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The impact of urban population on housing cost: the case of Australia

Chris Leishman[1], Weidong Liang[1] and Nicholas Sim[2]✉

Rapid population expansions in urban areas have significant implications for housing costs, creating challenges for housing affordability. However, estimating the causal effect of population on housing costs is challenging due to various confounding issues, such as unobserved location-specific attributes, measurement error, and the potential bi-directional relationship between population and housing costs. To address them, we adopt a city-level analysis and introduce a novel instrumental variable (IV) that enables us to employ fixed effects IV estimation. Our findings indicate that housing costs tend to increase at a faster rate than population growth. As individuals and households with lower incomes tend to allocate a larger proportion of their earnings to housing expenses, an upward trajectory of housing costs may dramatically widen the inequality in income after housing expenditure.

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INTRODUCTION

Population expansions contribute to urban agglomeration and productivity growth, but they also come with the potential drawback of increasing social costs, such as the cost of housing. Balancing the benefits and costs of urban agglomeration is a crucial objective for all urban planners and policymakers who play a role in planning housing affordability. Although the economic advantages of larger cities, including population size and density, have been extensively studied[1,2], there is a scarcity of quantified evidence regarding the specific costs associated with population growth, particularly in relation to housing. For policymakers, having such evidence on the costs and benefits of population growth is important for managing the expansion of the city population.

As such, estimating the effects of city population on urban costs has garnered significant interest over the years. However, obtaining such estimates is far from straightforward—besides the usual concerns like omitted variable bias, the presence of measurement error could lead to attenuation bias, a situation where the estimated effect is biased towards zero and therefore understates the true effect of interest. Moreover, the high cost of living in urban areas may discourage population growth[3], leading to a reverse effect. To address these concerns, we propose a new approach to estimate the elasticity of housing cost with respect to city population using Australian panel data. Our work employs a fixed effects model to eliminate the confounding effects of unobserved heterogeneity, known as fixed effects, such as unobserved location attributes that might jointly influence population growth and housing cost. To address the confounding issues of reverse causality and measurement error, we propose a new instrumental variable (IV) for the city population to identify its effect on housing costs.

For our IV to be applicable within a panel fixed effects framework, it must contain both cross-sectional and time variations. To this end, we construct a Bartik-style IV by interacting data on city climate with visa issuance. A Bartik-style IV is one that is created by taking the interaction between a time-varying variable common across all cross-sectional units and a time-invariant variable that varies cross-sectionally. This interaction term will create an IV that exhibits variations across both time and space, ensuring that its effect on the endogenous variable (i.e., city population) will not be washed out by the inclusion of fixed effects into the regression model.

In our case, our time-varying variable is related to overseas immigration, which directly contributes to population growth and is measured by the log of the visas issued by the Australian government. Immigration has been a significant driver of Australia's population expansion since 1995, and visa issuance, decided by the Australian federal government in response to the country's labor market and economic conditions[4], determines the annual number of new overseas migrants entering Australia. For our work, it is important to emphasize that Australian cities do not have the authority to influence visa issuance levels, which implies that visa issuance from a city planner's perspective is taken as given. Our cross-sectional variable is city climate, which influences people's location choices and, consequently, city population levels[5,6]. We adopt the climate zone classification provided by the Bureau of Meteorology (BoM) in Australia to indicate the climate types of cities. Like visa issuance, it is reasonable to assume that climate is exogenous[7]. Thus, our IV for city population, which is constructed by interacting climate with visa issuance, should be plausibly exogenous.

We implement two-stage least squares (2SLS) regression using our climate-visas IV as an instrument for the city population. In the first stage, we find a positive relationship between the number of visas issued and the population, particularly in cities with favorable climates. This result aligns with the hypothesis that attractive climates attract more migrants, leading to more population growth[8]. Our second-stage estimates indicate that a 1% increase in city population is associated with an average increase in home prices ranging from 1.16% to 1.59% and an average increase in rental prices ranging from 1.84% to 1.97%. These elasticities suggest that housing costs tend to increase at a faster rate than population growth.

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[1]School of Business (UniSA Business), University of South Australia, Adelaide, Australia. [2]School of Business, Singapore University of Social Sciences, Singapore, Singapore.
✉email: nicholassimcs@suss.edu.sg

Overall, our study highlights the concerning trend that housing costs, especially rental costs, tend to rise more quickly than population growth. As individuals and households with lower incomes tend to allocate a larger proportion of their earnings to housing expenses, an increase in housing cost induced by population growth can significantly exacerbate the inequality of income net of housing expenditure. Therefore, proactive measures are needed to address the challenges posed by population growth on housing affordability.

We now provide a brief review of the literature and highlight the relevance of our paper to the existing literature. Our paper focuses on estimating the effect of population on housing prices across Australian cities. It is related to the broader literature that focuses on the issue of housing affordability. Galster and Lee[9] offer a systemic review of the international literature that explores the primary causes and effects of housing affordability. The literature reviewed spans the US, Europe, Asia, and South Africa, suggesting that housing affordability concerns are an international phenomenon. While our paper focuses on population growth as a contributor to the rise in housing costs, it should be emphasized that the drivers of housing affordability are multifaceted. These drivers may include direct supply-side factors such as construction cost and regulations[10,11] as well as demand-side factors such as income inequality[12–14].

Our study on the response of housing prices to population growth can also be understood from the lens of the effects of urban amenities. Pioneering this idea is Glaeser et al.[15], who argue that the phenomenon of rents rising faster than wages can be explained by the rising demand for urban amenities. Diamond[16] further argues that cities that are disproportionately productive for high-skilled workers attracted a larger share of skilled workers, leading to an increase in local productivity, workers' wages, and eventually improved local amenities that further fueled the demand for housing in already concentrated areas. Affirming this observation is Caragliu et al.[17], who find that even after accounting for production externalities, consumption externalities play an important role in explaining the correct city size effect.

More broadly, our paper is related to studies that focus on the issue of urban inequality and sustainability. Caragliu and Del Bo[18] explore whether urban smartness, characterized by human and social capital, transportation and ICT infrastructure, natural resources, and E-government, may cause the increase in digital divide among urban dwellers. They find, reassuringly, that contrary to the concern that within-city digital inequality is caused by the adoption of smart technologies in cities, urban smartness is, in fact, negatively associated with the internal digital divide. However, this is not to say that urban inequalities cannot arise in other forms. In the context of energy and transport poverty, Furszyfer Del Rio and collaborators[19] study four countries with very different national cultures, contexts and levels of wealth and find that low-income households and minorities are at greater risk of simultaneously experiencing energy and transport poverty. Additionally, Lenzi and Perucca[20] find that more intrinsic forms of inequalities, such as interpersonal inequality that is commonly overlooked, are more prominent in larger cities relative to smaller ones. Such inequalities, they argue, should not be downplayed as they can significantly lead to discontent among urban dwellers.

RESULTS

In this section, we present the estimation results from the OLS, reduced form, and 2SLS regressions. Details on the data and statistical models are provided under Methods. Further results from our robustness checks are provided in the Supplementary Information.

Table 1. OLS estimates of city population on housing cost.

	(1)	(2)	(3)	(4)
Dependent Variable	$\log(\text{home price}_{is,t})$		$\log(\text{rental price}_{is,t})$	
$\log(\text{population}_{is,t})$	0.461*** (0.0001)		0.384*** (0.0004)	
$\log(\text{population}_{is,t-1})$		0.412*** (0.0003)		0.297*** (0.0023)
$\log(\text{housing supply}_{is,t})$	0.0277 (0.2722)	0.0305 (0.2292)	−0.0685** (0.0188)	−0.0586** (0.0248)
$\text{employment rate}_{is,t}$	−0.000346 (0.9333)	0.0000233 (0.9956)	0.00167 (0.5256)	0.00227 (0.3842)
Adj. R^2	0.72	0.72	0.79	0.78
City FE	Yes	Yes	Yes	Yes
State year FE	Yes	Yes	Yes	Yes
Observations	4988	4821	4415	4248

Robust standard errors clustered at the city level are reported in parentheses.
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

OLS estimates

Table 1 presents the OLS estimates of the elasticities of home and rental prices with respect to current (population_{ist}) and lagged ($\text{population}_{ist-1}$) city population based on Eq. (1). The results indicate that the elasticities of home prices are 0.461 and 0.412, respectively, while the elasticities of rental prices are 0.384 and 0.297, respectively. All the OLS estimates show that the city population is statistically significant for housing cost at the 1% level. Interestingly, although the log of housing supply and employment rate shows the expected signs, they are statistically insignificant, suggesting that population growth plays a more significant role in driving home and rental prices in Australia than housing supply and employment.

Reduced form estimates

Table 2 presents the reduced form estimates of the effect of our instrument ($\text{favorable climate}_{is} \times \log(\text{visas}_{t-1})$ or $\textit{favorable climate}_{is} \times \log(\text{visas}_{t-2})$) on home and rental prices based on Eq. (3). In Columns (1) and (2), the estimated effects of our instrument on home prices are 0.578 and 0.772, respectively. This indicates that, on average, a 1% increase in visa issuance in the previous year ($t-1$) or previous two years ($t-2$) would lead to an additional 0.578% or 0.772% increase in home prices in cities with a favorable climate compared to those without. In Columns (3) and (4), the estimated effects of our instrument on rental prices are 0.611 and 0.678, respectively. This indicates that, on average, a 1% increase in visa issuance in the previous year or two years would lead to an additional increase in rental prices by 0.611% to 0.678% in cities with a favorable climate compared to those without. These estimates are statistically significant at the 1% level, which suggests that population growth through immigration is a significant driver of housing costs, especially in cities with favorable climates.

Two-stage least squares estimates

Table 3 presents the 2SLS estimates of Eq. (1) with city population instrumented as expressed by Eq. (2). The first-stage estimation results show that the coefficients on our IV are positive and statistically significant at the 1% level. Specifically, an increase of 1% in visa issuance by the federal government in year $t-1$ is associated with an additional increase of 0.035% to 0.050% in population in cities with a favorable climate compared to those without it (see Columns (1) and (3) of the lower panel in Table 3).

Table 2. Reduced form estimates of instruments on housing cost.

Dependent variable	(1) log(home price$_{is,t}$)	(2)	(3) log(rental price$_{is,t}$)	(4)
Favorable climate$_{is}$ × log(visas$_{t-1}$)	0.0568*** (0.0002)		0.0611*** (0.0021)	
Favorable climate$_{is}$ × log(visas$_{t-2}$)		0.0773*** (0.0000)		0.0678*** (0.0011)
Log(housing supply$_{is,t}$)	0.0522** (0.0358)	0.0331 (0.1287)	−0.0283 (0.1093)	−0.0292 (0.1013)
employment rate$_{is,t}$	0.00162 (0.7022)	0.000696 (0.8715)	0.00263 (0.2970)	0.00273 (0.2846)
Adj. R^2	0.72	0.72	0.78	0.78
City FE	Yes	Yes	Yes	Yes
State year FE	Yes	Yes	Yes	Yes
Observations	4988	4821	4415	4248

Robust standard errors clustered at the city level are reported in parentheses.
$*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Table 3. 2SLS Estimates of city population on housing cost.

Dependent variable (second stage)	(1) log(home price$_{is,t}$)	(2)	(3) log(rental price$_{is,t}$)	(4)
Log(population$_{is,t}$)	1.164*** (0.0001)	1.589*** (0.0000)	1.843*** (0.0009)	1.972*** (0.0004)
Log(housing supply$_{is,t}$)	−0.00930 (0.7866)	−0.0620* (0.0986)	−0.217** (0.0345)	−0.234** (0.0350)
Employment rate$_{is,t}$	−0.00626 (0.1722)	−0.0104** (0.0271)	−0.00910 (0.1576)	−0.0109* (0.0961)
Dependent Variable (first-stage)	log(population$_{is,t}$)		log(population$_{is,t}$)	
Favorable climate$_{is}$ × log(visas$_{t-1}$)	0.0499*** (0.0000)		0.0347*** (0.0000)	
Favorable climate$_{is}$ × log(visas$_{t-2}$)		0.0496*** (0.0000)		0.0357*** (0.0000)
Kleibergen–Paap Wald *F*-Statistic	97	106	73	77
Stock and Yogo critical value (10%)	16.38	16.38	16.38	16.38
City FE	Yes	Yes	Yes	Yes
State year FE	Yes	Yes	Yes	Yes
Observations	4988	4821	4415	4248

Robust standard errors clustered at the city level are reported in parentheses.
$*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Similarly, an increase of 1% in visa issuance in year $t - 2$ results in an additional increase of 0.036–0.049% in population in cities with a favorable climate. Furthermore, the Kleibergen–Paap first-stage *F*-statistics are all greater than the critical value at the 10% level, indicating that our IV is a powerful instrument for the city population.

The second-stage estimation results in Table 3 confirm that city population expansions would drive up both home and rental prices. For example, a 1% increase in city population would, on average, lead to a 1.164% to 1.589% increase in home prices (see Columns (1) and (2) of Table 3). Similarly, a 1% increase in city population would result in a 1.843% to 1.972% increase in rental prices on average (see Columns (3) and (4) of Table 3). Comparing the OLS estimates of the effects of city population reported in Table 1 with the 2SLS estimates reported here, we observe that the latter are about three times larger than the former. This discrepancy highlights the downward bias in the OLS estimates if confounding effects such as reverse causality and measurement error are not accounted for. Therefore, the 2SLS results underscore the importance of addressing these issues when estimating the impact of city populations on housing costs, as the impact size could be vastly underestimated.

Our 2SLS results are consistent with the conclusion drawn by Combes et al.[8], namely, that city population expansions inevitably lead to increases in housing costs. However, our second-stage estimates of city population on housing costs are considerably larger than those reported by them (see Table A1 on page 1586 in Combes et al.[8] for their two-stage least squares estimates). This disparity may be attributed to the application of an instrumental variable approach within a panel data set, allowing us to address the issues of reverse causality, measurement errors, and unobserved heterogeneity. On the contrary, Combes et al.[8] conducted their analysis using a pooled cross-sectional regression without accounting for the fixed effects of the city, which could confound the impact of the city population on housing costs.

DISCUSSION

The study explores the implications of the increase in urban population in terms of housing costs in Australia. We find strong evidence that city populations have a significant impact on housing costs. Furthermore, our elasticity estimates suggest that housing costs, particularly rental costs, tend to increase at a faster rate than population growth.

As such, our paper underscores the potential for population growth to exacerbate the inequality of income after housing expenditure, which can be driven by rising housing costs. Several studies have highlighted the link between population growth and housing costs. Using data from Organization for Economic Co-operation and Development (OECD) countries, Gevorgyan[21] finds that if population growth increases by one percentage point, house price growth increases by 1.4 percentage points. Using data from Amsterdam and Paris, Francke and Korevaar[22] find that a one percentage point increase in the current birth rate increases house prices about 25–30 years later by 4–5%. Our paper contributes to this literature by showing that housing costs may escalate at a faster rate than population growth in the Australian city-level context. As individuals and households with lower incomes tend to allocate a larger proportion of their earnings to housing expenses[23], an upward trajectory of housing costs may dramatically widen the inequality in income net of housing expenses.

Methodologically, our paper contributes to the existing literature in the following ways. Firstly, to the best of our knowledge, our study is among the first to estimate the effect of city population on housing costs by implementing an instrumental variable panel data approach. Previous studies by Thomas[24], Richardson[25], and Henderson[26] have examined the association between urban costs and population expansion. These studies have found a positive relationship between population size and the cost of living[24], and have documented that infrastructure spending, commuting time, and rental prices may increase due to urbanization[25,26]. However, as they do not consider an identification strategy, their point estimates could be biased and inconsistent. Combes et al.[8], on the other hand, employ an instrumental variable approach as an identification strategy to estimate the elasticity of housing costs (i.e., house and land prices) with respect to city population using French data. However, their study uses pooled cross-sectional data and does not exploit panel data. Thus, their estimation approach cannot account for city fixed effects, which may jointly drive both population and housing costs. In our study, we employ an instrumental variable approach in a panel data set so that we may address both the issue of reverse causality and unobserved heterogeneity.

Secondly, our paper introduces a new method for estimating the relationship between urban population and housing cost. Previous studies have instrumented city population using historical population levels[1,8,27,28]. However, historical population levels may be unsuitable as instruments as they are endogenous to housing cost[29,30]. Other studies have explored using geological characteristics such as fertile soil to explain population size[31,32], but using such data to construct an instrument for population size may be difficult to justify for a country like Australia, whose economy is not primarily driven by the agricultural sector. Finally, there are studies that link city population to city amenities, such as the number of hotel rooms[8,33], but the theoretical justification for this relationship may be challenging and such fine-level data may not be available. Our approach has the advantage of constructing an instrument using publicly accessible data on national-level visa issuance and city climate, which makes the construction of such an instrument potentially more feasible for studies based in other countries.

METHODS

Data

Our dataset comprises a panel of 513 Australian cities, specifically defined as Local Government Areas (LGA), covering the period from 2003 to 2016. The housing cost and supply data are obtained from the Australian Urban Research Infrastructure Network (AURIN) and are reported on a monthly basis. To capture housing costs in cities, we use the average home and rental prices transacted for each city. Additionally, the total number of houses listed in the market is used as a proxy for city housing supply. In order to align with the frequency of our data (population, visa issuance, and employment), we aggregate the monthly data into yearly frequencies.

Table 4. Summary Statistics.

Variable	obs.	mean	s.d.	min.	max.
log(population)	7140	9.43	1.72	4.53	14.00
log(visas)	7182	5.06	0.19	4.68	5.25
log(rental price)	4582	5.55	0.36	4.17	7.55
log(house price)	5621	12.49	0.70	8.72	15.07
log(house supply)	6656	8.10	1.88	5.62	12.62
employment rate	5515	0.56	0.07	0.36	0.84

Data on city populations and employment rates are sourced from the Australian Bureau of Statistics (ABS). The employment rate data are derived from the ABS Census conducted in 2001, 2006, and 2011 and are not available on a yearly basis. Therefore, we employ extrapolation methods to estimate the employment rates for the missing years between Censuses. For visa issuance, we consider visas issued to permanent and temporary skilled migrants (residents), international students, and long-stay businessmen. These categories account for over 70% of the total visas issued. However, visitor visas corresponding to short-term stays in Australia are excluded from our analysis. The visa issuance data are obtained from the Department of Home Affairs (for additional information regarding these data, please refer to https://www.homeaffairs.gov.au/research-and-statistics/statistics/visa-statistics/live/migration-program). The summary statistics on the variables are presented in Table 4.

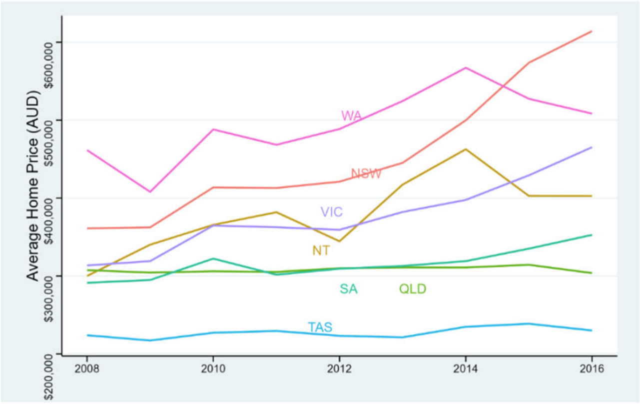
For the climate of cities, we utilize the city climate zone data provided by the BoM. The BoM categorized all Australian cities into seven climate zones based on historical climate conditions, specifically precipitation, temperature, and humidity levels between 1961 and 1990. The climate zone classification is depicted in Fig. 8.

For instance, if a city's average annual temperature, average annual 9 am humidity, and average annual rainfall levels fell within the ranges of 18–24 degrees Celsius, 50–70%, and 1000–2000 mm, respectively, between 1961 and 1990, it is classified under "Zone 2: Warm, humid summer and mild winter". On the other hand, cities with average annual temperatures between 9 and 18 °C, average annual 9 am humidity levels of 70–80%, and average annual rainfall of 600–1500 millimeters within the same period are assigned to "Zone 7: Cool temperate".

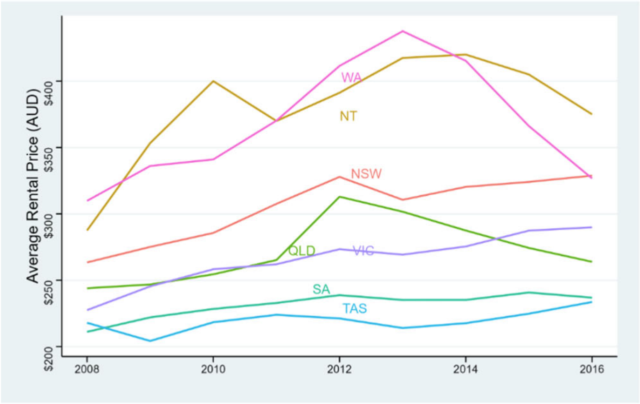
To conserve space, we will not present the detailed construction of the remaining zones based on average humidity, temperature, and precipitation levels between 1961 and 1990. Interested readers may refer to the climate zone map provided by the Australian Building Codes Board (ABCB) from the BoM's website (see http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp?maptype=tmp_zones#maps).

Housing cost trends in Australia. Figure 1 plots the average prices for homes and rental properties by state in Australia. Average prices are calculated by taking the average prices across the LGA for each state. Since 2008, there has been significant growth in the average housing cost across New South Wales, Victoria, and Western Australia. Home prices in the Northern Territories also trended significantly upwards but declined after 2014. Prices in Queensland, South Australia, and Tasmania remained stable throughout these years (Fig. 1).

Interestingly, trends in rental prices may not always closely follow home prices. For instance, rental prices in New South Wales, Victoria, and Western Australia had not risen as sharply as home prices. While the home price trend in Queensland remained flat, rental prices in the state had risen rather sharply until 2012 before tapering off.



(a) Average Home Prices



(b) Average Rental Prices

Fig. 1 Average home and rental prices by state. The figure is constructed by the authors using data from the Australian Urban Research Infrastructure Network (AURIN). Panel (**a**) shows the average home prices. Panel (**b**) shows the average rental prices. The average home and rental prices are computed by taking the average of the respective prices across the local government areas (LGAs) for each state.

It should be emphasized that these trends account for the home and rental prices across all LGAs within the state. Thus, home and rental prices in capital cities may display a different trend. For example, the home price growth across all of Queensland was −1.23% during this period. However, in Brisbane, the growth was 26.74%. Similarly, home price growth across all of New South Wales was 53.13% but 98.08% in Sydney. For the rental market, rural regions in certain states may perform more strongly than capital cities. The contrast is especially clear for Western Australia, where the rental price growth was 5.31% compared to −10.51% in Perth, the state capital.

Population growth and visa issuance. Australia has experienced significant population growth over the years. Figure 2 illustrates this trend, showing an increase in population from 3.7 million in 1901 to 25 million in 2019, with a projected growth to 40 million by 2051. Among OECD countries, Australia had the third fastest growing population[34]. Notably, the population expansion in Australia has been particularly rapid in the last two decades, with an annual increase of over 325,000 people.

This population growth can be attributed to two main factors: new births and overseas migration. Figure 3 sheds some light on the contribution of each factor. Before 2006, the quarterly average of new births remained around 60,000 but modestly increased to 78,000 in 2017. By contrast, the quarterly average number of new overseas migrants arriving in Australia more than tripled, rising from below 50,000 in 1982 to 138,000 in 2017. As a remark, "overseas migrants" refers to the sum of all Australian temporary and permanent residents/migrants. Temporary migrants include individuals with temporary visas for purposes such as studying and working. Our study excludes temporary visitors who come to Australia as tourists.

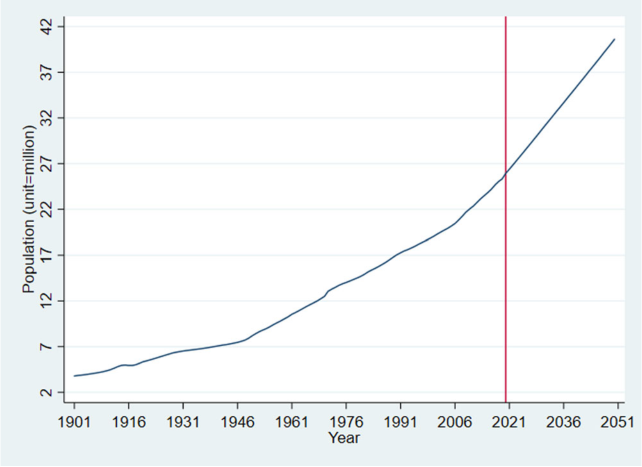


Fig. 2 Australian population level (1901–2050) The figure is constructed by the authors using data from the Australian Bureau of Statistics.

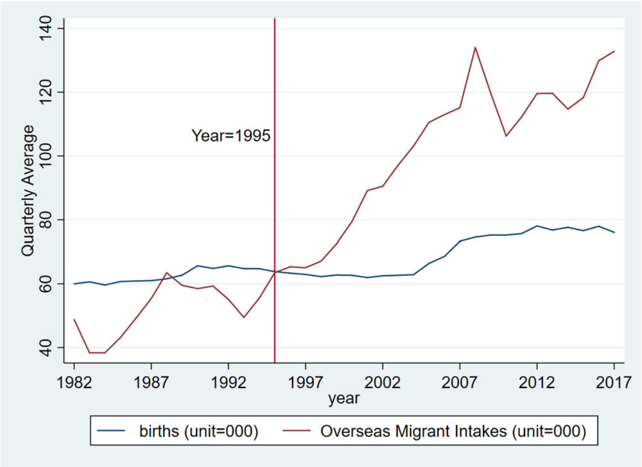


Fig. 3 Australian population expansion: new births vs overseas migrants (time series). The figure is constructed by the authors using data from the Australian Bureau of Statistics.

To calculate the percentage of new births (or overseas migration) in Australian population expansion each year, we divide the annual number of new births (or new overseas migrants) by the annual total new population (i.e., the sum of new births and overseas migrants). For example, if there were 10 new births and 20 new overseas migrants in 2002, the total new population would be 30. The percentage of new births in the new population would be approximately 33% in 2002. Examining the proportion of population growth attributed to new births and overseas migration, Fig. 4 reveals that between 1982 and 1995, approximately 54% of population expansion came from new births, while 46% was due to new overseas migrant intakes. However, in 2017, new overseas migrants accounted for 65% of the population growth, while births contributed to the remaining 35%. Thus, new overseas migrant intakes have become the

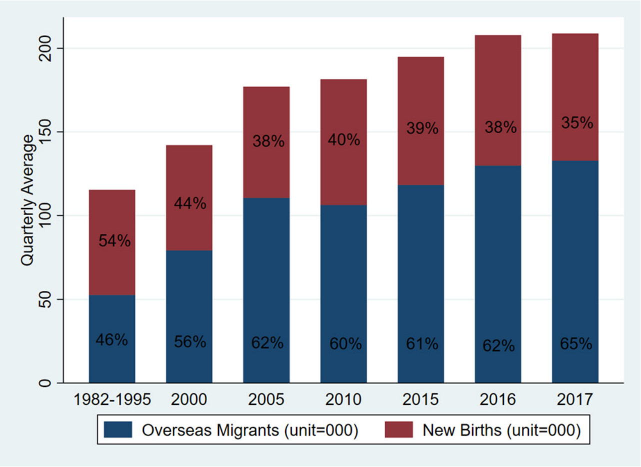


Fig. 4 **Australian population expansion: new births vs. overseas migrants (proportions).** The data are drawn from the Australian Bureau of Statistics.

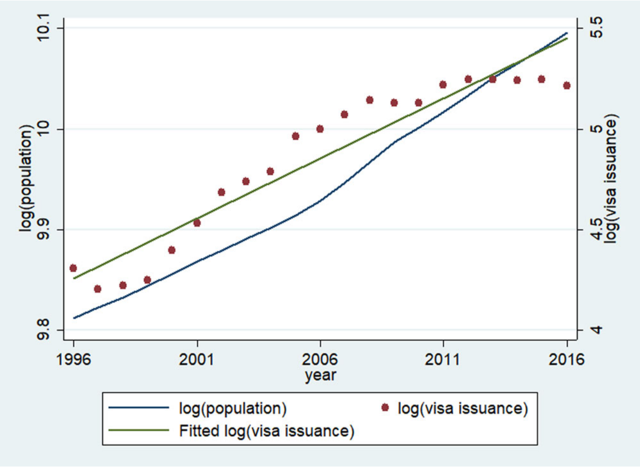


Fig. 5 **Populations vs. visa issuance in Australia.** The figure is constructed by the authors using data from the Australian Bureau of Statistics and the Department of Home Affairs.

primary driving force behind Australia's population expansion in recent years.

Unsurprisingly, the growth in population driven by overseas migration is closely linked to the number of visas issued by the Australian federal government. The government carefully manages the influx of overseas migrants into Australia, taking into account the prevailing conditions of the labor market in the country[4]. This approach allows the government to respond to labor supply shortages in specific sectors such as healthcare, information technology, engineering, and construction trades[4]. For example, starting in 1995, the federal government increased the issuance of visas to attract immigrants from these occupational groups[35]. As depicted in Fig. 5, the federal government temporarily reduced the number of visas issued in 2009 and 2010 in response to the economic downturn caused by the Global Financial Crisis. Consequently, the number of visas issued has increased significantly since 1995, as shown in Fig. 5.

To examine the relationship between visa issuance and the Australian population, we analyze the logarithmic forms of both variables from 1996 to 2016, as shown in Fig. 5. The upward trends of log(population) and log(visa issuance) indicate a positive relationship between visa issuance and Australia's population at the national level. Since national populations are made up of city populations, we can also infer a positive association between visa issuance and city-level populations. To further explore this relationship, we select four Australian capital cities and plot their populations against the number of visas issued, as depicted in Fig. 6. The similarity in the trends of the log number of visas issued and the log populations of these selected cities supports the argument that population growth in these cities is driven primarily by migration, which in turn depends on the number of visas issued.

Climate and Population Spatial Variation in Australia. The population distribution in Australia exhibits significant spatial variation. As shown in Fig. 7, the populations of certain cities, such as MacDonnell and Diamantina, located in the middle of Australia, averaged less than 10,000 between 2001 and 2020. By contrast, the coastal city of Brisbane has consistently housed over 1 million people during the same period.

The considerable disparity in city populations across Australia can be attributed, in part, to variations in climate conditions[36,37]. When selecting their residential locations, households take into account local climate conditions and are more inclined to settle in areas with a more favorable climate for living[6]. For instance, individuals often prefer suburban, sunny, and coastal areas characterized by mild, warm, or cool climates[6,38–40]. On the other hand, they are generally reluctant to reside in remote areas characterized by hot-dry summers or extremely cold winters[41–43].

To gain further insight into how climate conditions are associated with population spatial variation in Australia, we adopt the climate zone classification provided by the BoM in Australia. As shown in Fig. 8, the Australian cities are categorized into seven climate zones. These climate zone data are developed by BoM to assist the Australian Building Codes Board (ABCB) in regulating the building and construction industry. The data can be accessed at https://www.abcb.gov.au/Resources/Tools-Calculators/Climate-Zone-Map-Australia-Wide. BoM developed eight zones for ABCB, but for this study, we consider cities with some alpine climate areas as having a cool temperate climate, which results in the analysis of seven climate zones.

Examining the population levels of cities within each climate zone, Table 5 provides the average city population between 2001 and 2018, as well as the average number of foreign migrants in each city from 2016 to 2019 for each climate zone. The data reveal that cities characterized by a warm-summer, mild, or cool climate have significantly higher populations compared to those with hot or hot-dry summer climates. Therefore, the disparity in climate conditions may explain the spatial distribution of Australian city populations, with cities possessing a more livable climate (i.e., warm, mild, or cool) that attracts larger populations and overseas migrants. For our work, we consider climate Zones 2, 5, 6, and 7 as favorable climates.

The model

Our primary model examines the relationship between the logarithm of housing costs (i.e., home and rental prices), denoted as $\log(\text{price}^{k}_{is,t})$, and the logarithm of population, denoted as $\log(\text{population}_{is,t})$, for city i, state s, and year t. The equation is specified as follows:

$$\log(\text{price}^{k}_{is,t}) = c + \alpha \log(\text{population}_{is,t}) + \boldsymbol{\gamma}'\mathbf{x}_{is,t} + \mu_i + \mu_{st} + \epsilon_{is,t} \tag{1}$$

where the superscript k indexes home or rental price. The vector $\mathbf{x}_{is,t}$ consists of a set of control variables that include the log of housing supply and employment rates. The terms μ_i and μ_{st} represent the city-fixed effects and state-year fixed effects, respectively. The state-year fixed effects capture all state-level factors, both time-varying and time-invariant factors, that influence housing costs. Since the state is a disaggregation of a

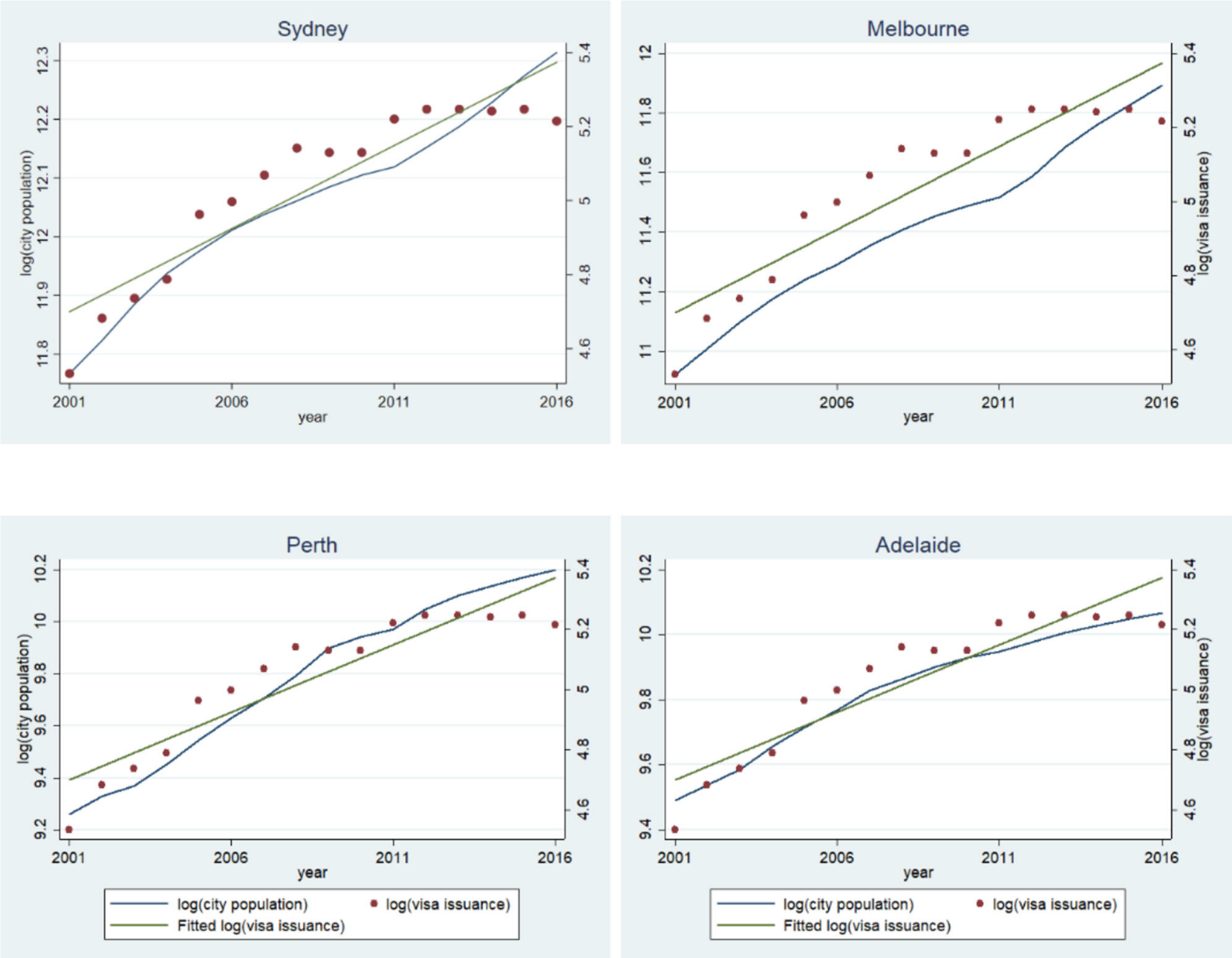


Fig. 6 City populations and visa issuance. The figure is constructed by the authors using data from the Australian Bureau of Statistics and the Department of Home Affairs.

country, the state-year fixed effects will subsume the year fixed effects, which capture all macroeconomic (i.e., country) level factors. Therefore, the year-fixed effects are redundant once state-year fixed effects are included. Finally, the variable $\epsilon_{is,t}$ denotes the idiosyncratic error term clustered at the city level.

The main focus of this study is to estimate the parameter α in Eq. (1). This represents the elasticity of housing cost with respect to city population. To achieve this objective, we incorporate various fixed effects and control variables into Eq. (1). The inclusion of city fixed effects, μ_i, enables us to control for time-invariant city-specific characteristics such as location and land size and other unobserved location-related attributes. The inclusion of state-year fixed effects, μ_{st}, enables us to control for the influence of macroeconomic variables and macroeconomic shocks (e.g., interest rates and Global Financial Crisis), as well as for factors that vary across states and years, such as annual economic and labor market conditions within states. We also incorporate city housing supply and employment rate in Eq. (1) to control for local housing and labor market conditions, which are likely correlated with population sizes and housing costs[44].

Despite the inclusion of these fixed effects and control variables, we may still encounter challenges that would hinder the identification of α, the effect of the population of the city on housing costs. The first challenge arises from measurement errors in $\log(\text{population}_{is,t})$. Since the city population data used in our study are estimated, measurement errors could be prevalent. Consequently, if these measurement errors were classical, the estimate of α would be biased toward zero.

The second challenge is related to reverse causality. On the one hand, the expansion of the city population can drive up local housing costs[8,45,46]. On the other hand, high housing costs may discourage people from moving to certain cities[3]. Therefore, given this bi-directional relationship, it is important to disentangle the effect of city population on housing cost from the reverse confounding effect.

Lastly, other determinants of city housing costs that are correlated with population may be captured in the error term $\epsilon_{is,t}$. For example, the safety of a city can influence both population levels and house prices[47]. If the influence of unobserved characteristics on housing cost and city population is not eliminated, the OLS estimates could still be susceptible to omitted variable bias.

Estimation strategy. To address the aforementioned issues, we propose an instrumental variable (IV) approach within a panel data framework to estimate the relationship between city populations and housing costs. Our IV strategy involves interacting two variables that exhibit exogenous variations across cities and over time.

The first variable is city climate, which is considered to be exogenous to economic outcomes such as housing cost[5,7]. Climate can influence residential choices, and cities with more favorable climates, characterized by mild, warm, or cool conditions, tend to have larger populations compared to cities

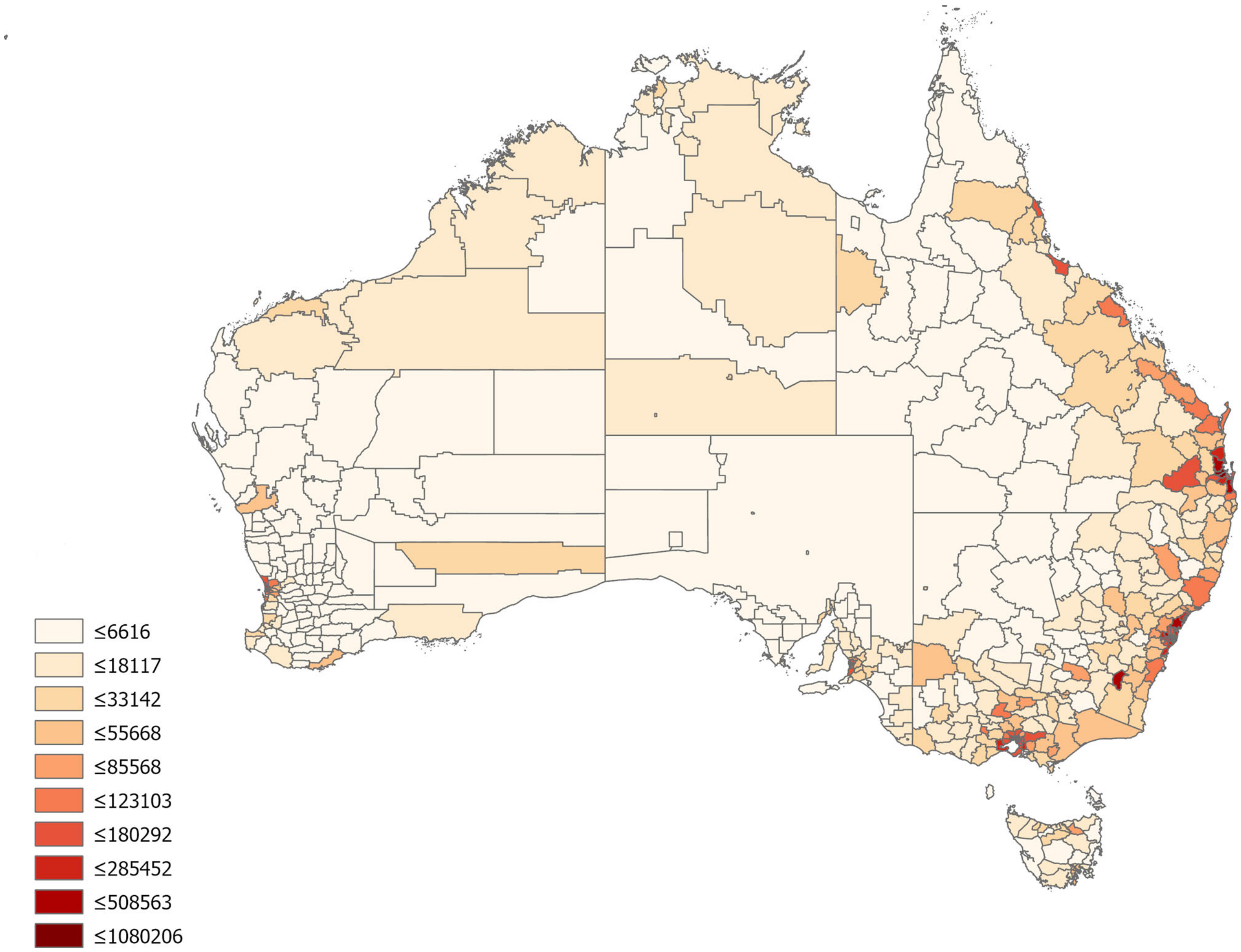


Fig. 7 **Average city population (2001–2020).** This figure was constructed by the authors using city population data from the Australian Bureau of Statistics.

with less favorable climates, such as those with hot-dry summers or extremely cold winters[6,38,39] In the context of Australia, cities with more livable climates tend to have larger populations compared to cities with hot-dry summer climates. Therefore, we classify mild, warm, and cool climates as favorable climates and indicate them with a dummy variable, favorable climate$_{is}$. This variable serves as the cross-sectional component of our IV.

The second variable is the number of visas issued, which we argue is plausibly exogenous with respect to housing cost. As shown earlier, overseas migration is the primary driver of population expansion in Australia since 1995. The Australian federal government operates the Migration Program, and the issuance of visas positively influences overseas migration to Australia. Thus, the annual number of visas issued can be considered a determinant of Australian city populations (see Fig. 6). Importantly, since the number of visas issued is determined by the federal government based on the country's labor market needs, visa issuance should be exogenous to current housing costs in the cities. Therefore, we utilize $\log(\text{visas}_{t-j})$, the log of the number of visas issued at time $t-j$ where $j = 1$ or 2, as the time-varying component of our IV.

Our first-stage regression model is defined as follows:

$$\log(\text{population}_{is,t}) = c + \beta_j \times \text{favorable climate}_{is} \times \log(\text{visas}_{t-j}) + \boldsymbol{\theta}'\mathbf{x}_{is,t} + \mu_i + \mu_{st} + w_{is,t}, \tag{2}$$

where our IV is the interaction between favorable climate$_{is}$ and $\log(\text{visas}_{t-j})$. The main identifying assumption is that the number of visas issued affects housing costs solely through its impact on city populations. This assumption would be violated if: (1) visa issuance directly affects local housing costs, implying that it is not an excluded factor, or (2) housing costs reverse causally influence visa issuance. The first concern is irrelevant since the number of visas issued does not directly impact city housing costs, but rather, affects housing cost by affecting city population size. It should also be noted that while there are visa programs that are associated with investments in real estate, this is not the case for Australia. The second concern is also unlikely as visa issuance is influenced by the Migration Program designed by the Australian federal government to address the labor conditions of the entire country[4]. Nevertheless, to ensure the validity of our instrument, we utilize the lagged number of visas issued, which is predetermined with respect to home and rental prices.

Our main estimation approach employs 2SLS regression, where Eq. (1) is estimated as a second-stage model in conjunction with Eq. (2) as the first-stage model. This allows us to address the issues of reverse causality and measurement error associated with city populations. In addition, we also estimate the influence of our instrument on housing costs via the following reduced-form regression:

$$\log(\text{price}^{k}_{is,t}) = c + \delta_j \times \text{favorable climate}_{is} \times \log(\text{visas}_{t-j}) + \boldsymbol{\psi}'\mathbf{x}_{is,t} + \mu_i + \mu_{st} + \eta_{is,t}. \tag{3}$$

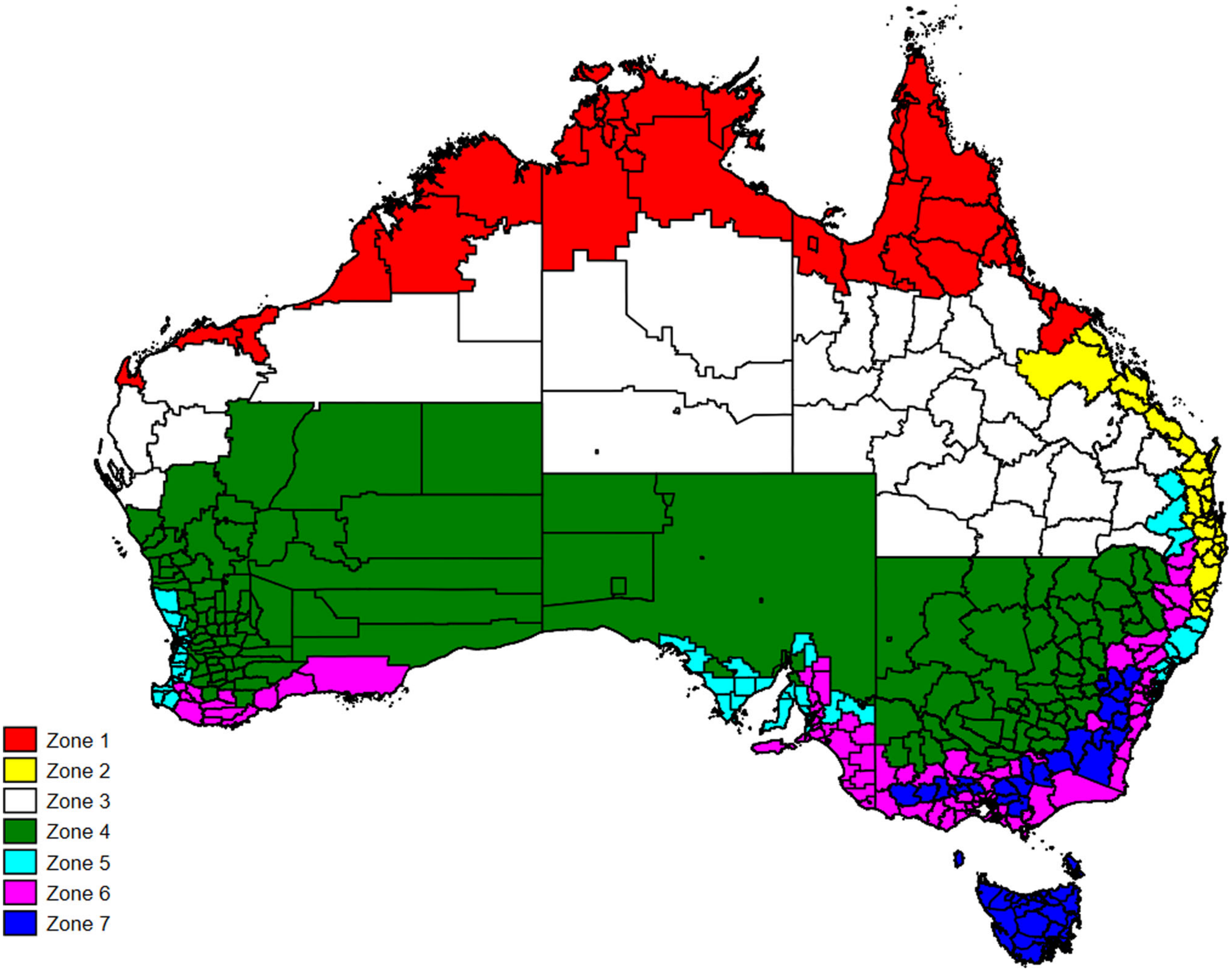


Fig. 8 **Climate zones in Australia.** This figure is constructed by the authors using climate zone classification from the Bureau of Meteorology.

Table 5. Climate and population and migrant spatial variation.

Climate zone	Average city population (2001–2018)	Average city overseas migrants (2016–2019)
Zone 2: Warm humid summer and mild winter	128,223	116,980
Zone 6: Mild temperate	64,053	84,472
Zone 5: Warm temperate	60,329	30,126
Zone 7: Cool temperate	25,243	10,127
Zone 1: Hot humid summer and warm winter	15,022	3364
Zone 4: Hot dry summer and cool winter	7428	4590
Zone 3: Hot dry summer and mild winter	7140	841

This specification allows us to explore the combined effect of favorable climate and visa issuance on housing costs while controlling for other factors captured by the vector of control variables $\boldsymbol{\psi}'\mathbf{x}_{is,t}$.

Before we conclude this discussion, it is important to note that once city-fixed effects and state-year fixed effects are included, there is no need to control for the variables, favorable climate$_{is}$ and visas$_{t-j}$. The city fixed effects will wash out all time-invariant city-level factors (as well as all time-invariant factors at a higher level of aggregation, such as at the state or country level). Therefore, the effect of favorable climate$_{is}$ will be controlled for by city fixed effects. Additionally, the state-year fixed effects will wash out all time-varying state-level factors, as well as all time-varying factors at a higher level of aggregation, such as at the country level. Therefore, the influence of visas$_{t-j}$ will be accounted for by state-year fixed effects.

Further remarks on the estimation strategy. Our estimation strategy bears similarities to the shift-share instrument commonly used in urban and housing literature[29,45,46,48]. These studies construct instruments by interacting the historical share of migrant population to total population at the local level, which provides cross-sectional variation, with the current national migrant level, which provides time variation. The rationale is that the current location decisions of immigrants are expected to be influenced by the location decisions of earlier immigrants (say, from the same country of origin). Therefore, this interaction term can be interpreted as an approximation of the yearly immigration level to a local area.

However, the validity of such an IV has been subject to debate. For it to be valid, the cross-sectional variation, i.e., the historical share of the migrant population to the total population, must be exogenous. However, Sharpe[29] and Broxterman and Larson[30] have argued that the historical migrant population share could be influenced by housing costs. Moreover, it could also be correlated with initial economic conditions, city characteristics, and housing cost[29]. Consequently, the exclusion restriction assumption necessary for the validity of such instruments may not hold.

By contrast, our new instrument addresses these issues by relying on climate conditions to generate the cross-sectional variation in our instrument rather than the historical share of the migrant population. Unlike the latter, a city's climate is exogenous to economic variables, including housing costs[7,49,50]. Additionally, the time-varying component in our instrument—national-level visa issuance—is determined by the Australian federal government based on the country's overall labor market conditions. Therefore, our proposed instrument, which is based on the interaction between city climate and visa issuance, is plausibly exogenous to city housing costs.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

DATA AVAILABILITY

All data related to this article, as well as the codes used to process the data, are available from the authors upon request.

CODE AVAILABILITY

All codes used to process the data are available from the authors upon request.

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AUTHOR CONTRIBUTIONS

C.L.: Research design and conceptualization, paper writing and editing. W.L.: Data preparation, methods design, data analysis, paper writing, and editing. N.S.: Methods design, data analysis, paper writing, editing.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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Correspondence and requests for materials should be addressed to Nicholas Sim.