larger ϕ values is explained by the modelling framework, whereby all agents with mortgages have to borrow at the loan-to-mortgage ratio defined at a set value. As this ratio increases, the second-period budget constraint becomes less and less viable as second-period repayment costs with high mortgage to house price ratios may exceed the return from any price appreciation. To address this, in the next section, a model with the equality constraint for the loan-to-value ratio is relaxed, and instead, owner-occupiers can borrow any amount up to the equality constraint.

7 Alternative Model Specification

The model presented places a constraint by demanding that owner-occupiers and landlords always take the maximum possible mortgage as described by condition (7). To modify the model, we can relax these assumptions by changing it to the following for owner-occupiers:

$$l_t^o \leq \phi_o p_t H_t^o \tag{76}$$

Solving this, assuming the constraint (76) doesn't bind, such that $l_t^o < \phi_o p_t H_t^o$ (if the constraint binds, we arrive at the result previously derived), leads to the following optimal conditions[2] for owner-occupiers:

$$\boxed{c_{1,t}^* = \frac{w_t}{1+\beta+\theta}} \tag{77}$$

$$\boxed{c_{2,t+1}^* = \frac{\beta(1+r_2)w_t}{1+\beta+\theta}} \tag{78}$$

$$\boxed{H_t^{o*} = \frac{\theta w_t}{(1+\beta+\theta)\left((1+\delta-\alpha)p_t - \frac{p_{t+1}}{1+r_2}\right)}} \tag{79}$$

$$\boxed{l_t^{o*} = \frac{w_t}{(1+\beta+\theta)}\left[\frac{\frac{\theta p_{t+1}}{1+r_2}}{\left((1+\delta-\alpha)p_t - \frac{p_{t+1}}{1+r_2}\right)} - \beta\right]} \tag{80}$$

It should be noted that the equality constraint has been retained for the landlords to prevent the possibility of arbitrage (landlord using a lower interest rate owner-occupancy mortgage to purchase rental housing).

7.1 Alternative Model Specification Results

We run the same experiments as for the original model specification, considering the impact of a varying interest rate and separately the effect of varying the mortgage loan-to-value ratio.
As can be seen in Figure 6, the effect of an increasing interest rate, similarly to the original model, is to decrease the price of housing monotonically. The same

[2]Full derivation can be found in Appendix A.

explanation as before holds; as the interest rate increases, the cost of servicing mortgages and the opportunity cost of purchasing a house also increase, due to the higher returns from safe assets like government bonds. There is a minimal effect on the price of rental housing as the interest rate varies; in fact, the fluctuation seen is likely within the error bounds of the numerical solver, and it can therefore be assumed that the rental price is actually approximately constant in this model. This can be explained by the fact that rental prices should reflect the actual user value of housing. Whilst house prices have a component that will be influenced by expected future returns, equation (65) shows us that demand for housing by renters is not directly affected by expected future house prices. Therefore, in this model, where agents are less constrained than in the previous model, the rental price should revert to the utility weighting factor assigned to housing of 0.2. As can be seen in the top left chart of 6, the rental cost is approximately equal to 0.2 (which can be interpreted as 20% of lifetime earnings). The decreasing rental yield with higher interest rates mirrors what has been seen in the UK over the last 30-40 years, as shown in Figure 3.

At low interest rates, the equilibrium tenure distribution of this model results in everyone being an owner-occupier. However, as the interest rate increases, the demand for owner-occupancy decreases, and the demand from landlords and renters increases (middle chart on the right in Figure 6). It can also be seen that the population of renters increases at a faster rate than the population of landlords, meaning that as the interest rate increases, the average landlord is supplying more rental property (i.e., the average landlord is making a larger investment in rental properties).

Increasing the maximum loan-to-value ratio decreases the house price, whilst the rental price remains constant (top left chart in Figure 6). This is again explained by the fact that whilst owner-occupiers do not have a strict equality constraint for their mortgages (see equation (76)), the landlords are still constrained in this way. The landlord demand function for housing to live in decreases with increased ϕ_o and ϕ_q, whilst the landlord supply of rented housing increased with ϕ_o and ϕ_q (see equations (48) and (51)). However, to relax the loan-to-value equality constraint would require additional model complexity (such as a maximum loan-to-wage ratio), as otherwise the optimisation problem would be underconstrained. This is beyond the scope of this paper.

Meanwhile, as the maximum loan-to-value ratio increases, the demand from owner-occupiers initially decreases, and then increases again marginally. Landlord demand is approximately constant before reducing, and renter demand increases monotonically. However, the renter population again increases at a higher rate, and the landlord population decreases, showing that at a high loan-to-value ratio, there are relatively few landlords supplying a moderate amount of housing to many renters (who are consuming relatively little housing on a per capita basis).

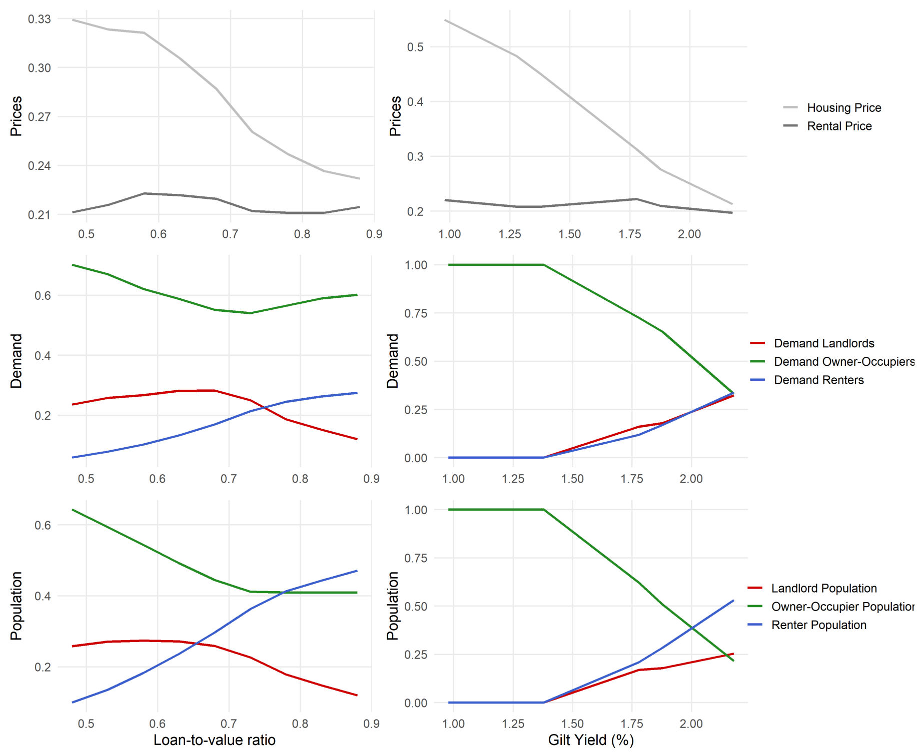

Figure 6: *The effect of (a) varying mortgage loan-to-value ratios on equilibrium housing and rental prices, demand across agent type, and population across agent types and (b) varying interest rates on equilibrium housing and rental prices, demand across agent types, and population across agent type. The landlord demand refers to the landlord demand for housing to live in. By definition, at equilibrium, landlord supply equals the renter demand. Prices are relative to lifetime earnings.*

8 Conclusion

Both models have shown how key parameters may influence house prices, rental prices, and tenure distributions. Similar to previous research, we have found that interest rates can have a profound effect on house prices and a modest impact on rental prices. Increasing interest rates increase the cost of servicing mortgage debt and also increase the opportunity cost of a down payment for a mortgage (as saving becomes relatively more lucrative compared to borrowing). This means that at lower interest rates, rental yields are lower, which mirrors what has been observed in the UK over the last 30 years, where interest rates have declined and house prices have risen at a faster rate than rents. This suggests that, given the recent interest rate increases, house prices may decrease, or increase (due to other factors such as supply constraints) at a lower rate compared to a counterfactual in which interest rates were still very low. The model suggests that rental prices are relatively insensitive to interest rates. The models also show that at higher interest rates, the number of renters and landlords increases. This is because relatively few landlords (with high surplus $\gamma q_t H_t^q$) can afford to purchase housing at higher interest rates, and many would-be owner-occupiers are crowded out.

The models suggest that increasing the availability of mortgage credit may actually decrease house prices. This is against conventional wisdom and is likely an artefact of the modelling approach. Nonetheless, some model predictions align closely with what has been observed in the UK. As loan-to-value ratios of both owner-occupier and buy-to-let mortgages increase, landlords are more able to leverage the increased credit availability compared to owner-occupiers to purchase extensive rental housing. In particular, a decreasing number of landlords supply an increasing number of rental properties, suggesting an increase in wealth inequality where a relatively small group own a relatively large proportion of the total housing stock. This mirrors what has occurred in the UK, where regulatory reform and the introduction of buy-to-let mortgages over the last 30-40 years have increased the proportion of people living in the PRS.

These findings are of relevance to the DWP and wider government. DWP has an interest in long-term rent forecasts, particularly as many households in receipt of housing support already face significant shortfalls between their rents and the amount of housing support they receive. The findings suggest that interest rates might not be particularly affected by increasing interest rates, even if landlords' mortgage repayment costs increase. The findings also indicate that mortgage credit liberalisation could exacerbate housing wealth inequality by increasing the demand from landlords to purchase housing as an investment. These findings suggest that these macroeconomic variables are important factors that both DWP and the wider government should carefully model and track to inform housing-related policymaking.

There are, however, many areas for further improvement in this work. Firstly, the impact of changing other exogenous variables, such as the predicted next period house price or the housing supply, could be studied. Alongside this, a more systematic sensitivity analysis which examines the effects of varying input parameters on the model outputs should be explored.

To explore distributional effects, which are often the questions of greatest relevance to DWP, the lifetime earnings variable could take a distributional form, or equivalently, a distribution of initial endowments could be provided to the young population in the OLG model. To model housing support expenditure, a proportion of lower-income households could have part of their housing expenditure, if renting, paid for by housing support. The challenge with adding more heterogeneity to the model is that each added variable adds significant computational expense to solving the equilibrium conditions, so additional heterogeneity should only be added where a strong justification exists.

A further set of exogenous parameters could be introduced, and the effects of varying them could be studied without adding significant computational expense to the model. Firstly, taxation could be added by including a tax on labour income and rental income; it could also be used to explore the impacts of a tax on imputed rent for owner-occupiers (which doesn't currently exist in the UK). Some transaction costs for purchasing houses, to reflect the Stamp Duty Land Tax, could be incorporated.

Further realism could be included by adding more periods to the OLG model, so that agents go through more than two stages of life. This would allow for the possibility of people initially renting and then becoming owner-occupiers at a later age, which is a more realistic model than only ever being in one tenure. In such a setup, including some trading frictions, so that moving house isn't costless, could also be incorporated. This would also allow for the possibility of introducing varying interest rates over agents' lifetimes, which more closely reflects UK mortgages.

Finally, solving the model dynamically, and incorporating initial housing endowments in some population of the young would represent a significant jump in model complexity but would allow for true forecasting of future house prices, rental prices and tenure distributions. In this way, the impacts of an economic shock (e.g., a sudden jump in interest rates) could be modelled, alongside other factors such as population changes, changes in housing supply, changes in household composition, and changes in DWP housing support. This would allow for smooth and gradual transitions between tenures by different agents, representing a richer picture of the housing market compared to the static equilibrium cases we have considered.

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9 Appendix A: Alternative Model Derivation

9.1 Owner Occupiers

Owner-occupiers have the following utility function:

$$U = log(c_{1,t}) + \beta log(c_{2,t+1}) + \theta log(H_t^o)$$

So the maximisation problem can be written as:

$$\max_{c_{1,t},\, c_{2,t+1},\, H_t^o} \{\log(c_{1,t}) + \beta \log(c_{2,t+1}) + \theta \log(H_t^o)\} \tag{81}$$

and face the following budget constraints:

$$c_{1,t} = w_t + \alpha p_t H_t^o - p_t H_t^o + l_t^o - \delta p_t H_t^o \tag{82}$$

$$c_{2,t+1} = p_{t+1} H_t^o - (1 + r_2) l_t^o \tag{83}$$

$$l_t^o \leq \phi_o p_t H_t^o \tag{84}$$

Solve for $c_{1,t}, c_{2,t+1}, H_t^o, l_t^o$.
Define:

$$A \equiv c_{1,t} = w_t + (\alpha p_t - p_t - \delta p_t) H_t^o + l_t^o \tag{85}$$

and

$$B \equiv c_{2,t+1} = p_{t+1} H_t^o - (1 + r_2) l_t^o \tag{86}$$

Then:

$$U = log(A) + \beta log(B) + \theta log(H_t^o)$$

$$\frac{\partial U}{\partial l_t^o} = \frac{1}{A} - \beta \frac{1 + r_2}{B} = 0 \quad \Rightarrow \quad B = \beta(1 + r_2)A \tag{87}$$

$$\frac{\partial U}{\partial H_t^o} = \frac{(\alpha - 1 - \delta)p_t}{A} + \beta \frac{p_{t+1}}{B} + \frac{\theta}{H_t^o} = 0 \tag{88}$$

Use $B = \beta(1 + r_2)A$ to eliminate B:

$$\frac{(\alpha - 1 - \delta)p_t}{A} + \frac{p_{t+1}}{(1 + r_2)A} + \frac{\theta}{H_t^o} = 0 \tag{89}$$

let

$$D = (\alpha - 1 - \delta)p_t + \frac{p_{t+1}}{(1 + r_2)} \tag{90}$$

then:

$$\frac{\theta}{H_t^o} = -\frac{D}{A} \tag{91}$$

$$A = -\frac{D}{\theta} H_t^o \tag{92}$$

Now insert $B = \beta(1 + r_2)A$ into the two budget constraints:

$$A = w_t + \alpha p_t H_t^o - p_t H_t^o + l_t^o - \delta p_t H_t^o \tag{93}$$

$$\beta(1 + r_2)A = p_{t+1} H_t^o - (1 + r_2) l_t^o \tag{94}$$

Then we get:

$$H_t^{o*} = \frac{\theta w_t}{(1 + \beta + \theta)(-D)} \tag{95}$$

And the following final expressions:

$$\boxed{c_{1,t}^{*} = \frac{w_t}{1+\beta+\theta}} \tag{96}$$

$$\boxed{c_{2,t+1}^{*} = \frac{\beta(1+r_2)w_t}{1+\beta+\theta}} \tag{97}$$

$$\boxed{H_t^{o*} = \frac{\theta w_t}{(1+\beta+\theta)\left((1+\delta-\alpha)p_t - \frac{p_{t+1}}{1+r_2}\right)}} \tag{98}$$

$$\boxed{l_t^{o*} = \frac{w_t}{(1+\beta+\theta)}\left[\frac{\frac{\theta p_{t+1}}{1+r_2}}{\left((1+\delta-\alpha)p_t - \frac{p_{t+1}}{1+r_2}\right)} - \beta\right]} \tag{99}$$

If $l_t^o \leq \phi_o p_t H_t^o$ is not satisfied we revert to the binding constraint solution derived in the main section.

10 Appendix B: Mapping of KSBs

In this section the relevant KSBs have been mapped to the corresponding section of the paper.

10.1 Applied Economic Analysis

- **Apply economic knowledge to inform a range of business and/or policy decisions.** As can be seen in the section describing the model, I developed a model using economic knowledge to help the DWP and wider government understand better the drivers of house prices and tenure distributions.

- **Assess and argue what an appropriate method and data source(s) are, and identify any limitations in the policy/business situation.** In the methodology section I outline why an OLG model is used (for analytical tractability). In the model calibration section I also justify the data sources I have used.

- **Give a clear explanation of the assumptions made in the analysis and argue effectively why these are appropriate.** In the methodology section, I clearly outline the key model assumptions and why they are considered appropriate.

- **Choose a presentation style and data visualisation tools that effectively describe the analysis and draw out recommendations for policy/business decisions.** In the introduction I use data visualisation to help describe the motivations for the project by showing how much house prices have increased in the UK. In the results section, I use data visualisation and group the charts for the different models to clearly separate them and use the charts as a visual aid to outline key recommendations for DWP.

- **Identify data relevant to the issue and the limitations of that data when judging validity and usefulness.** In the section where I calibrate the model, I clearly cite the data sources I've used. In the conclusion I highlight the limitations of these data sources.

- **Evaluate how limitations in the method/data selected could be improved upon and judge what the risks are for the project's conclusions.** In my conclusion section, I outline the limitations of the approach and describe how it could be improved upon. I also describe what the risks of the approach are.

- **Explore ways to improve assumptions through new analysis and create convincing arguments to support their judgements.** I considered a modification of the original model specification within the paper, arguing why the original specification gave slightly unexpected results.

- **Make predictions of the likely impact of their recommendations on the business/policy situation.** In the conclusion, I suggest how the findings from the analysis might impact strategic housing analysis.

10.2 Project Management and Planning

- **Set out a clear project scope and ensure the correct resources are available to deliver the project requirements.** In my introduction section I set out the scope of the work (e.g., saying that I will not be incorporating social housing into the model).

- **Understand the risks to the project and provide evidence of how these were mitigated during the project.** I understood a risk of the project was that it would be very computationally expensive to get model outputs/results. I ensured that I tested the time it took to solve the model computationally early on in the project, so that I could adapt the problem and make it simpler if it turned out to be infeasible.

- **Draw on other sources of expertise and opinion, where required, to inform results and ensure maximum impact.** I discussed the project at multiple stages with my academic supervisor, to make use of his external expertise, to inform the approach I took and ultimately influence the outputs and impact of the project.

- **Demonstrate how learning generated during the project could be used to inform future projects and/or the wider workplace.** This work could be used to inform the development of more complex models of housing price and tenure distribution which capture a broader range of costs associated with housing - this is relevant to DWP and wider government. I explain this in the conclusion.

- **Devise processes for interdisciplinary working or tools to improve the effectiveness of interdisciplinary collaboration.** I used interdisciplinary processes by discussing this work at length with other analysts in my department, who are of other analytical professions (statisticians, operational researchers, and social researchers). In this way I was able to get a wide range of input in how I developed the proeject.

10.3 Effective Communication

- **Communicate complex economic ideas to a non-economist audience.** In the non-technical summary for this paper, I explain the modelling approach, assumptions, and findings to a non-technical audience.

- **Demonstrate the ability to tailor communication to the needs of different audiences.** The main body of the paper I have written so as to be accessible to a professional economist as they will want to understand the underlying economic reasoning, whereas the non-technical summary, in which I focus more on the motivations and implications of the research, I have written to be accessible to others in government (e.g., policy colleagues). This demonstrates my ability to tailor the communication to the needs of different audiences.

- **Explore options and trade-offs.** In the conclusion I describe clearly how additional complexity can be added to the model, but that with some additional parameters there was the trade-off that it would be more computationally expensive to get model outputs.

- **Set out key uncertainties.** In the results and conclusion sections of this paper, I describe clearly the key limitations of the analysis and how this translates into uncertainty.

- **Frame advice to show awareness of how stakeholders will react to analysis or recommendations.** In the results and conclusion I frame the advice to ensure the limitations of the approach are clear.

10.4 Horizon Scanning

- **Show how trends, future opportunities, and future challenges will affect their analysis.** I showed that future model improvements could affect the analysis by incorporating a broader set of parameters. In addition to this, I emphasised that my approach was a static model which showed how long-run effects might affect prices and tenure distributions rather than a dynamic model.

- **Demonstrate how their conclusions are resilient to future events or represent least-regret solutions.** In the conclusion, I described many ways in which the modelling could be improved or changed. This might affect the results. My conclusions are resilient to future trends as the modeling approach I took are very flexible. In this way, if for example, interest rates change, the model can be used to understand what the impact of this might be.

10.5 Maintaining Quality Standards

- **Devise a robust quality assurance process to ensure analysis and written outputs are accurate and error-free.** I shared a copy of this written paper with both my academic supervisor and my manager in the DWP to check that is was error-free. As explained in the results section, I also solve the model through two different numerical integrators as a quality assurance process.

- **Clearly set out and reference all sources used, including both data sources and the source of ideas.** I included a detailed bibliography in this paper which cites all the sources I used. In addition to this, when writing the methodology section I cite all the papers that contributed as sources of ideas for this project.

- **Select the appropriate level of detail necessary to achieve the required output.** I chose the appropriate level of detail, as explained in my methodology section, to allow for the main determinants of house prices to be included in the model. A more complex model would have been beyond the scope of the paper as it would have been too time consuming to develop.

- **Compare results with those from other methods or studies to check validity of conclusions.** I compared the findings from my research with findings from published research in the conclusion. For example, I compared to previous work looking at the impact of interest rates on house prices.

- **Describe the steps taken to ensure analysis is free from bias.** I discussed the project proposal with my academic supervisor to ensure that it was a sensible approach. In addition to this, I decided on all of the model parameters before running the code to create model outputs, so I avoided any post hoc reasoning to choose model input parameters to give a certain output I was looking for.

- **Ensure that inconvenient facts or analyses that do not fit the argument are addressed.** The unexpected results whereby increasing the loan-to-value ratio increased the prices was addressed. I described why this was arising and how it could be mitigated in future iterations of the model.

- **Draw on new sources of expertise external to their organisation to substantially improve robustness or insight from findings.** I used external sources primarily through a literature review of existing research. This meant I was able to use external expertise to ensure that the methodology and approach were robust. I also discussed the approach and findings with my academic supervisor to draw on his external expertise.
- **Challenge conventional wisdom and/or existing approaches in a sensitive and effective way.** I adapted the approach taken by Greenwald and Guren (2021) - however, I did this sensitively by suggesting how the approach I took was more relevant to the UK housing market.

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