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Towards a theory of planned city size behaviour

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1. Introduction

Hundreds of brand-new cities are planned around the world in every decade (Côté-Roy and Moser, 2019, Van Noorloos and Kloosterboer, 2018, Moser and Côté-Roy, 2021). The administrative functions and sizes of these cities vary widely, placing various taglines such as capital city, smart city, satellite towns, new towns, eco-city and airport city. Examples included Canberra, Brasilia, Putrajaya, Islamabad, Abu Dhabi, Dholera, Songdo, Shenzhen, Kwinana, Yanbu, Waterfall City, and Lanseria Airport City (Herbert and Murray, 2015, Datta, 2015, Van Noorloos and Kloosterboer, 2018, Berghmans et al., 1984, Van Leynseele and Bontje, 2019, Hashim, 2012, Faria et al., 2013). The planning process of a city, new or existing, follows the prediction of its population size (Myers, 2001). It determines the demand for different land uses (residential, commercial, road network) and staged provision of goods and services (schools, hospitals, public transport) (Berke et al., 2006). For example, Canberra in Australia and Yanbu in Saudi Arabia were planned for 150,000 and 135,000 inhabitants respectively (Berghmans et al., 1984, Jones, 1973). However, the population sizes of new cities are often determined in an ad-hoc basis due to a lack of a priori (Li et al., 2022). As a result, evidence shows that while many cities are grappling with the challenges of increasing urbanisation; others are experiencing a population decline, resulting in wastage of costly resources (UN HABITAT, 2022, Van Noorloos and Kloosterboer, 2018). This necessitates the development of a new theoretical basis to determine the optimum size of cities in advance.

Numerous studies have investigated the links between city size and sustainability outcomes, often reporting conflicting findings. As an example, unlike the prevailing view that larger cities are economically productive, empirical studies found that such links either do not exist (Sveikauskas et al., 1988), or relatively smaller cities (<3M) are conducive to growth (Frick and Rodríguez-Pose, 2018). We hypothesize that such a conflict arises because cities are labelled as smaller or larger based on existing population rather than measuring it against the optimal sizes – the benchmark – perhaps due to the difficulty of determining the optimum size of cities. The determination of an optimum city size has long been debated in the literature (Alonso, 1971). Early studies focused on determining one single optimum size of cities (Richardson, 1972). If there is one optimum size, there should not be any size variations between cities. As a result, this approach is discarded by many and instead apply Zipf's law to examine the size variations of cities (Jiang et al., 2015). This law suggests that the largest city of a country is approximately two, three, four…and n times larger than the second, third, fourth…and nth largest city respectively (Gabaix, 1999). Despite its intuitive appeal, its empirical validity has widely been questioned (Soo, 2005). Importantly, the law explains existing city sizes, but does not apply to determine the optimum sizes (Shen et al., 2020). No two cities are the same. Each city maintains its own specificity and unicity. As a result, each city should have its own optimum size (Camagni et al., 2013). If so, this study hypothesizes that optimality can be determined by the specificity and unicity of cities (e.g. dominance in the broader city networks, local resources); which can also be altered by policy interventions.

The goal of planning is to prepare cities for sustainability and efficiency in future activities by carefully providing services (road networks, public transport, footpath, playground) against planned population sizes (Couch, 2017, Weber and Crane, 2012). When the actual population sizes are smaller than the planned sizes, cities fail to capitalise on agglomeration/compactness benefits and the resulting sparse settlement patterns promote unsustainable behavioural outcomes. In contrast, if actual population sizes exceed planned sizes, crowding effect occurs due to inadequacy of provided goods and services and the resulting repulsive forces (congestion, crime, pollution, poor-health), which again influence residents to behave unsustainably. Based on this hypothetical understanding, the overarching question that the study seeks to answer is: **To what extent do planned cities promote sustainable behavioural outcomes?**

2. Methodology

The main research question as outlined above requires to answer a secondary research question first: What is the optimum size of cities? This question is answered by identifying the key factors that influence the size of cities based on well-known theories on the topic such as the locational fundamental theory, increasing return to scale theory, central place theory and central flow theory (Table 1). The factors were derived from data gathered through secondary sources as shown in Table 1 and operationalized at 422 Urban Centres and Localities (UCLs) in Australia.

Table 1: Determinants of expected city sizes

Theory	Indicators	Description	Source of data
City size	Population	Dependent variable: Residential populations in UCLs	Census 2016
Locational fundamentals	Access to public transport	Car travel time to the nearest inter-city bus terminal, train station and airports from each suburb in a UCL at peak- and non-peak hours	ESRI network, AURIN, Census 2016
	Amenities	Point of interests per 10,000 residents within a UCL	AURIN
	Productivity	Average rent paid by residents in a week within a UCL	Census 2016
	Sprawl Index	$Sprawl\ Index_i = \frac{\left\lfloor urb_{i,t+n} - \left(urb_{i,t} * \left(\frac{pop_{i,t+n}}{pop_{i,t}}\right)\right)\right\rfloor * 100}{urb_{i,t}}$ where, *i* = UCL, *t* = initial year (2016); *t*+*n* = final year (2021), *urb* = size of urban area in km^2; *pop* = population	Census 2016 and 2011
	Capital city	Classification of UCLs based on capital city status	Assigned
Increasing return to scale	Accessibility	$A_i = \sum_{j=1}^{n} O_j\, e^{-\beta t_{ij}}$, where A_i = Jobs accessibility of UCL i, O_j = Number of jobs available in UCL j, β = decay parameter to be estimated, t_{ij} = driving time	ESRI network, Census 2016
	Agglomeration	Population density of UCL	Census 2016
	Urban diversity	$Diversity = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right)$, where n= employment in a particular category; N= employment in all categories	Census 2016
Central place theory	High level urban functions	Share of the labour forces in the professional industry within a UCL	Census 2016
	Clustering coefficient	Measures the degree to which UCLs in a network tend to cluster together	Census 2016 commuting flow
Central flow theory	Centrality	Betweenness, degree, closeness centrality (directed) derived to respectively represent UCLs' importance, accessibility, and transitivity based on commuting flow	Census 2016 commuting flow
	Borrowed size	Spatial lags of population located of each UCL discounted by travel time.	ESRI network, Census 2016
	Borrowed function	Spatial lags of the number of high-functional jobs of each UCL discounted by travel time.	ESRI network, Census 2016

The choice of which UCL to live in by an individual is driven by utility maximization, which is achieved when the benefits of living are equal or greater than the costs of living. City size can act both as a benefit (amenities) and as a cost (commuting distance). Based on the Cobb–Douglas utility function, both the benefit and cost functions can be estimated as a linear relationship using the following expressions:

$$\ln(B) = b_0 + \gamma \ln(city\ size) + \theta \ln(Y) \quad (1)$$

$$\ln(C) = a_0 + \alpha \ln(city\ size) + \beta \ln(X) \quad (2)$$

where, B = total benefits, C = total cost, $city\ size$ = total population, Y = other benefits, X = other costs, b_0 = intercept of the benefit curve, γ = coefficient of city size variable in the benefit function, θ = coefficient(s) of other benefit variable(s), a_0 = intercept of the cost curve, α = coefficient of the city size variable in the cost function, and β = coefficient(s) of other cost variable(s). In an equilibrium condition, the marginal costs are equal to the marginal benefits. As a result, Eq.1 and Eq.2 can be written as:

$$\frac{\delta(\ln(C))}{\delta(city\ size)} = \frac{\delta(\ln(B))}{\delta(city\ size)} \quad (3)$$

Based on (Camagni et al., 2013), Eq.3 can be solved and simplified as:

$$\ln(city\ size) = a + b\ln(Y) - c\ln(X) \quad (4)$$

A multiple linear regression model was estimated to derive the coefficients associated with each of the factors. Multicollinearity among the factors was checked and removed based on the variance inflation factor (>5). A parsimonious model of expected city size was estimated by gradually removing insignificant factors (p>0.05).

The main research question essentially tests the validity of the inherent assumption that cities in the equilibrium of expected and actual population sizes would produce better behavioural outcomes for cities. If this hypothesis is to be true, then an optimum sustainability outcome for cities would be achieved when the differences between actual and expected population sizes are zero. Empirically, this is operationalised in a non-linear piecewise regression model using community strength data (% of people aged 15 years and over engaged in volunteering activities) downloaded from AURIN. Mathematically, the model can be expressed as:

$$y = \begin{cases} \beta_0 + \beta_1 x + \varepsilon, x \leq \alpha \\ \beta_0 + \beta_1 x + \beta_2 (x - \alpha) + \varepsilon, x \geq \alpha \end{cases} \quad (6)$$

where, y = community strength, x = % difference between actual and expected population sizes, α = breakpoint to be estimated, β_0 = constant, β_1 and β_2 = model coefficients before and after the breakpoint, and ε = error term.

3. Results

Table 1 shows the multiple linear regression analysis results to estimate the expected size of cities. Overall, the model was found to explain 82% variations in actual city sizes and with significant factors from all four theoretical constructs (locational fundamental theory, increasing return to scale theory, central place theory and central flow theory). In sum, the estimated results show that (Table 1):

- A reduced access to public transport services reduces the expected size of cities;
- Cities labelled as capital increase their expected sizes;
- An increasing accessibility to jobs supports larger expected size of cities;
- City sizes are expected to be larger with larger agglomeration;
- Diverse job opportunities in a city are expected to increase its population capacity;
- Cities with a large share of professional jobs increase their population potential;
- Multiple cities clustered together reduces their population sizes;
- Cities with a greater degree of influence are expected to have larger size; and

- Cities that dependent on neighbouring cities for high level function are expected to have smaller sizes.

Table 2: Multiple linear regression analysis results showing the effects of different factors on city sizes*

Theoretical basis	Factors	B
Locational fundamental	Log of drive time to train station (min)	-0.15
	Capital city status (1 – yes, 0 – no)	1.29
Increasing return to scale	Log of accessibility (number of jobs accessible)	0.13
	Log of agglomeration (density) (pop/km^2)	0.25
	Log of urban diversity (Simpson's diversity index of jobs)	7.31
Central place	Log of high-level urban functions (% of profession jobs)	0.58
	Log of clustering coefficient	-1.47
Central flow	Log of betweenness centrality	0.12
	Log of borrowed function (spatial lag of professional jobs)	-0.02
	Constant	4.03
Adjusted R^2		0.82
N		422

* All coefficients (B) are significant at the 0.01 level

Figure 1: Expected vs. actual population sizes

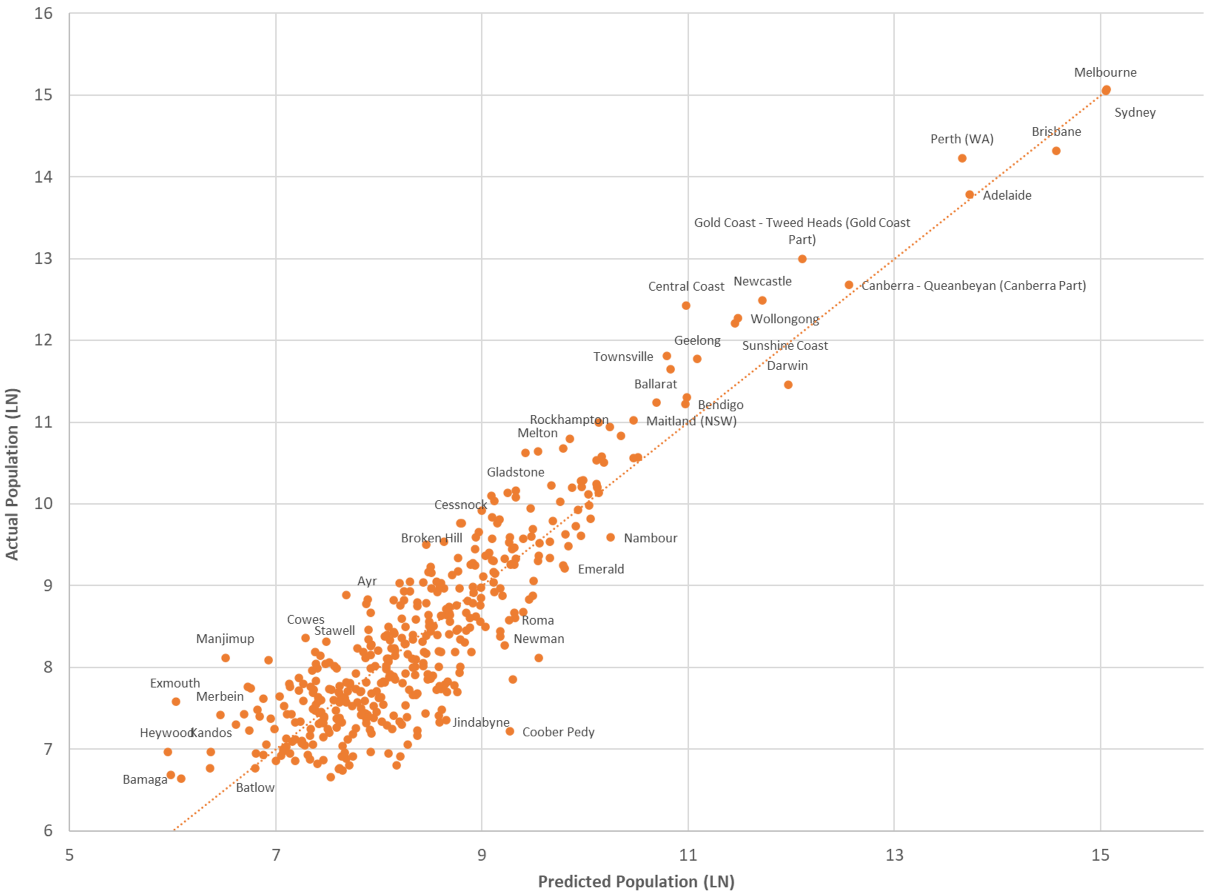
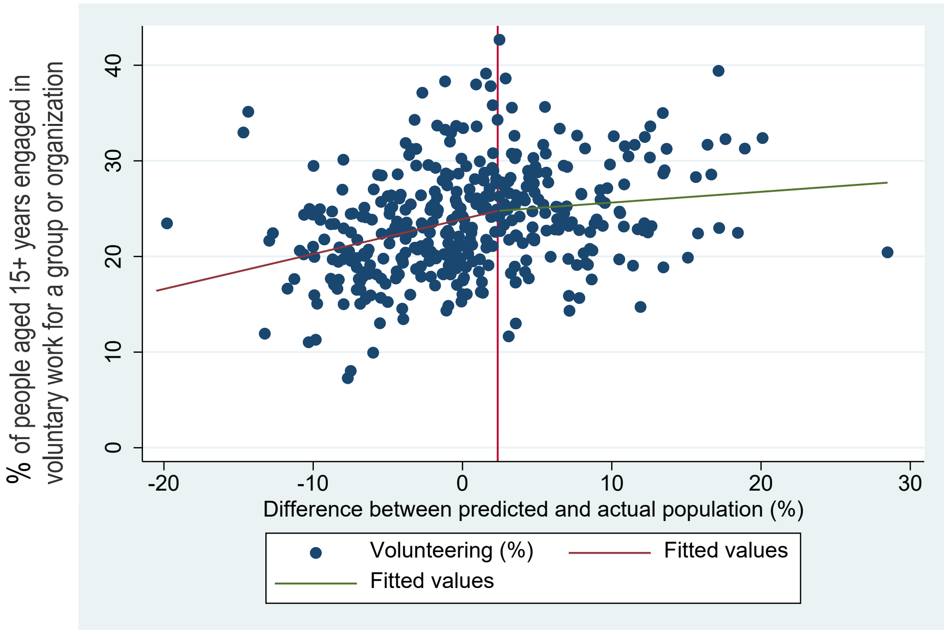


Fig. 2 shows the discrepancies between the log of actual size and log of predicted size of the centres. The range of the percentage difference is between -22% (size is smaller than expected) and +25% (size is larger than expected) – showing a reasonable fit of the model. The difference represents that possible margin of growth exist for centres that shows a negative sign (e.g. Coober Pedy) – these centres may afford to accommodate a larger population size than they currently have due to their locational efficiency. However, the reason for not being able to attract further population in these centres remains matter for further investigation. The opposite condition holds for those centres that show a positive sign – possible causes might include (but not captured in the model) good urban governance, effective marketing, symbolic effects linked to political and economic power and control that cumulatively pushed urban size beyond its equilibrium point.

Using the percentage difference between expected and actual sizes as a regressor and community strength as an outcome, the piecewise regressions estimated breakpoints at about 2.5% (Fig.2). The estimated slope (+β2) beyond the breakpoint is smaller in magnitude and statistically insignificant than the slopes before the breakpoint (+β1), supporting the hypothesis that optimum behavioural outcome of cities achieved when their actual population sizes are theoretically determined. However, the breakpoint at 2.5% level suggests that actual size should be 2.5% less that the expected size of cities to maximise the behavioural benefits.

Figure 2: Relationship between predicted vs. actual population size and community strength



4. Discussion and conclusion

This study provides first empirical evidence towards a new "theory of optimal city sizes". Despite theoretical developments and century long debates around optimal city sizes, none were able to explain variations in city sizes, their optimality and spatial distribution to inform urban growth policy. This study provides a new theoretical framework to inform policy relevant indicators to design cities for optimality. Empirically the study determines optimum city sizes based on their spatial opportunities and constrains – i.e. how much of a theoretically derived optimum size (e.g. +10%, -10%) produces optimum outcomes for cities. In addition, the findings from this study can serve as a source for intervention strategies to increase the population potential of cities. As shown in Fig.1, Central Coast, for example, fall above the line of best fit (red line) - i.e. actual size > expected size. This means that Central Coast lacks locational/network advantages and requires changes within the spatial network to allow them to function efficiently. This change could be a new railway connection to regional UCLs, or better access to existing train station. Some UCLs, such as Melbourne and Sydney, fall on the line of best fit. It indicates that their expected population size is proportional to the actual population. A similar strategy can be undertaken for these UCLs to increase their population potential. Other UCLs, for example Darwin, fall below the line of best fit (i.e. actual < expected). This means that these UCLs have the capacity to accommodate more people without any further spatial interventions.

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