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Social outcomes of the housing market under climate change

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ABSTRACT

Climate change results in unequal social outcomes within housing markets. Using the Australian housing market data, we examine its disparate social outcomes under climate scenarios presented by the shared socioeconomic pathways (SSPs). Our results suggest that even sustainable pathways with expected societal benefits have the potential to exacerbate social inequities, for example, by disproportionately imposing financial burdens on tenants in the rental market. Specifically, we demonstrate how intervention mechanisms, including insurance premiums, housing taxes, and mortgage rates, can counterproductively deepen social inequities among socio-economic groups by increasing unaffordability and homelessness across different climate scenarios. Theoretically, the results indicate the non-linear and disparate trajectory of social outcome of housing supply and demand in climate scenarios with reference to tipping points, while practically the results call for contextually defined housing policies that support targeted intervention mechanisms for just housing outcomes in the face of climate change.

1. Introduction

The housing affordability crisis is threatening the fundamental human right to housing across diverse urban areas worldwide (Lima, 2021; Tayefi Nasrabadi et al., 2025; Wetzstein, 2017). Unaffordable housing contributes to widening inequities and adverse social outcomes, including increased reliance on informal housing (Gurran et al., 2020), forced migration (Hao & Wang, 2024), and homelessness amid shortages of affordable rental and social housing (Batterham et al., 2021; Hipp et al., 2025; Pawson, 2021). Such social outcomes face further uncertainty in the face of climate change, with the potential significant impacts on housing supply and demand equilibriums and the stability of housing markets (Ahmad et al., 2025; Costello et al., 2009).

Climate change not only causes direct physical damage (Head et al., 2014) but also heightens market vulnerabilities (Baldauf et al., 2020) through evolving risk perceptions (Lawrence et al., 2014) and shifting investment behaviors (Gourevitch et al., 2023). Between 2000 and 2019, global costs of extreme weather events totaled AU$4.3 trillion (Newman & Noy, 2023). By 2030, these extreme events are projected to cause economic losses exceeding AU$571 billion in the Australian housing market alone (Steffen et al., 2019). Coupled with population growth, urbanization, and constrained housing provision, the social costs of climate change are expected to escalate further under realistic scenarios (Actuaries Institute, 2022; Tol, 2023). Understanding the social and economic impacts of climate change on housing markets is therefore essential for designing targeted adaptation and mitigation initiatives, as well as for implementing effective market interventions.

While prior studies demonstrate that physical climate risks and risk perceptions influence housing prices (Baldauf et al., 2020; McNamara et al., 2024), the broader social outcomes of the price effects have received limited attention (e.g., Gurran et al., 2020). These social outcomes have rarely been connected to future scenarios, including climate trajectories (Ingels et al., 2024). This gap restricts understanding of how governance and market mechanisms may moderate or exacerbate housing market vulnerability under climate change (e.g., Head et al., 2014). Our study integrates housing market dynamics to assess future

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social outcomes, including affordability pressures, homelessness, and informal housing, under alternative climate change scenarios.

In this research, we translate shared socioeconomic pathways (SSPs) to explore the social outcomes of the housing market under climate change. We further consider the impact of common intervention mechanisms, such as insurance premiums, taxes, and mortgage rates. Using empirical data from the Australian economy and housing market (2003−2021), we simulate market behavior through a macroeconomic stock-flow model under five SSPs, developed through the integrated assessment model (IAM) (O'Neill et al., 2016) by the Intergovernmental Panel on Climate Change (IPCC). Our results provide insights into how interventions shape social outcomes, highlighting variations in market behavior under extreme climate conditions at both national and household levels across different socioeconomic groups. The contribution of this research lies in translating shared socioeconomic pathways into market-level housing dynamics, demonstrating interactions of climate change, within the economic and social systems, and establishing a methodological foundation for evaluating how interventions may counterproductively exacerbate social inequities within housing markets.

2. Background

2.1. Drivers of the housing affordability crisis

Housing affordability is not just the outcome of short-term price surges; rather, it reflects the interplay of demand, supply, and governance (e.g., Büchler et al., 2023; Freemark, 2024; Ganong & Shoag, 2017). On the demand side, urbanization, population growth, economic expansion, and demographic change contribute to rising housing prices (Gennaioli et al., 2014; Leishman & Goel, 2024). For example, in Jordan, the arrival of 1.3 million Syrian refugees sharply increased rental prices, as housing supply remained unresponsive (Rozo & Sviatschi, 2021). On the supply side, productivity, land-use regulations, zoning, and development practices shape the responsiveness of housing markets (Glaeser et al., 2006). In Australia, overall housing supply has persistently lagged behind demand, a trend exacerbated by construction delays, thereby intensifying the affordability crisis (Groenhart & Burke, 2014). These examples illustrate how adverse social outcomes in the housing markets can emerge from the intersection of economic, social, and political drivers (e.g., Freemark, 2024; Ganong & Shoag, 2017).

However, the dynamics of these drivers can significantly change as a result of climate-related risks that are expected to impact supply and demand imbalances and eventually the associated social outcomes. For example, Australia witnessed a 5.9% surge in home insurance premiums in 2021, the largest rise in seven years (GlobalData, 2022). Even under a low-emission scenario, where global warming is expected to remain below 2 °C by 2050, vulnerable households in Australia who spend more than four weeks of gross income on insurance, will face a 14% deterioration in home insurance premium affordability in the same period (Actuaries Institute, 2022).

2.2. Interventions in response to the housing affordability crisis

Understanding the future of housing markets under climate change requires attention to the intervention mechanisms that shape such outcomes. At the market level, these interventions can be broadly categorized into supply-side and demand-side interventions. Governments have frequently relied on supply-side levers to address housing unaffordability (Compton, 2024; Palm et al., 2020). These include deregulation of land development (Büchler & Lutz, 2024; Ferm et al., 2021) and modifications to land-use regulations and zoning (Aurand, 2010; Ihlanfeldt, 2007). Evidence shows that deregulatory planning reforms can increase housing supply, although often at the cost of quality (Ferm et al., 2021).

Demand-side interventions aim to stabilize housing markets by influencing housing costs. Traditionally, such interventions include tax increases, mortgage rate adjustments, and changes in insurance premiums (e.g., Long & Zhuang, 2025). Growing climate-related risks have also prompted the design of novel interventions, such as multi-country risk pools (Ciullo et al., 2023; Jarzabkowski et al., 2022) and pricing strategies (DellaVigna & Gentzkow, 2019).

2.3. Housing affordability as climate adaptation strategy

In the context of escalating climate-related risks and socioeconomic complexities, mitigation and adaptation initiatives have been introduced alongside market-level interventions. However, these mitigation and adaptation initiatives often fail to distribute benefits justly or achieve their intended purpose without spill-over adverse impacts (Owen, 2020). The effectiveness of these climate initiatives depends on timing, expectations, and the ability to anticipate disruptions (Battiston et al., 2017; Nicolini, 2024). As climate extremes exceed records (Fischer et al., 2021), large-scale disaster exposure estimates need to be revised (Smith et al., 2019). This need arises from heightened uncertainty, which could potentially lead to unprecedented conditions, causing social and market failures (Andrew, 2008). Planning for just resilience housing outcome requires protecting vulnerable populations and ensuring that they share in the benefits of adaptation and mitigation. In this context, affordability itself emerges as a dimension of climate adaptation and mitigation.

2.4. Social outcomes of the housing market under climate change

While further research into novel, context-specific initiatives is essential (Lucas et al., 2021), there is a need to explore the effectiveness of both current and emerging initiatives. More specifically, understanding the social outcomes of the housing market under extreme climate change scenarios prepares policymakers to manage, confront and adapt to a highly uncertain future. Such understanding can further inform policies on a wider range of scenarios, thereby improving the effectiveness of both existing and novel alternatives.

To explore social outcomes of housing market under climate change, a range of scenarios is needed to capture different pathways for supply and demand dynamics and intervention mechanisms. We select the five shared socioeconomic pathways (SSPs) to represent a set of plausible future scenarios and uncertainties, each characterized by distinct combinations of challenges to mitigation and adaptation. The SSPs provide a foundation for exploring population change, income growth, inequality, and land development, thereby shaping both supply and demand dynamics. They also enable analysis of the impacts of demand-side interventions, while supply-side interventions are captured through land development trajectories.

An overview of the SSP narratives is derived from the work of Riahi, Van Vuuren, Kriegler, Edmonds, O'neill, Fujimori, Bauer, Calvin, Dellink, and Fricko (2017a). The sustainability scenario, SSP1, describes a scenario where collective action toward sustainability leads to a gradual shift toward a more sustainable path and inclusive development. SSP2 represents a middle-of-the-road scenario characterized by uneven development, income growth, and environmental degradation. Under this pathway, the world follows a path where social, economic, and technological trends do not shift significantly from historical patterns, making it a suitable baseline for analyzing other pathways. The regional-rivalry scenario, SSP3, portrays a world of resurgent nationalism, authoritarian governance, environmental degradation, and limited progress toward sustainability. The inequality scenario, SSP4, illustrates increasing inequalities, fragmented societies, and concentrated power, resulting in moderate economic growth. Finally, SSP5 represents the fossil-fueled scenario, in which the exploitation of abundant fossil fuel resources is continued with prioritization of technological, economic, and social development.

3. Data and methodology

3.1. Data

We used data from the Australian Bureau of Statistics (ABS), the Household, Income and Labour Dynamics in Australia (HILDA) Survey, and the World Bank, as summarized in Table 1. To estimate total housing demand in eq. (2), we used population and household size from 2003 to 2021, along with disposable income from ABS, and measured real net national disposable income per capita, reflecting inflation-adjusted income at annual frequency from 2003 to 2021. To capture annual changes in residential dwelling prices and housing inflation, we used ABS Residential Property Price Index, and scaled the index to average dwelling prices in 2003 so that each year's index value represents the average housing price. We calculated housing costs (the user cost of housing) as the sum of rent payments, utility payments, and mortgage or unsecured loan repayments, and defined ownership cost by assigning a value of zero to rent payments for owners, while we defined rent cost by assigning a value of zero to mortgage payments for tenants. Housing costs and prices are deflated. We extracted tenure type from ABS, and used rent, housing price, and tenure variables to calibrate eqs. (2) and (3).

We obtained homelessness data from ABS, which is only available for 2006, 2011, 2016, and 2021, and affordability measures from HILDA microdata on household income and rent. While ABS provides national-level indices for rent and income, HILDA data is required to estimate homelessness from the distribution of household-level income and rent. We then used these annual observations for 2006, 2011, 2016, and 2021 to estimate homelessness and calibrate eq. (5). We adjusted GDP to billion US dollars in 2005 to ensure consistency with the SSPs, and we used urban land area from the World Bank, and construction start rates from ABS to calibrate eq. (7).

We interpolated all the data to monthly frequency so the model operates at a monthly time step. This approach ensures internally consistent simulation but does not capture intra-year variability. Instead, our result reflects annual changes in the housing market, consistent with the predominantly annual availability of input data. All datasets used in the analysis are publicly accessible and listed in Table 1, along with their temporal coverage, frequency, and role in the model.

3.2. Method

We use a macroeconomic stock-flow model to capture the dynamics of the housing market through the asset-price approach (McNamara et al., 2024; Meen et al., 2022; Poterba, 1984; Poterba & Sinai, 2008). These models are particularly suited for policy analysis, exploring market dynamics, and examining social equity (Andrews et al., 2011; Cao et al., 2020; Dafermos et al., 2017; Fu et al., 2023; Jackson & Victor, 2015). We include interactions between ownership and rental markets, integrate household decision-making and affordability constraints, and incorporate intervention mechanisms, including country-level insurance premiums in Australia. Fig. 1 presents the core causal loop diagram of the model.

Our model integrates the dynamics of supply (Epple et al., 2010; Poterba, 1984) and demand (Miles & Pillonca, 2008), while accounting for variation in housing costs. Population and affordability determine total housing demand. Population is an exogenous variable determined by data, while affordability is influenced by rent prices, GDP, and ownership costs, which depend on sales prices, mortgage rates, taxation settings, and insurance premiums. Population growth or improvements in affordability, such as those arising from GDP gains or lower insurance premiums, increase total demand.

We allocate total demand between the ownership and rental markets through a demand-division ratio. The share of demand directed toward ownership declines when ownership costs rise and increases when rent prices rise, reflecting the inverse relationship to rental demand. A portion of total demand may not be met due to affordability constraints and contributes to homelessness. Homelessness is a function of GDP, rent prices, and the GINI index, with higher rents, weaker macroeconomic conditions, and greater inequality increasing the likelihood that households cannot secure adequate housing.

Total supply comprises vacant dwellings and new construction. New construction is driven by sales prices, construction productivity, and available land, including both new land releases and demolition of existing stock. Higher sales prices, productivity gains, or increases in land availability raise the construction rate. Construction responds to demand conditions and price signals with a lag due to project lead times. We allocate total supply between the ownership and rental markets through a supply-division ratio determined by relative profitability. Higher rent prices increase developers' incentives to allocate supply toward the rental market, while higher sales prices shift supply toward the ownership market. Interactions between demand and supply determine sales and rent prices. Higher demand or lower supply increases prices, whereas lower demand or higher supply reduces them. Price movements feed back into the system through three primary feedback loops: (i) higher sales prices increase ownership costs, lowering total demand and reallocating demand toward rental; (ii) higher rents reduce total demand and increase demand for ownership; and (iii) higher sales and rent prices stimulate new construction and increase total supply. These feedback loops lead to dynamic behavior of the system over time.

3.2.1. Housing price adjustments

The housing market is shaped primarily by fluctuations in supply and demand, which lead to adjustments in prices over time (DiPasquale & Wheaton, 1994; McCarthy & Peach, 2002; Tu et al., 2017). We analyze the dynamic relationship between supply, demand, and past prices to predict current housing prices in both rental and ownership markets through the following equation:

Table 1
Data description.

Variable	Range	Frequency	Units	Equation	Source
Population	2003–2021	Annual	People	Eq. 2	ABS data
Household size	2003–2021	Biennial	People	Eq. 2	ABS data
Disposable income	2003–2021	Annual	AU$ per week	Eq. 2	ABS data
Sales price	2003–2021	Quarter	AU$	Calibration	ABS data
Rent price	2003–2021	Biennial	AU$ per week	Calibration	ABS data
Tenure type	2003–2021	Biennial	Percentage	Calibration	ABS data
Ownership cost	2003–2021	Annual	AU$ per week	Eq. 2 and 3	ABS data
Affordability	2006–2021	Annual	Dimensionless	Eq. 5	HILDA survey
Homelessness	2006, 2011, 2016, 2021		Percentage	Calibration	ABS data
Construction start rate	2003–2021	Quarter	Dwellings	Calibration	ABS data
GDP	2003–2021	Annual	Adjusted to 2021 AU$	Eq. 7	The World Bank
Urban land area	2000, 2010, 2015, 2020		Km^2	Eq. 7	The World Bank and Gao and O'Neill (2020)

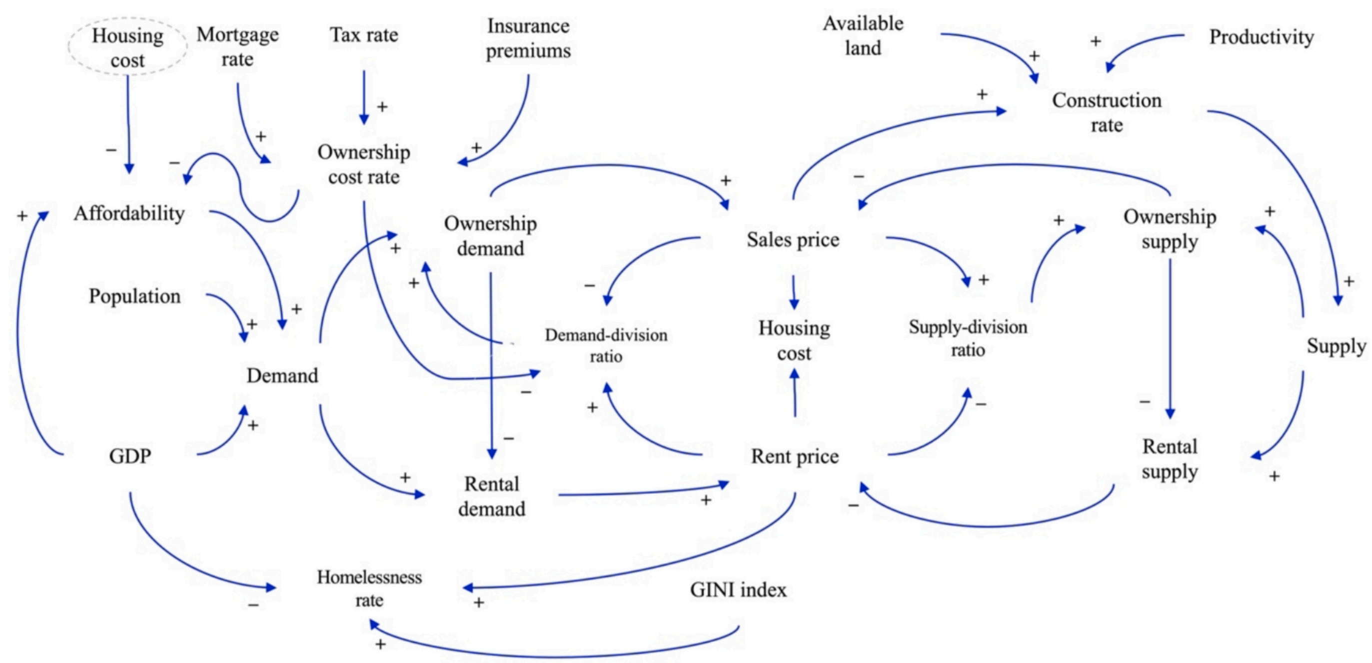

Fig. 1. Causal loop diagram of housing market dynamics.

$$\Delta P_t = C_1 P_{t-1} ln\left(\frac{D_t}{S_t}\right) \tag{1}$$

where P_t represents the price at time t, and C_1 is a constant determined through calibration. Demand (D) and supply (S) are then determined by the following equations.

3.2.2. Housing demand side

Demand dynamics are influenced by demand-side forces, including disposable income, population size, and the user cost of housing, as supported by previous empirical studies (Andrews et al., 2011; McNamara et al., 2024; Meen et al., 2022; Miles & Pillonca, 2008; Poterba, 1984). The user cost of housing is shaped by interest rates, current and future price expectations, the relative cost of owning versus renting, and taxation policies. Therefore, at any given time t, the total demand, denoted as $D_{t,tot}$, is calculated as:

$$D_{t,tot} = D_{t-1,tot} \times \left(\frac{DI_t}{DI_{t-1}}\right)^{\alpha_1} \left(\frac{\rho_t/N_t}{\rho_{t-1}/N_{t-1}}\right)^{\alpha_2} \left(\frac{U_t}{U_{t-1}}\right)^{-\alpha_3} \tag{2}$$

where disposable income (DI), population (ρ), household size (N), and user cost of housing (U) are obtained from the collected data. The parameters α_1, α_2, and α_3 are determined by calibration.

3.2.3. Housing ownership demand

In the model, a portion of total housing demand is satisfied by occupied dwellings. The remaining unmet demand, $D_{t,u}$, is allocated between ownership and rental markets according to housing tenure. Empirical studies and asset-price approaches indicate that this allocation depends primarily on the relative costs of renting versus owning, including rent payments and ownership costs (McNamara et al., 2024; Poterba, 1984; Raya & Garcia, 2012; Tu et al., 2017). Therefore, at any given time t, ownership demand, denoted as $D_{t,o}$, is calculated as follows:

$$D_{t,o} = D_{t,u}\left(\frac{C_2}{1+\exp\left(-C_3\left(\frac{P_{t,r}}{OC_t} - C_4\right)\right)} + 1 - C_2\right) \tag{3}$$

In this equation, an S-shaped function captures the effect of ownership costs relative to rent prices on the allocation of demand between ownership and rental markets. When ownership costs rise compared with rent prices, demand shifts toward the rental market, and the reverse occurs when ownership becomes relatively less costly (Gallin, 2008; Poterba, 1984; Raya & Garcia, 2012; Tu et al., 2017). In this segment, $P_{t,r}$ represents the rent price; C_2, C_3, and C_4 are constants determined through calibration. The term OC_t denotes housing ownership costs, which directly correlate with the sales price and include components such as interest rates, mortgage rates, insurance premiums, taxes, depreciation, maintenance, moving fees, and expected house price growth (McNamara et al., 2024; Miles & Pillonca, 2008).

3.2.4. Housing rental demand

After determining ownership demand, the remaining demand shifts to rental but only if rent payments are affordable. Otherwise, a portion of low-income households may experience homelessness (e.g., Pawson, 2021). Rental demand is determined as follows:

$$D_{t,r} = D_{t,u} - D_{t,o} - \beta D_{t,total} \tag{4}$$

where β is an apportionment factor that evaluates rental affordability based on rent prices and disposable income. This factor is the log-normal cumulative distribution of the income-to-average-rent ratio. Its primary purpose is to determine the homelessness rate by calculating the probability that a household's income-to-rent ratio is less than or equal to a rental affordability threshold x, which is defined as:

$$\beta\left(\mu = \frac{DI_t}{P_{t,r}}, x, \sigma = \frac{\sigma'}{P_{t,r}}\right) = \frac{1}{2}\left[1 + erf\left(\frac{ln(x-\mu)}{\sigma}\right)\right] + \varepsilon \tag{5}$$

where μ represents the income-to-average-rent ratio, σ is the standard deviation, and ε signifies the proportion of the population experiencing homelessness due to factors not directly related to rental affordability, such as domestic violence and mental health (e.g., Piat et al., 2015). Historical data on disposable income and rent prices are used to determine μ, while σ is calculated as the standard deviation of the disposable income distribution (σ') divided by the average rent price. Both ε and x are calibrated using historical homelessness data.

We use a lognormal distribution for rental affordability based on empirical evidence showing that that both rent prices and income distributions are lognormal (Eguia & Xefteris, 2024; Lemoy & Bertin, 2012). Rental affordability is represented by the ratio of rent to income; therefore, a lognormal distribution is an appropriate representation of affordability as the ratios of lognormal variables tend to follow lognormal distributions. Empirical validation using Australian microdata further supports this specification. Fig. A1 shows the distribution of rental affordability measures derived from annualized rent divided by reported household income for renter households. The raw affordability ratios display characteristics of lognormal behavior. After log transformation, the distributions approximate symmetry, confirming that the lognormal form provides an appropriate basis for modelling.

3.2.5. Housing supply side

Changes in housing supply result from the reconstruction of existing buildings, urban development, and the availability of vacant dwellings from property sales or expired rental contracts. The supply from vacant dwellings is determined by transaction dynamics within the model. Furthermore, housing supply from sources other than vacant dwellings is estimated following previous empirical studies and the asset-price approach, which is grounded in the Cobb–Douglas production function (Epple et al., 2010; Jalali et al., 2022; Poterba, 1984; Tan et al., 2020). In this framework, the model specifies the optimal supply-to-land ratio (S_t/L_t) that maximizes profit as follows:

$$\frac{S_t}{L_t} = A^{\left(\frac{1}{1-\eta}\right)} \left(\frac{P_{t,c}}{\eta P_{t,s}}\right)^{\left(\frac{\eta}{\eta-1}\right)} \tag{6}$$

where η represents a constant reflecting the sensitivity of output to input variations, while A represents productivity. Both parameters are calculated through calibration. The available urban land area, L_t, is calculated by accounting for both new land development and the demolition of existing dwellings. New land development is inferred from historical data, while the demolition rate (r_d) is derived through calibration. $P_{t,s}$ represents the sales price. The construction costs, $P_{t,c}$, are influenced by GDP, following Ashuri et al. (2012), who identified GDP as a leading indicator. Therefore, the change in construction costs is defined as $\Delta P_{t,c} = \lambda \Delta(GDP)$, where λ is a constant determined through calibration. The supply function can then be written as the following:

$$S_t = L_t A^{\left(\frac{1}{1-\eta}\right)} \times \left(\frac{P_{t_0,c} + \lambda\, \Delta(GDP)}{\eta P_{t,s}}\right)^{\left(\frac{\eta}{\eta-1}\right)} \tag{7}$$

3.2.6. The type of housing supply

The type of housing supply determines the division between ownership and rental supply. This division is not fixed and can be influenced by sales and rental incomes (Büchler et al., 2021; Mense et al., 2023; Sommer & Sullivan, 2018). To represent this dynamic, an S-shaped function is used to estimate the number of dwellings allocated to the ownership market, with the remainder designated as rental supply. The rationale behind this function is that when the ratio of rental prices to sales prices increases, profit-seeking owners are more inclined to rent out their dwellings rather than selling them. However, the second term on the right-hand side of the equation caps the increase in the number of dwellings allocated to the rental market, regardless of changes in rental or sales prices. In other words, despite high rental prices, some homeowners or sellers will always choose to sell their dwellings. The function is expressed as the following:

$$S_{t,o} = S_{t,tot}\left(\frac{C_5}{1+\exp\left(-C_6\left(\frac{P_{t,s}}{P_{t,r}} - C_7\right)\right)} + 1 - C_5\right) \tag{8}$$

where C_5, C_6, and C_7 are constants determined through calibration, $S_{t,tot}$ denotes the total supply, and $S_{t,o}$ represents the ownership supply.

3.2.7. Adjustment times

Each stock in the model is associated with an adjustment time. Initially, parameter ranges are determined using data and recommendations from Australian sources, including grey literature. Subsequently, these parameters are calibrated within their specified ranges. The adjustment times include those related to owners (t_{owners}) and tenants ($t_{tenants}$), accounting for how long it takes them to adjust their tenure type if they decide to change. Additionally, the adjustment times for shifts in demand and supply between ownership and rental markets ($t_{demand\text{-}shift}$ and $t_{supply\text{-}shift}$) affect the market's vacancy dynamics, while construction time ($t_{construction}$) determines the responsiveness of housing supply.

3.2.8. Operationalizing social outcomes

We represent social outcomes through rental affordability, ownership affordability, the homelessness rate, and the share of informal housing. We operationalize these outcomes using indicators that capture the financial pressures experienced by households and the distributional consequences of housing market conditions.

We measure ownership affordability using the income-to-ownership-cost ratio, which reflects the burden of ownership-related expenses on household budgets. We then measure rental affordability through the income-to-rent ratio, indicating the extent to which rental costs constrain household resources. Together, these indicators provide insight into the intensity of the housing crisis, which is referred to as a disruption in which rising housing-related expenses outpace salary and wage increases (Wetzstein, 2017).

Homelessness and informal housing serve as indicators of housing equity among low-income households (e.g., Rantissi & Gitis, 2024). The potential for experiencing homelessness is defined as the probability that a household's income-to-rent ratio falls below a specified rental affordability threshold. In practical terms, the homelessness rate reflects the portion of the population at risk of losing access to secure housing without additional support. The share of informal housing refers to arrangements such as subdivided housing or living in non-residential buildings that vulnerable households may resort to when they are unable to access formal affordable rental options (Gurran et al., 2020). A high share of informal housing, coupled with complex social issues such as economic booms (e.g., Haslam McKenzie & Rowley, 2013) and a shortage of affordable rental housing (e.g., Gurran et al., 2020), signals elevated housing-related stress. To quantify the potential for informal housing, we evaluate the number of households able to afford housing as tenants or owners relative to the number of available dwellings. This indicator provides a proxy for the likelihood that low-income households may be pushed into informal arrangements due to insufficient access to affordable formal accommodation.

3.3. Model calibration

We calibrate the parameters listed in Table 2 through an iterative process designed to ensure robust model performance. Calibration is conducted in three sequential stages rather than simultaneously. Calibrating eqs. (5) and (7) separately before integrating them into the full model reduces the dimensionality of the optimization problem, lowers calibration error, and prevents convergence challenges associated with estimating a large number of parameters simultaneously.

In the first stage, we estimate the parameters of the homelessness rate in eq. (5), with the objective of minimizing the mean absolute percentage error (MAPE) of the homelessness rate. Optimization terminates once improvements in the best MAPE fall below 0.1%. In the second stage, we calibrate the construction rate in eq. (7), again with the objective of minimizing MAPE of the construction rate. Optimization terminates once improvements in the best MAPE fall below 0.1%. In the third stage, we integrate the calibrated parameters from stages one and two into the full model and estimate the remaining parameters. The objective in this stage is to minimize the average MAPE across three key

Table 2
Calibration result.

Parameters	Values
C_1	0.003
C_2	0.500
C_3	5.000
C_4	0.650
C_5	0.650
C_6	0.600
C_7	0.050
α_1	1.000
α_2	1.000
α_3	0.500
r_d	0.0007
x	0.390
ε	0.0043
η	0.310
λ	2.200
A	*1.800*
t_{owners}	*120*
$t_{tenants}$	*20*
$t_{demand\text{-}shift}$	*1.778*
$t_{supply\text{-}shift}$	*3.470*
$t_{construction}$	*12*

metrics: tenure type, housing prices, and rent. To evaluate the robustness of the calibrated model, we conduct a behavior reproduction test, a verification process, and a sensitivity analysis, as detailed below.

3.3.1. Behavior reproduction test

Fig. 1 illustrates the trajectories of the model outputs and collected data for sales price, rent price (annual rent payment), the number of owners, the number of tenants, homelessness, and supply. For this behavior reproduction test, we use data from 2003 to 2018. We also verify the calibration by comparing the model outputs with data from 2018 to 2021. The quality of fit between the data and model outputs is assessed using the measures presented in Table 3. The R^2 values range from 0.82 to 0.99, indicating negligible variability. Additionally, the MAPE and MAE/Mean values fall within an acceptable threshold of less than 10% (Chen et al., 2003; Lewis, 1982). As a result, the model is capable of reproducing historical data and capturing the patterns and relationships within the data used for verification. Specifically, our model is tested on a dataset covering 18 years to examine market behavior over a 30-year period (up to 2050) under SSPs. The results of this test demonstrate the model's suitability and robust performance for implementing future scenarios (Chen et al., 2003; Lewis, 1982).

3.3.2. Sensitivity analysis

To demonstrate the uncertainty of the impact of the model parameters, a sensitivity analysis is conducted on various parameters. For brevity, only the sensitivity analysis results on construction costs are presented in Fig. 2.

Our analysis examines the effect of ±10% uncertainty in construction costs on housing markets in terms of prices and tenure type over time. Fig. 3 demonstrates that considering growth in construction costs does not significantly alter the behavior of the model, except under SSP1, where a slight variability is observed due to the balance between supply and demand in this scenario, making it more sensitive to changes. However, the trajectory of tenure type, represented by the number of owners and tenants, remains nearly constant, implying that households' attitudes toward tenure choice remain unaffected by this uncertainty. Moreover, in the results, we consider the uncertainty inherent in different supply-demand inputs, such as construction cost, productivity, GDP, population, and insurance premiums, each with an uncertainty of ±5%, which are displayed as boundaries in the figures.

3.4. Scenario development: Shared socioeconomic pathways (SSPs)

Following the calibration process, we apply the SSPs to explore social outcomes under climate change. These scenarios serve as the inputs to the model and are summarized in Table 4. The SSPs characterize societal futures with particular combinations of challenges to mitigation and adaptation (O'Neill et al., 2017). Mitigation and adaptation initiatives in response to climate change are incorporated through demographics, human development (e.g., health and education), economic growth, inequality, governance, technological change, and policy orientations. These initiatives influence the intricate interactions among social, technical, economic, and climate factors, which in turn shape the scenarios and their underlying assumptions. For instance, migration as a form of adaptation (Black et al., 2011) is analyzed by considering population growth across different SSPs, while the adoption of green standards and climate-resilient practices is examined in relation to governance, technological change, and policy orientations.

The macro-level projections of SSPs have been widely applied in country-level and subnational studies (e.g., Bruhn et al., 2025; Clark & Miller, 2025; de Ruig et al., 2022; Tesselaar et al., 2023). These studies include modelling life-cycle emissions in the building sector (Bruhn et al., 2025), estimating climate-driven impacts on regional housing prices (Clark & Miller, 2025), and simulating population growth in floodplains while accounting for housing market responses (Tesselaar et al., 2023). SSPs have also informed the development of risk-based insurance premiums for socially beneficial adaptation interventions in housing markets (de Ruig et al., 2022). Using this literature, we demonstrate that macro-level SSP projections, when linked to empirically grounded behavioral models, enable meaningful insights into micro-level housing outcomes. We translate SSPs into inputs for an established asset-price housing model. Behavioral mechanisms governing supply, demand, affordability, tenure decisions, and intervention processes remain empirically grounded and unchanged. Macro-level SSPs instead shape exogenous variables, including population, GDP, and insurance premiums, which define the broader context in which housing market dynamics unfold.

A subset of country-level factors is obtained from the SSP database (https://tntcat.iiasa.ac.at/SspDb/) and studies on the SSP database. Data on population (Kc & Lutz, 2017), GDP (Dellink et al., 2017; Rao et al., 2019), and Gini index (Rao et al., 2019) are sourced from the SSP database. Productivity growth data are obtained from Leimbach et al. (2017), urban land area development data from Gao and O'Neill (2020), and insurance premiums data from Actuaries Institute (2022). Insurance premium projections are available only for SSP1 and SSP5. For the remaining scenarios, we interpolate within the SSP1–SSP5 range, reflecting the relative mitigation and adaptation challenges and the associated warming pathways. SSP5 represents the highest climate risks

Table 3
Behavior reproduction test.

	Mean	STD	RMSE	R^2	MAPE	MAE/Mean
Sales price (AU$)	497,747.2	123,387.5	41,063.98	0.97	0.060	0.064
Rent price (AU$)	16,535.3	2410.2	1292.54	0.89	0.056	0.058
Number of owners	5,824,104.9	330,183.1	68,800.67	0.97	0.009	0.009
Number of tenants	2,665,633.0	249,297.1	81,110.58	0.98	0.028	0.028
Homelessness (%)	0.00468	0.00017	0.00002	0.99	0.005	0.004
Supply	192,020.9	30,680.6	1,653,668.2	0.82	0.069	0.068

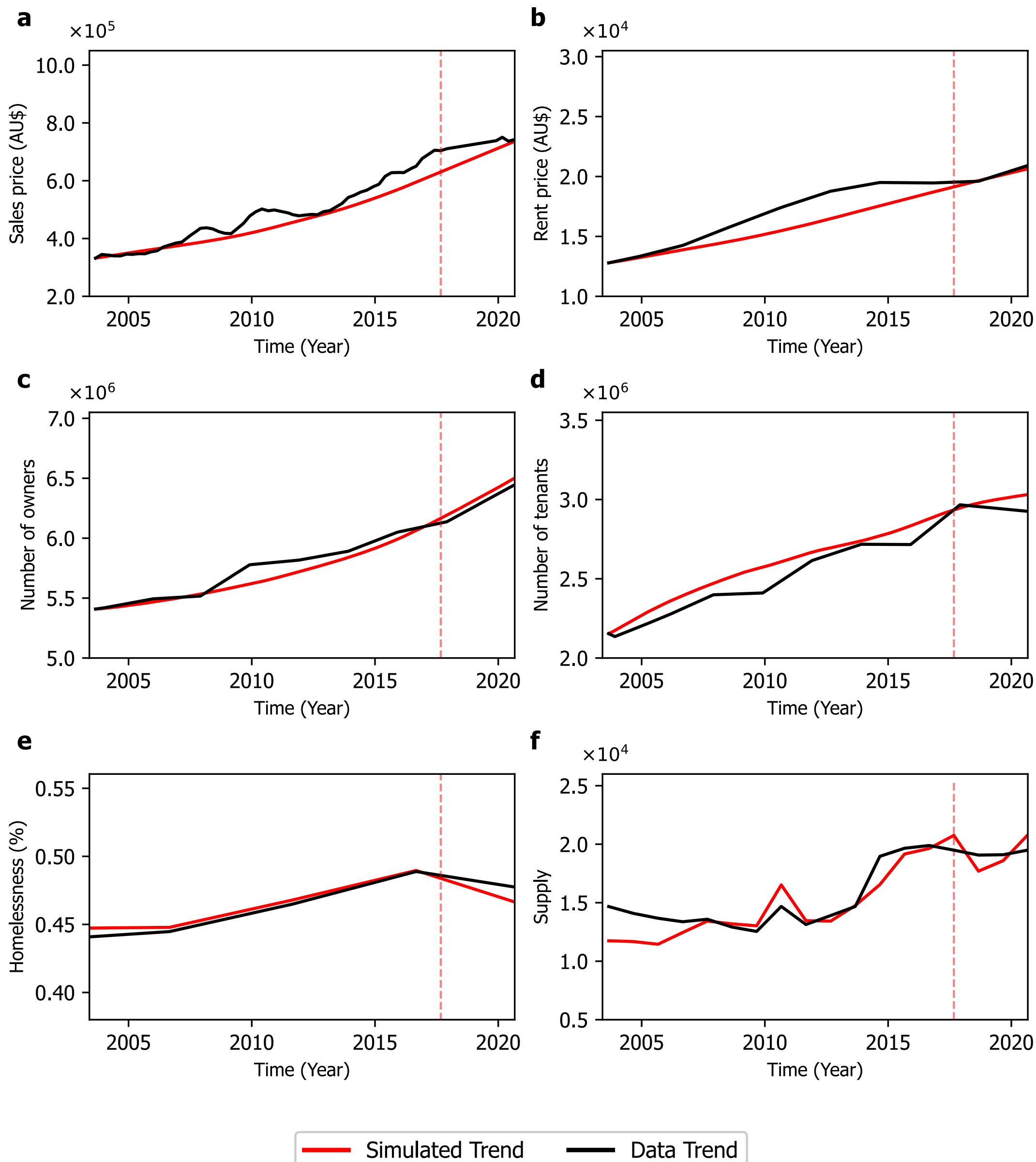

Fig. 2. Behavior reproduction test. (a) Sales price. **(b)** Rent price. **(c)** Number of owners. **(d)** Number of tenants. **(e)** Homelessness. **(f)** Supply.

and therefore forms the upper bound of premiums, while SSP1 represents the lowest climate risk pathway and defines the lower bound. To assess the robustness of this assumption, we also evaluated alternative trajectories through targeted interventions that adjust insurance premiums and tested the sensitivity of model outputs to these exogenous inputs.

In the SSP database, the disposable income of households is not explicitly calculated. Instead, GDP and the Gini coefficient are utilized for calculation. To determine average disposable income within this context, we initially employ GDP data (Dellink et al., 2017) and the elasticity between GDP and average disposable income in Australia (Botev et al., 2022; Causa et al., 2014) as given in eq. (9):

$$\Delta ln(Disposable\ Income) = \gamma \Delta ln(GDP) \tag{9}$$

where γ denotes the elasticity between GDP and average disposable income, which is set as 0.178. Regarding the distribution of disposable income and its standard deviation, we assume that disposable income follows a lognormal distribution. The standard deviation of the disposable income distribution (σ') is calculated using the Gini coefficient data for the given scenarios (Rao et al., 2019), based on previous studies (Chen et al., 2010; Nishino & Kakamu, 2011) as given in eq. (10):

$$\sigma' = \sqrt{2}\phi^{-1}\left(\frac{G+1}{2}\right) \tag{10}$$

where G represents the Gini coefficient, and ϕ denotes the cumulative distribution function (CDF) of the standard normal distribution.

4. Results

4.1. Supply and demand trajectories

Fig. 4 illustrates the interplay between demand and supply dynamics within the housing market across the five SSPs. These dynamics may result in either a market bust with reduced prices, as observed in SSP2, SSP3, SSP4, and SSP5, or a balanced market, as seen in SSP1. Population growth serves as the primary driver of demand, resulting in increased total demand and upward pressure on housing prices. However, as prices rise, supply gradually neutralizes the impact of population growth on

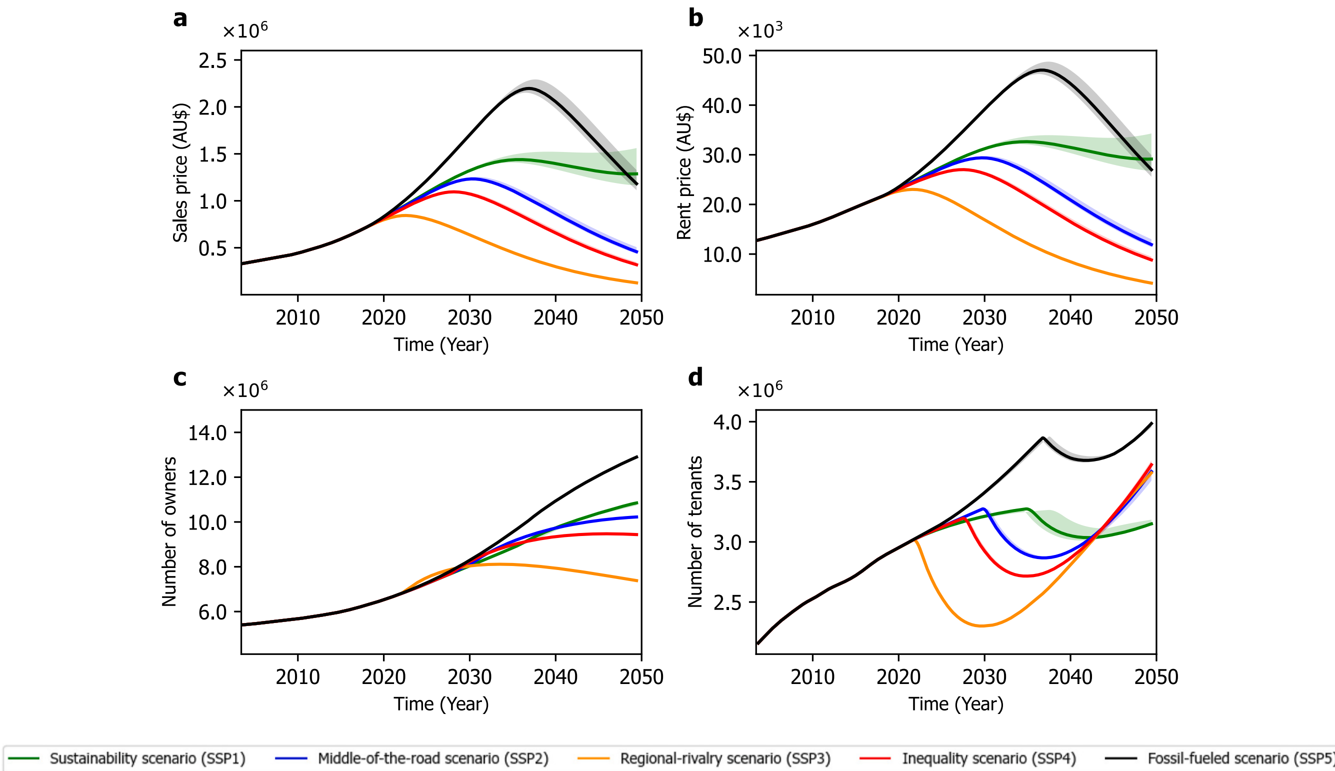

Fig. 3. Sensitivity analysis results. (a) Sales price. **(b)** Rent price. **(c)** Number of owners. **(d)** Number of tenants.

Table 4
Description of scenarios.

Scenario	Scenario name	Challenge to mitigation	Challenge to adaptation	Population	Disposable income	GINI index	Insurance premiums	Productivity growth	Urban land area
SSP1	Sustainability	Low	Low	+40%	+(8–9)%	-2%	+(12−13)%	+29%	+6.9%
SSP2	Middle of the road	Medium	Medium	+38%	+(6–8)%	+1%	+(14–15)%	+25%	+30%
SSP3	Regional rivalry	High	High	+13%	+(2–4)%	+6%	+(14–16)%	+10%	+8%
SSP4	Inequality	Low	high	+32%	+(8–9)%	+7%	+(13–14)%	+21%	+29%
SSP5	Fossil-fueled	High	low	+64%	+(11−12)%	-2%	+(17–18)%	+41%	+54%

the market. This gradual supply response stems from construction delays which contribute to boom-and-bust cycles (Wang, 2019). The point at which prices level off, in conjunction with land availability, determines whether supply can adequately meet the growing demand.

Fig. 4a and b show the trajectories of sales and rent prices across the five SSPs. We discuss key changes relative to the 2020 baseline to interpret these trajectories. Under SSP5, rapid population growth leads to the steepest early price escalation, with sales price increasing by approximately 150% and rent by 93% by 2037. However, extensive land development and delayed supply response reverse this trajectory, resulting in more moderate increases of 43% in sales price and 17% in rent by 2050 relative to the baseline. SSP1 also exhibits notable price growth, but limited land development constrains supply, causing prices to level off; sales and rent prices rise by roughly 76% and 40% by 2050, respectively. SSP2 and SSP4 have similar population trajectories to SSP1 but allow for greater land development, enabling supply to exceed demand after an initial price rise. Sales and rent prices rise by roughly 44% and 23%, by 2030 in SSP2, respectively, and by 28% and 17% by 2027 in SSP4, after which prices decline sharply. By 2050, both sales and rent prices decline by approximately 45% under SSP2 and 60% under SSP4 relative to the baseline. SSP3 shows the most substantial decline, with increases of less than 1% followed by decreases of approximately 80% by 2050.

The housing market is composed of rental and ownership markets, while the dynamics between these two markets are governed by (i) the ownership-cost-to-rent ratio, and (ii) the rental yield (rent-to-sales-price ratio). In SSP2, SSP3, and SSP4, there is a pronounced rate of increase in these ratios due to reduced prices and improved affordability, leading to a surge in demand within the ownership market. Subsequently, an increase in the ownership-cost-to-rent ratio makes the rental market more attractive for households, as depicted in Fig. 4c, and leads to a shift in demand from ownership to rental. Simultaneous to this demand shift, the rental yield levels off toward a more intense demand and supply imbalance in the rental market, as shown in Fig. 4d. In other words, the rental yield decreases, but this decrease is slowed down by the rise in the ownership-cost-to-rent ratio. Notably, in SSP1 and SSP5, where the ownership-cost-to-rent ratio rises at a slower rate, the rental yield levels off later than scenarios such as SSP3. Eventually, when the imbalance in both markets equalizes, the rental yield starts to increase, leading a shift of supply to the rental market.

4.2. Impact of intervention mechanisms

Fig. 5 illustrates how intervention mechanisms, such as rising insurance premiums, affect housing market dynamics. The intervention mechanisms raise the ownership-cost-to-rent ratio through increasing

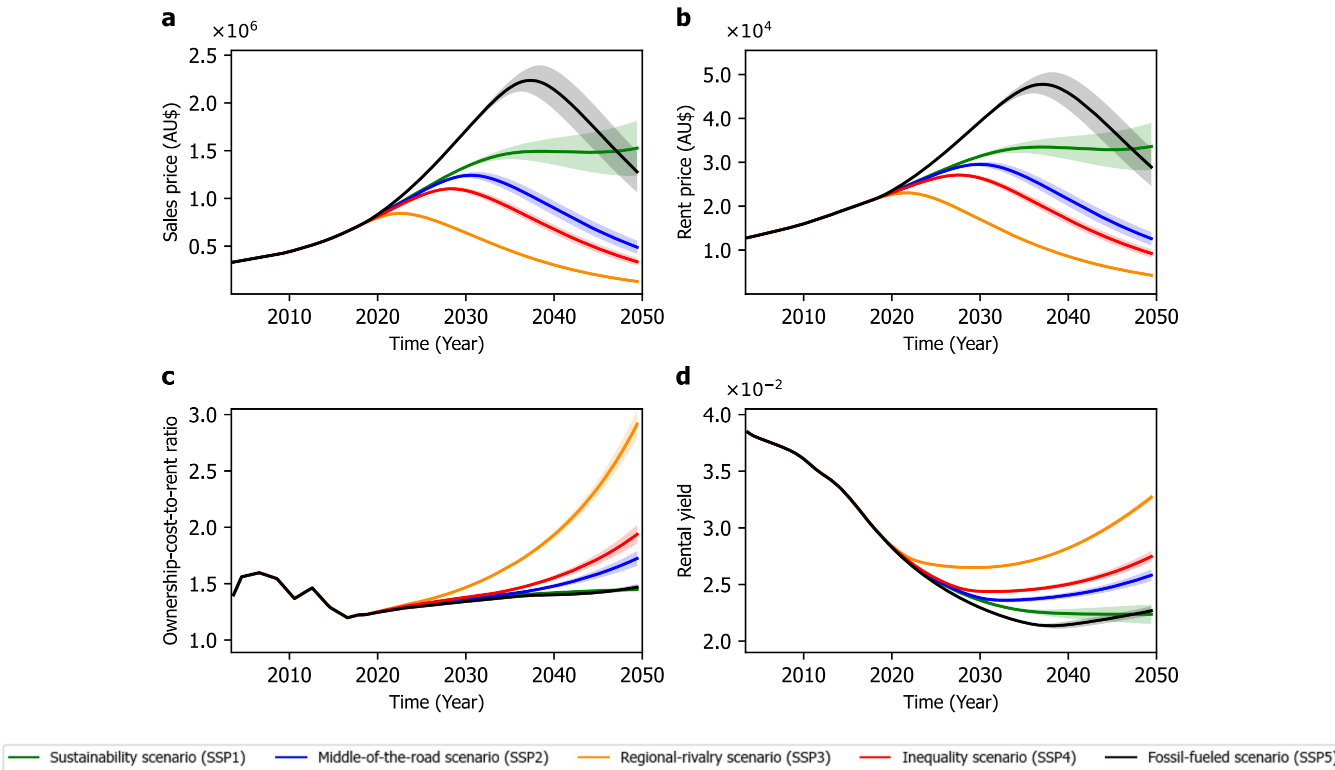

Fig. 4. Market behavior. (a) Sales price. **(b)** Rent price. **(c)** Ownership-cost-to-rent ratio. **(d)** Rental yield.

the ownership costs, which in turn leads households to the rental market. Fig. 5a to 5e show that this shift in demand results in increased demand burden in the rental market and decreased demand burden in the ownership market, leading to an increase in the rental yield. Fig. 5g to 5k demonstrate that higher growth in ownership costs across all socioeconomic pathways intensifies the demand shift from the ownership market to the rental market, resulting in an increased ratio of tenants to owners. The impacts of intervention mechanisms on households display three consistent features across SSPs: market responses are non-linear, heterogeneous, and characterized by tipping points. The patterns observed in Fig. 5f and summarized in Table A1 highlight the sensitivity of housing market dynamics to changes in annual ownership costs growth.

First, increasing annual ownership costs growth leads to a non-linear market response. Rental yields remain largely unchanged under small cost increases but rise sharply once growth in ownership costs exceeds threshold values, with elasticities ranging from approximately 2% to 5% across SSPs in Table A1. Threshold values vary modestly between scenarios; in SSP1, SSP2, and SSP5, sharp increases in rental yields emerge when annual ownership costs growth surpasses around 3%, whereas in SSP3 and SSP4 similar accelerations occur at approximately 1.5%. This non-linearity may stem from households' reluctance to change tenure type, a market elasticity due to transaction costs associated with moving, which discourage frequent relocation in response to minor fluctuations in income or housing price (Raya & Garcia, 2012).

Second, the impacts of higher ownership costs growth are heterogeneous across households. After rental yields cross the relevant threshold, the elasticity of maximum rental yield with respect to ownership costs growth remains relatively stable and does not fluctuate markedly at higher growth rates. This pattern reflects a segment of homeowners who are minimally affected by extreme increases in ownership costs. These households include those without mortgage debt, as well as those exhibiting rigid demand due to strong and persistent preferences for homeownership regardless of price (Wang, 2018).

Third, the interaction of non-linearity and heterogeneity gives rise to tipping points in tenure behavior. Once ownership cost growth exceeds the relevant threshold, demand shifts abruptly toward rental tenure. Under SSP3, for example, a 5% annual increase in ownership costs nearly doubles the tenant-to-owner ratio within a decade relative to the baseline, as depicted in Fig. 5i. After crossing the tipping point, the market settles into a new equilibrium characterized by distinctly different tenure shares and rental yields. These dynamics imply a form of irreversibility, as the new and previous equilibrium points differ substantially across core indicators, including tenure type and rental yields.

Fourth, these features are consistent across SSPs, showing that factors such as transaction costs and persistent preferences for homeownership operate similarly across SSPs. However, the sensitivity of tenure type and rental yield trajectories to intervention mechanisms depends on the degree of imbalance between rental and ownership markets. Scenarios with relatively small differences in imbalance intensity between the two markets, such as SSP3 in Fig. 4d, exhibit stronger increases in the rental market relative to the ownership market. Conversely, scenarios with larger imbalance differentials, such as SSP1 and SSP5, are less sensitive to demand shifts.

4.3. Social outcomes of the housing market

To examine social outcomes of the housing market under climate change, we analyze four indicators: the income-to-ownership-cost ratio (ownership affordability), the income-to-rent ratio (rental affordability), the potential share of informal housing, and the potential for experiencing homelessness, as depicted in Fig. 6.

Ownership affordability declines most abruptly in scenarios characterized strong early price pressures and limited supply responsiveness. Fig. 6a and Table A2 show that ownership affordability falls steeply under SSP5, reaching 50% of its 2020 baseline by 2036. Although it subsequently recovers, it remains 18% below baseline by 2050. SSP1

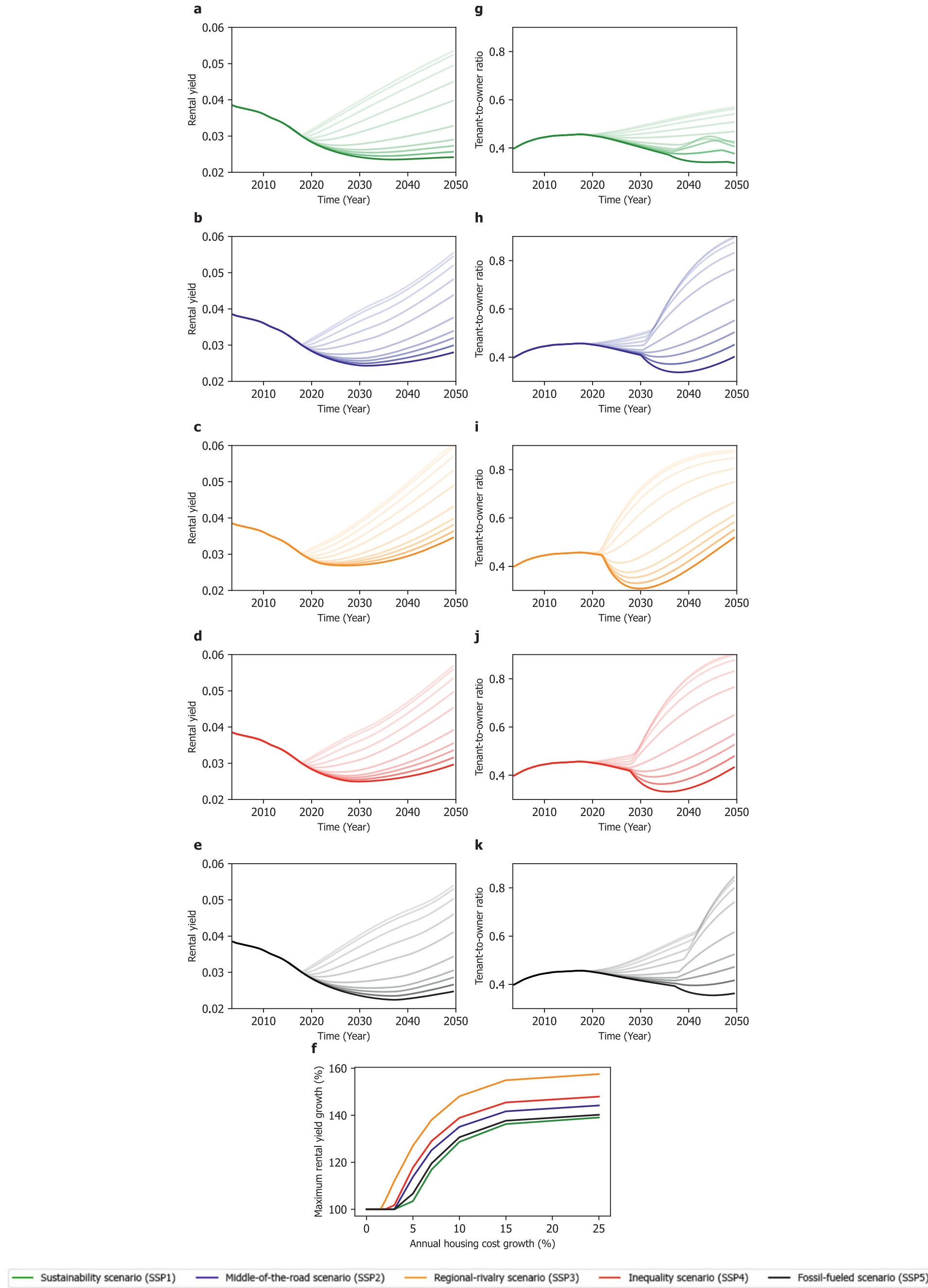

Fig. 5. Market behavior in response to intervention – Increasing ownership cost (0.5%, 1%, 1.5%, 2%, 3%, 5%, 7%, 10%, 15%, 25%). (a) Rental yield trends under SSP1. **(b)** Rental yield trends under SSP2. **(c)** Rental yield trends under SSP3. **(d)** Rental yield trends under SSP4. **(e)** Rental yield trends under SSP5. **(f)** Sensitivity of rental yield toward ownership cost growth. **(g)** Tenant-to-owner ratio trends under SSP1. **(h)** Tenant-to-owner ratio trends under SSP2. **(i)** Tenant-to-owner ratio trends under SSP3. **(j)** Tenant-to-owner ratio trends under SSP4. **(k)** Tenant-to-owner ratio trends under SSP5.

exhibits a similar but less severe pattern: ownership affordability drops to 69% of the baseline in 2036 and stabilizes at approximately 74% by 2050. In SSP2, SSP3, and SSP4, ownership affordability initially declines by 22% in 2030, 2% in 2022, and 16% in 2028, respectively, before rising sharply and increasing by 53%, 143%, and 84% relative to the baseline by 2050.

Rental affordability exhibits a similar pattern, paralleling the trend in ownership affordability but with a steeper early decline, as shown in Fig. 6b and Table A2. Under SSP5, rental affordability falls to roughly 45% of its 2020 baseline by 2036 before rebounding to nearly 97% by 2050. SSP1 also experiences an initial decline to around 77% of baseline, followed by a recovery to approximately 85% by 2050. In SSP2, SSP3, and SSP4, rental affordability initially falls by 16% in 2030, less than 1% in 2022, and 9% in 2028, before rising substantially by 2050, increasing by 109%, 450%, and 182% relative to the baseline, respectively.

The potential share of informal housing generally declines across scenarios, except under SSP5, where reduced affordability modestly increases informality. Fig. 6c shows that under SSP5, affordability pressures marginally raise the likelihood of informal housing among low-income households, although the increase remains small, peaking at less than 1% above baseline in 2021. In contrast, the potential share of informal housing declines in SSP1, SSP2, SSP3, and SSP4, as high prices relative to construction costs result in supply growth outpacing population growth. These outcomes suggest that initial affordability

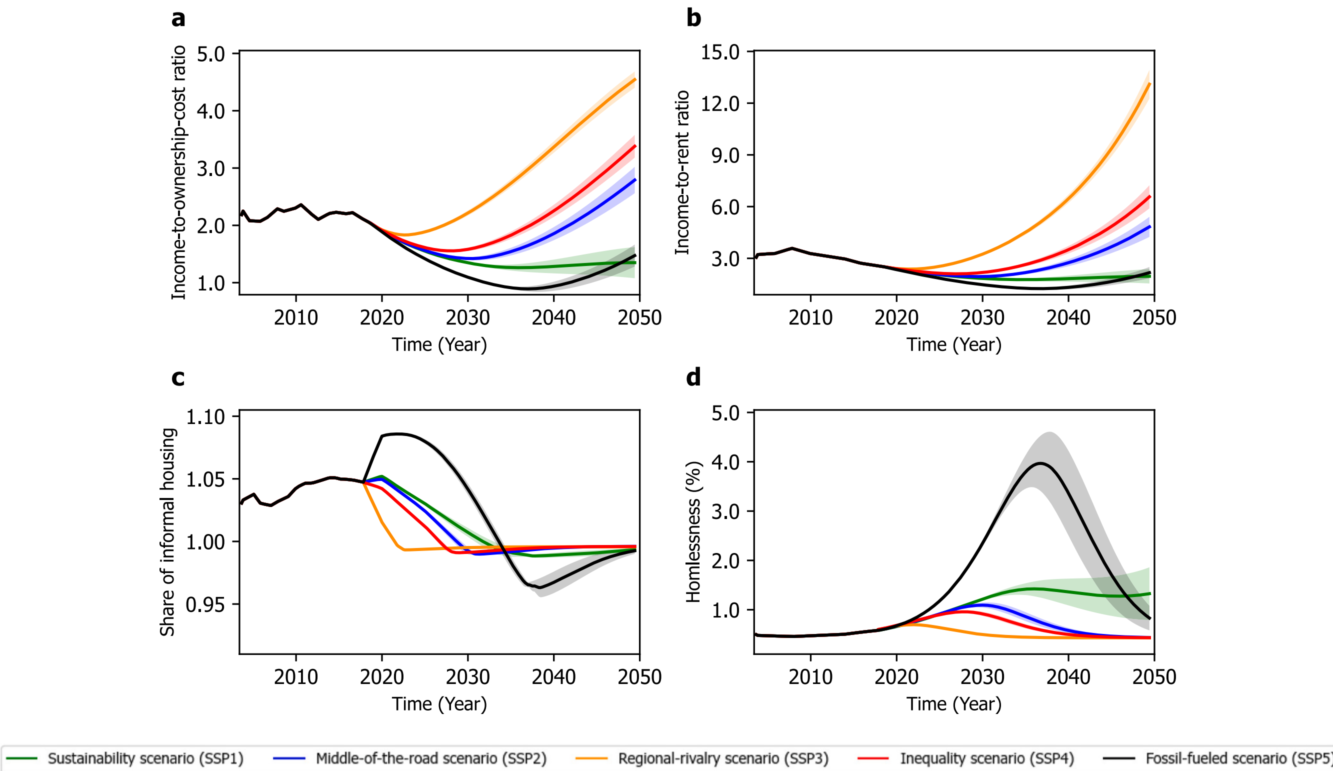

Fig. 6. Social outcomes of SSPs. (a) Income-to-ownership-cost ratio. **(b)** Income-to-rent ratio. **(c)** Potential share of informal housing. **(d)** Potential for experiencing homelessness.

pressures in these scenarios are driven mainly by changes in income and housing costs rather than population growth, potentially reflecting multi-property ownership, investment demand, or high vacancy rates.

While the overall trend shows an increase in the potential for experiencing homelessness across all SSPs, the intensity and timing of peaks differ. Fig. 6d shows that under SSP1, homelessness peaks in 2036 at 104% above 2020 baseline levels, and then declines to 90% above baseline by 2050. SSP2 peaks in 2030 with a 55% increase before declining to 38% below baseline by 2050. SSP3 shows a peak of less than 1% above baseline in 2022, before declining to 38% below baseline by 2050. SSP4 peaks in 2028 with a 33% increase before declining to 40% below baseline by 2050. SSP5 records the most severe peak, rising by 442% in 2036 before declining to 14% above baseline by 2050.

These trajectories in the social outcomes of the housing market underscore three central insights. First, parallel declines in ownership and rental affordability, alongside rising homelessness, highlight the broad exposure of both owners and tenants to market dynamics. Second, trajectories of affordability, informal housing, and homelessness are primarily shaped by changes in housing costs rather than by income. Table A3 shows that although incomes rise between 3% and 11% across SSPs between 2020 and 2050, changes in rents, which range from a decline of 47% to an increase of 40%, and changes in sales prices, which range from a decline of 84% to an increase of 43%, dominate affordability outcomes. Third, these results exhibit the importance of considering the social outcomes of the housing market when interpreting SSPs. For example, under SSP5, despite the highest average income growth and a reduction in the Gini Index, rapid population growth leads to demand that exceeds supply, producing the most severe affordability losses and the largest homelessness peak. Similarly, SSP1 results in declining affordability and persistent homelessness despite income growth and a reduction in the Gini Index.

4.4. Social outcomes across income groups

The mean values of these ratios may not represent the extent and varied experience of the impacted population, especially the most vulnerable groups. To gain a more nuanced perspective on income disparities and their interaction with different SSPs in the face of climate change, Fig. 7 presents the average of the third quintile and the boundary delineating the disparity between the average affordability of households in the first quintile, which represents low-income households, and the fifth quintile, which represents high-income households.

As displayed in Fig. 7, in the case of SSP2, SSP3, and SSP4, both low and high-income households experience enhanced affordability along these pathways. However, the gap widens in terms of rental and ownership affordability between low-income and high-income households, exacerbating existing inequities. This divergence is most pronounced in SSP3. Conversely, under SSP1 and SSP5, where both rental and ownership affordability decrease, the disparity between income groups is less pronounced until 2035. For example, in SSP5, the disparity is 45% of its 2020 level in ownership affordability, and 50% for rental affordability. In SSP1, these figures are 65% and 70%, respectively. This reduced disparity occurs because the affordability of high-income households decreases more compared to low-income households. Subsequently, affordability remains relatively stable under SSP1, while there is a rebound in affordability for SSP5, while the gap between income groups is still less pronounced, i.e., 70% of its 2020 level for ownership and 85% of its 2020 level for rental.

4.5. Social outcomes of intervention mechanisms

We further examine the social outcomes associated with intervention mechanisms, including rising insurance premiums, tax rates, and mortgage rates. Fig. 8 exhibits how interventions worsen both affordability and homelessness relative to the baseline pathways. As illustrated

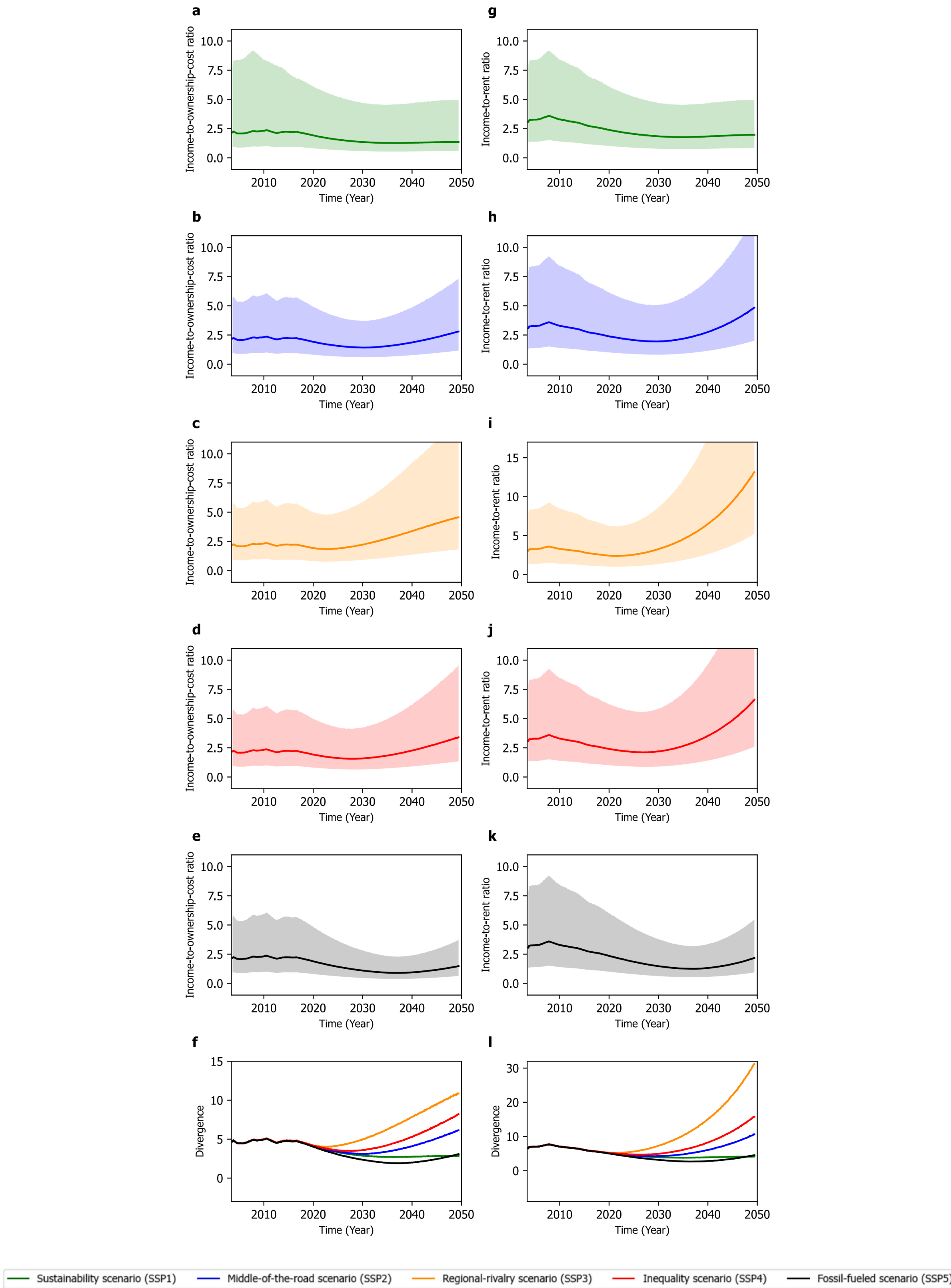

Fig. 7. Affordability. (a) Income-to-ownership-cost ratio under SSP1. **(b)** Income-to-ownership-cost ratio under SSP2. **(c)** Income-to-ownership-cost ratio under SSP3. **(d)** Income-to-ownership-cost ratio under SSP4. **(e)** Income-to-ownership-cost under SSP5. **(f)** Divergence between high-income and low-income households' ownership affordability. **(g)** Income-to-rent ratio under SSP1. **(h)** Income-to-rent ratio under SSP2. **(i)** Income-to-rent ratio under SSP3. **(j)** Income-to-rent ratio under SSP4. **(k)** Income-to-rent ratio under SSP5. **(l)** Divergence between high-income and low-income households' rental affordability.

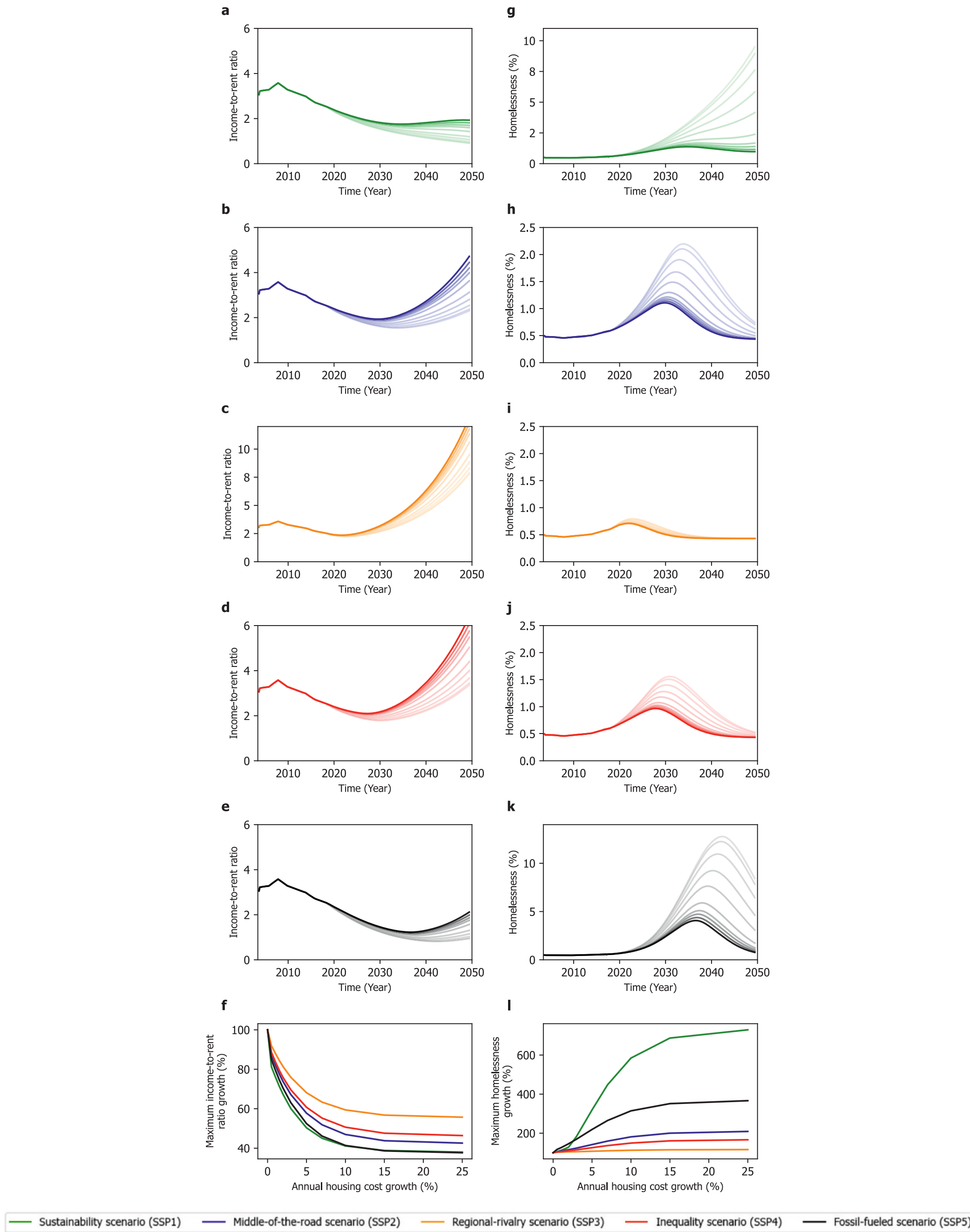

Fig. 8. Social outcomes of interventions - Increasing ownership cost (0.5%, 1%, 1.5%, 2%, 3%, 5%, 7%, 10%, 15%, 25%). (a) Income-to-rent ratio trends under SSP1. **(b)** Income-to-rent ratio trends under SSP2. **(c)** Income-to-rent ratio trends under SSP3. **(d)** Income-to-rent ratio trends under SSP4. **(e)** Income-to-rent ratio trends under SSP5. **(f)** Sensitivity of income-to-rent ratio toward ownership cost growth. **(g)** Homelessness trends under SSP1. **(h)** Homelessness trends under SSP2. **(i)** Homelessness trends under SSP3. **(j)** Homelessness trends under SSP4. **(k)** Homelessness trends under SSP5. **(l)** Sensitivity of homelessness toward ownership cost growth.

in Fig. 8f and l, and summarized in Table A1, SSP1 and SSP5 exhibit the strongest sensitivities to intervention mechanisms. For example, under SSP5, a modest intervention of 0.5% annual growth in ownership costs results in a 16% increase in homelessness relative to the baseline and a 15% decline in rental affordability. Even under SSP2, SSP3, and SSP4, homelessness increases and rental affordability declines, although these effects are more moderate than those observed under SSP1 and SSP5. This observation is primarily due to the demand shifts imposed on society, which can lead to increased financial burdens for households and potentially result in vulnerable populations experiencing homelessness. Moreover, more intense interventions can push the housing market closer to failure in terms of its social outcomes.

5. Discussion

We extend the application of shared socioeconomic pathways (SSPs) to show the divergent social outcome of the housing market. The findings demonstrate that the housing market can amplify climate-related stress rather than acting as a passive endpoint. Two broad insights emerge. First, we extend our understanding of the collapse of social systems driven by the failure of markets to supply affordable housing. This pattern aligns with evidence that Australian housing dynamics are shaped by slow responses arising from planning delays, construction lags, and spatial mismatches (AHURI, 2017; Productivity Commission, 2025). Across all SSPs, changes in housing costs have a more significant impact on affordability than changes in household income. In our analysis, even under SSP1 and SSP5, that represent favorable macroeconomic conditions and reduced inequality, market dynamics can lead to adverse social outcomes. For example, in SSP5, which represents rapid economic growth (Riahi, van Vuuren, Kriegler, Edmonds, O'Neill, Fujimori, Bauer, Calvin, Dellink, Fricko, Lutz, et al., 2017b), high income growth and a declining Gini index are insufficient to offset affordability losses arising from the housing market dynamics. Similarly, SSP1, the green-road scenario, exhibits affordability pressures and elevated homelessness despite its emphasis on economic growth and human well-being (Riahi, van Vuuren, Kriegler, Edmonds, O'Neill, Fujimori, Bauer, Calvin, Dellink, Fricko, Lutz, et al., 2017b). This observation extends empirical evidence showing that sustainability-oriented transitions do not automatically resolve housing vulnerabilities (Garcia-Lamarca et al., 2021). Our results also highlight the disproportionate distribution of affordability stress across income groups. Although overall affordability improves in SSP2, SSP3, and SSP4, high-income households benefit more than low-income households, widening disparities over time.

Our results highlight the need for integration of the housing market dynamics and climate mitigation and adaptation policy. Macroeconomic improvements alone cannot ensure favorable social outcomes of the housing market when affordability is driven primarily by housing cost dynamics. Policies, therefore, need to target the drivers of housing costs, including the use of price growth caps in high-pressure markets, reducing construction times to accelerate supply, using density bonuses to expand housing options, and adopting adaptive zoning systems that respond to real-time indicators such as affordability thresholds and demand surges.

Second, we extend the understanding of housing market behavior under a range of intervention mechanisms. Across all SSPs, interventions that increase ownership costs lead to nonlinear and heterogeneous responses with reference to the tipping points. These responses arise from transaction costs (Raya & Garcia, 2012) and rigid demand (Wang, 2018). The observed patterns are consistent with bifurcated regime dynamics, in which systems respond gradually until a critical threshold is crossed, after which dynamics shift abruptly (Scheffer et al., 2003). Crossing these thresholds pushes the housing market into new equilibrium states marked by rapid increases in rental demand, higher rental yields, and declining rental affordability. Comparable dynamics have been documented in past crises where sudden demand shifts triggered cascades of foreclosures, disinvestment, and system-wide instability, for example in the 2008 financial crisis (Immergluck, 2009). Our results show that interventions intended to stabilize prices and pool risks in response to climate threats (Jarzabkowski et al., 2019) can counterproductively deepen social inequities by reducing rental affordability and increasing homelessness. This outcome aligns with emerging evidence that insurance-related cost increases are becoming a dominant driver of housing costs under climate change in Australia (Climate Council of Australia, 2022).

These results highlight the need for intervention mechanisms that are carefully calibrated to avoid triggering nonlinear tenure shifts or worsening social outcomes. Relevant policies include government-backed reinsurance schemes, premium caps for disadvantaged households, and early warning indicators to monitor proximity of the housing market trajectories to tipping points (Ayub et al., 2020).

6. Conclusions

We extend the study of housing market behavior to extreme contexts resulting from exogenous disruptions associated with climate change, including higher insurance premiums. Our analysis uses shared socioeconomic pathways (SSPs), which represent distinct combinations of socioeconomic challenges related to mitigation and adaptation at both the country level and household level across different socioeconomic groups. We explore a nuanced perspective on the social outcomes of SSPs and intervention mechanisms in the housing market, focusing on: (i) the housing affordability crisis, and (ii) its vulnerability.

The intensity of the housing crisis is measured through affordability indicators. Vulnerability is a concept that encompasses exposure and system sensitivity to potential impacts (Adger, 2006). In this context, it refers to the sensitivity of social costs associated with climate change risks. Our analysis of SSPs in relation to these challenges reveals distinct patterns. The sustainability (SSP1) and fossil-fueled scenarios (SSP5) are characterized by high levels of both housing affordability crisis and vulnerability, while the middle-of-the-road (SSP2) and inequality scenarios (SSP4) display moderate levels of housing affordability crisis and vulnerability. In contrast, the regional-rivalry scenario (SSP3) demonstrates relatively low levels of housing affordability crisis and vulnerability under unprecedented conditions.

A consistent pattern across all SSPs indicates that individuals within the rental market disproportionately experience housing unaffordability compared to those in the ownership market. This variation in market dynamics not only affects rental versus ownership markets but also leads to disparities between low-income and high-income households. Notably, even in scenarios where overall affordability improves, such as SSP2, SSP3, and SSP4, the gap between low- and high-income households widens. Additionally, intervention mechanisms aimed at reducing these disparities may lead to unintended social outcomes, including reduced housing affordability and an increased rate of homelessness. The impacts of such interventions exhibit non-uniform and non-linear behavior, often reaching a tipping point that shifts market demand. Once these tipping points are exceeded, socioeconomic factors can trigger forced migrations as they surpass the system's capacity to adapt (e.g., Marotzke et al., 2020).

Our findings advance theoretical understanding of just urban resilience by empirically demonstrating how climate, economic, and social dynamics interact to shape pathways toward housing justice (Diezmartínez & Short Gianotti, 2024; Tao et al., 2025). We demonstrate that future developments of the SSPs need to examine housing dynamics as an active driver of social outcomes under climate change rather than as a passive endpoint. By exploring disparate social outcomes, our analysis contributes to understanding of urban resilience through the housing system (Meerow & Newell, 2019) and advances the distributional dimension of justice by showing how disadvantaged groups are disproportionately affected (Meerow et al., 2019). The varying impacts of climate pathways through the housing market also highlight challenges for achieving just housing outcomes (e.g., Culwick Fatti, 2022) and underscore the need to benchmark social outcomes of the housing market within climate change policy design and intervention mechanisms to ensure responsive and equitable adaptation (e.g., Swanson, 2025). In the face of unprecedented changes in climate, understanding the potential social ramifications of interventions is crucial for developing effective contextual responses to promote a more equitable housing market.

Our findings translate into practice by informing the design of targeted policy responses to the housing affordability crisis under climate change. Effective policies need to address the drivers of housing costs while avoiding the triggering of nonlinear shifts associated with tipping points. Relevant policy levers operate across market, regulatory, and land-use domains. On the demand side, regulatory and market-based instruments, such as price-growth caps in high-pressure markets and insurance or cost-premium caps for disadvantaged households, can mitigate affordability pressures. On the supply side, reducing construction timelines can accelerate housing delivery, while land-use policies, including density bonuses for affordable housing and adaptive zoning, can expand supply and limit housing cost escalation. All such policies require continuous calibration and should be supported by early-warning systems capable of detecting emerging tipping points in housing market dynamics, thereby enabling timely policy adjustment and the avoidance of nonlinear market responses.

While this study focuses on Australia, its findings have broader implications for the dynamics of other housing markets in the face of climate change and housing crises. Although model inputs will vary for other housing markets, the model can be adapted for different areas. The results inform targeted intervention policies to support vulnerable populations and address the exacerbation of inequities in the housing market. Such analysis can also inform preparedness for a wider range of scenarios to avoid unintended consequences in the form of migration (Bangura & Lee, 2023), increasing inequality, and adverse impacts on vulnerable populations.

The primary objective of our top-down approach is to translate climate scenarios into broader social outcomes within the housing market under extreme conditions induced by climate change. We use macroeconomic models grounded in the asset-price approach to explore the extent of the housing affordability crisis and the impacts of national intervention mechanisms, such as taxation and social housing at both the country level and household level across different socioeconomic groups. Regional-level studies can be developed by integrating internal migration models, such as gravity models (Reimann et al., 2023), into our model to capture local variations and differences in social outcomes across different areas.

Our macroeconomic model is calibrated using historical data and market behaviors, integrating the impact of heterogeneous behavioral responses (Bakkensen & Ma, 2020), climate change perception (Bernstein et al., 2019; Gallagher, 2014), social interactions (Hu, 2022), and attitudes toward wealth accumulation and market financialization. However, the model does not consider behaviors beyond historical human experiences. Specifically, while it accounts for market trends toward financialization and household tenure changes driven by risk perception, these behaviors are based on historical data. In addition to exploring the impact of emergent behaviors, future research could extend this by exploring the pricing strategies of insurance premiums and their local impacts (DellaVigna & Gentzkow, 2019).

CRediT authorship contribution statement

Peyman Habibi-Moshfegh: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Nader Naderpajouh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Conceptualization. **Mohamadali Morshedi:** Writing – original draft, Validation, Methodology, Data curation, Conceptualization. **Saeideh Fallah-Fini:** Validation, Methodology, Formal analysis. **Woon-Weng Wong:** Validation, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Fig. A1 illustrates the rental affordability distributions across HILDA survey waves. The raw income-to-rent ratios in 2006, 2011, 2016, and 2021 are highly right-skewed, as shown in Fig. A1 a–d. However, applying a logarithmic transformation, as shown in Fig. A1e–h, yields more symmetric distributions. This comparison suggests that rental affordability is well approximated by a lognormal distribution and shows that the broad distributional shape of affordability has remained relatively stable over time

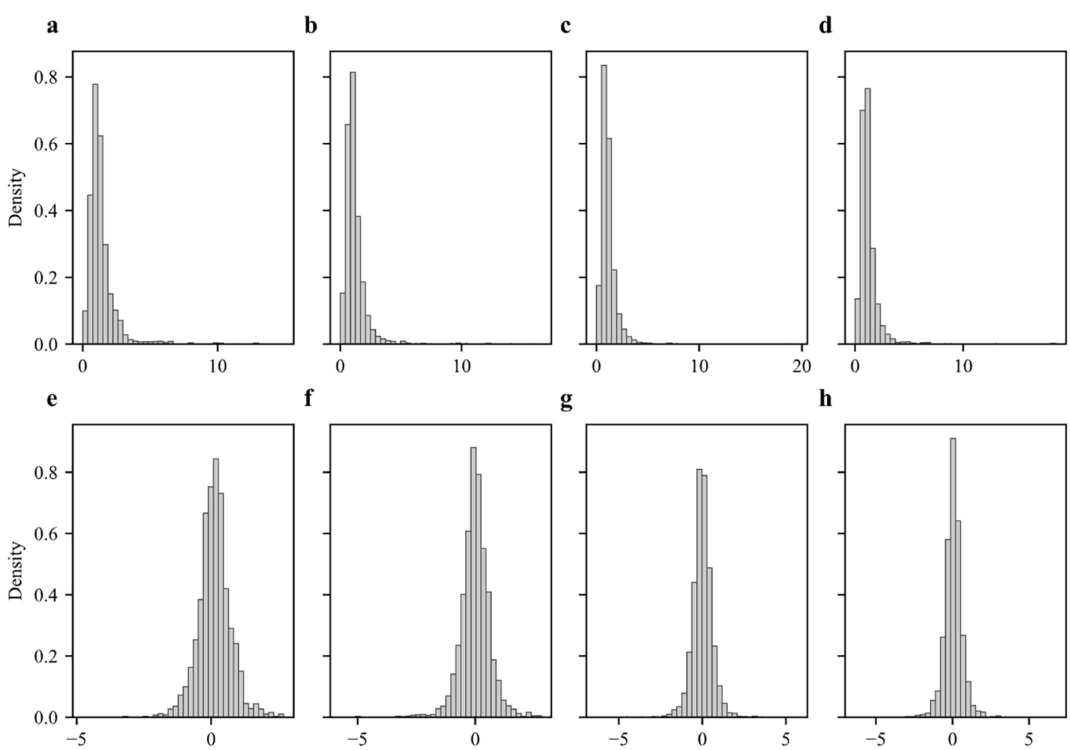

Fig. A1. Distribution of rental affordability across HILDA survey waves. (a–d) report the distribution of tenants' income-to-rent ratios for survey years 2006, 2011, 2016, and 2021, respectively. **(e–h)** present the corresponding distributions on a logarithmic scale for the same four survey waves (2006, 2011, 2016, and 2021).

Table A1 presents the sensitivity of rental yields, homelessness rates, and rental affordability to alternative annual ownership cost growth scenarios under SSP1 to SSP5, expressed as percentage deviations from their 2020 baselines and as elasticities

Table A1
Sensitivity of rental yields, homelessness, and rental affordability to annual ownership cost growth under SSP1–SSP5.

Scenarios	Annual ownership cost growth (%)	Rental yield		Homelessness rate		Rental affordability	
		Change percentage	Elasticity	Change percentage	Elasticity	Change percentage	Elasticity
SSP1	0.5	0	0	5.5	10.99	−18.78	−37.57
	1.5	0	0	19.78	13.19	−28.58	−19.06
	3	0	0	82.96	27.65	−40	−13.33
	7	16.89	2.41	348.06	49.72	−54.97	−7.85
	10	28.7	2.87	484.47	48.45	−58.87	−5.89
	15	36.28	2.42	586.78	39.12	−61.16	−4.08
	25	39.06	1.56	629	25.16	−61.99	−2.48
SSP2	0.5	0	0	5.25	10.51	−12.81	−25.61
	1.5	0	0	11.83	7.88	−22.34	−14.89
	3	0	0	23.62	7.87	−32.87	−10.96
	7	25.14	3.59	59.56	8.51	−48.14	−6.88
	10	35.1	3.51	81.22	8.12	−53.04	−5.3
	15	41.69	2.78	100.11	6.67	−56.21	−3.75
	25	44.18	1.77	108.98	4.36	−57.42	−2.3
SSP3	0.5	0	0	3.38	6.76	−8.07	−16.14
	1.5	0	0	4.06	2.71	−15.5	−10.33
	3	12.09	4.03	5.37	1.79	−24.11	−8.04
	7	38.06	5.44	9.87	1.41	−36.65	−5.24
	10	48.08	4.81	12.67	1.27	−40.6	−4.06
	15	54.93	3.66	15.05	1	−43.24	−2.88
	25	57.53	2.3	16.11	0.64	−44.29	−1.77
SSP4	0.5	0	0	3.21	6.42	−11.43	−22.86
	1.5	0	0	7.36	4.91	−20.48	−13.65
	3	1.77	0.59	14.75	4.92	−30.47	−10.16
	7	29.03	4.15	36.57	5.22	−44.75	−6.39
	10	38.92	3.89	49.4	4.94	−49.36	−4.94
	15	45.47	3.03	60.87	4.06	−52.41	−3.49
	25	47.94	1.92	66.32	2.65	−53.61	−2.14
SSP5	0.5	0	0	16.76	33.51	−15.04	−30.09
	1.5	0	0	35.64	23.76	−25.34	−16.9
	3	0	0	69.25	23.08	−36.99	−12.33
	7	19.52	2.79	165.03	23.58	−53.86	−7.69
	10	30.67	3.07	214.31	21.43	−58.63	−5.86
	15	37.7	2.51	251.34	16.76	−61.35	−4.09
	25	40.22	1.61	266.34	10.65	−62.3	−2.49

Table A2 summarizes key changes in four social outcomes, expressed as percentage deviations from their 2020 baselines under SSP1 to SSP5. For each outcome, the percentage change in 2050 and the extreme percentage change over the projection period are reported

Table A2
Divergence in long-term social outcomes across SSP1–SSP5.

Social outcome	Year	SSP1	SSP2	SSP3	SSP4	SSP5
Ownership affordability	Change (%) (year)	−26.11 (2050)	52.65 (2050)	142.54 (2050)	83.62 (2050)	−17.50 (2050)
	Extreme (%) (year)	−30.90 (2036)	−22.33 (2030)	−2.18 (2022)	−15.55 (2028)	−50.07 (2036)
Rental affordability	Change (%) (year)	−15.01 (2050)	109.03 (2050)	450.24 (2050)	182.08 (2050)	−3.35 (2050)
	Extreme (%) (year)	−23.43 (2034)	−15.89 (2029)	−0.26 (2021)	−9.72 (2026)	−44.69 (2036)
Share of informal housing	Change (%) (year)	−5.20 (2050)	−4.72 (2050)	−1.00 (2050)	−3.94 (2050)	−8.56 (2050)
	Extreme (%) (year)	−0.04 (2021)	−0.04 (2021)	−0.09 (2021)	−0.05 (2021)	0.03 (2021)
Homelessness rate	Change (%) (year)	90.49 (2050)	−38.04 (2050)	−37.67 (2050)	−39.98 (2050)	13.72 (2050)
	Extreme (%) (year)	104.43 (2036)	54.87 (2030)	1.02 (2021)	32.83 (2027)	442.73 (2036)

Table A3 reports percentage changes in household income, rent prices, sales prices, rental affordability, and ownership affordability for each SSP between 2020 and 2050. Log-change decompositions quantify the contribution of income and housing costs to changes in affordability, allowing a consistent comparison of how shifts in housing costs and income levels shape both rental and ownership outcomes across scenarios

Table A3
Decomposition of changes in affordability under SSPs.

Indicator	Component	SSP1	SSP2	SSP3	SSP4	SSP5
Δ Income (%)		8.21	6.83	3.43	8.31	10.56
Δ Rent price (%)		40.16	−47.37	−81.41	−61.13	17.42
Δ Sales price (%)		75.99	−43.46	−84.16	−60.74	43.19
Δ Rental affordability (%)		−15.01	109.03	450.24	182.08	−3.35
Δ Ownership affordability (%)		−26.11	52.65	142.54	83.62	−17.5
Contribution to Δln(Ownership affordability)	Income	−0.26	0.16	0.04	0.13	−0.52
	Ownership cost	1.26	0.84	0.96	0.87	1.52
Contribution to Δln(Rental affordability)	Income	−0.31	0.09	0.02	0.08	−1.67
	Rent	1.31	0.91	0.98	0.92	2.67

Data availability

All datasets are publicly available, with detailed descriptions provided in the Data Collection Section. The model is developed in AnyLogic software. The Java code necessary to reproduce the results is available in a public GitHub repository (https://github.com/PH-Code-hub/Stock_Flow_Dynamic.git) and Zenodo (doi: https://doi.org/10.5281/zenodo.11526448).

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