Inferring urban polycentricity from the variability in human mobility patterns

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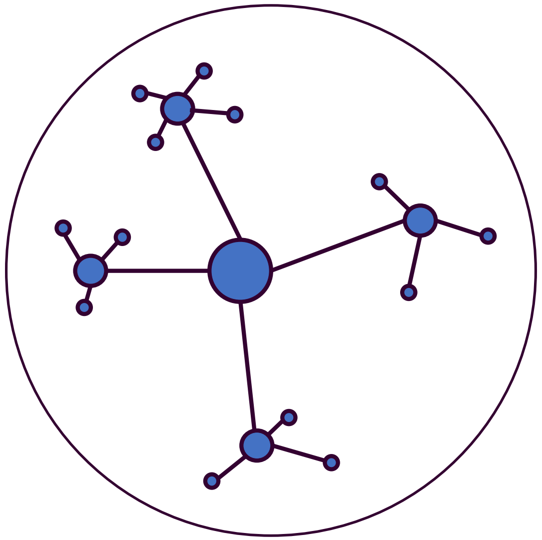
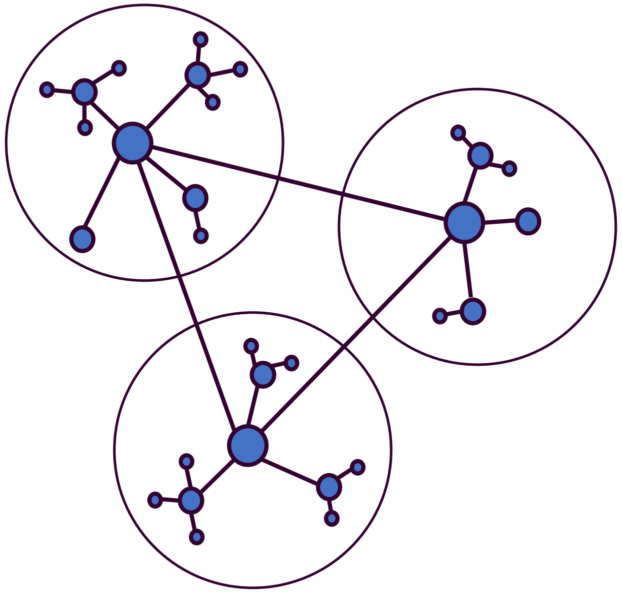
Introduction – background and motivation

- The **simplest form of urban structure is the monocentric city**, which prevailed until the industrial revolutions but since then, cities have gradually decentralised
- Polycentricity has become the focus of much spatial policy
- Despite the raise in the popularity of **polycentricity** it **remains a fuzzy concept**
- So, **how to measure polycentricity?**
- There is a long tradition of theoretical research and empirical evidence surrounding the debate on monocentricity versus polycentricity



Monocentric

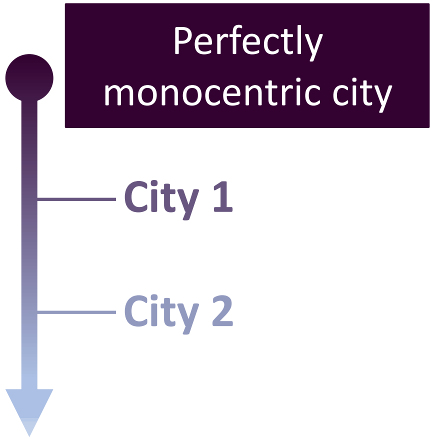


Polycentric

Introduction – aim

OVERALL AIM

To infer urban structure by examining the extent to which a city departs from the monocentric behaviour, by considering the variability inherent in human mobility patterns



CASE STUDIES

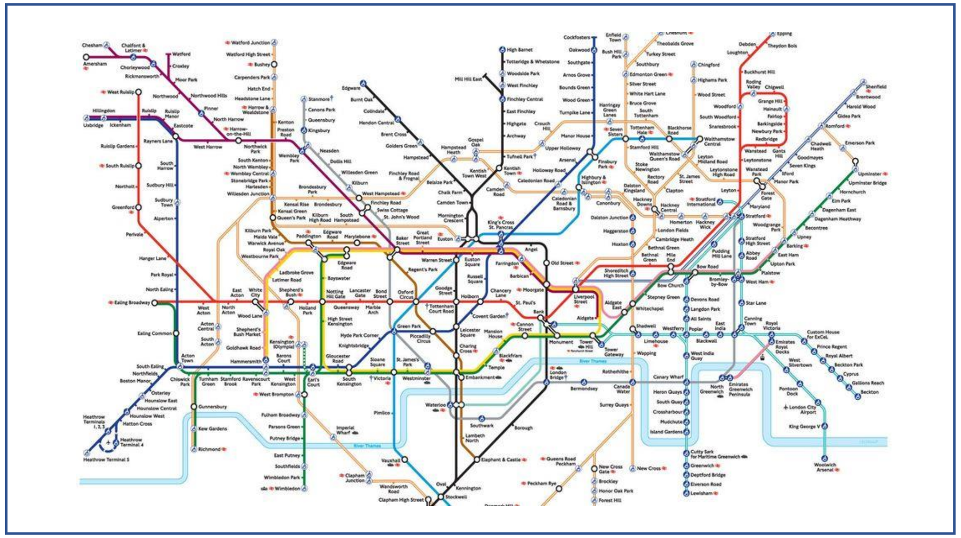
London
United Kingdom

Seoul
South Korea

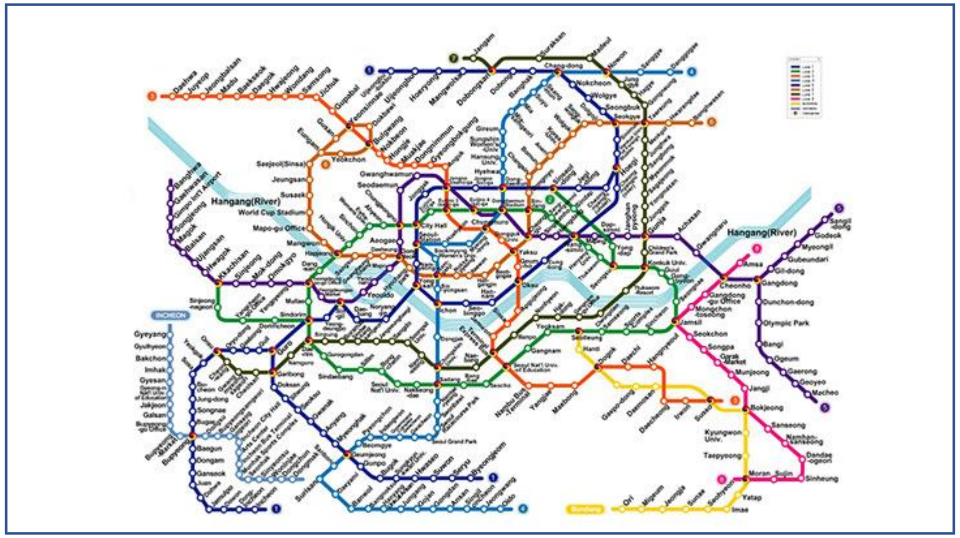
Data, notation and definitions

- Process the data to obtain the **length of the journeys terminating at each station on a typical weekday**

London



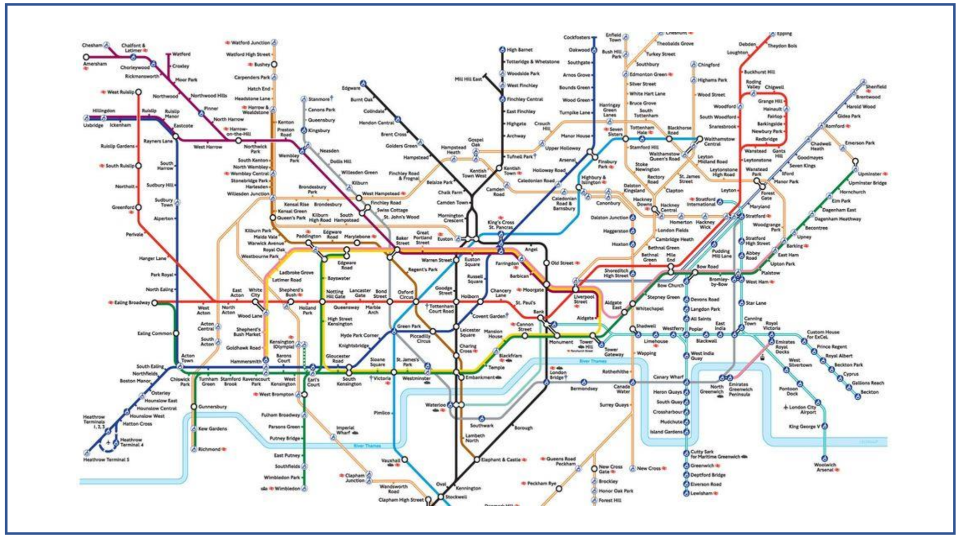
Seoul



Data, notation and definitions

- N stations, each station symbolised by S_i
- The length of the journeys terminating at S_i is denoted by $L_{i,}$ which is a random variable
- Conceptualise the transport system as a **network**
- Assume the length of a journey between stations S_i and S_j is equal to the network distance d_{ij}

London



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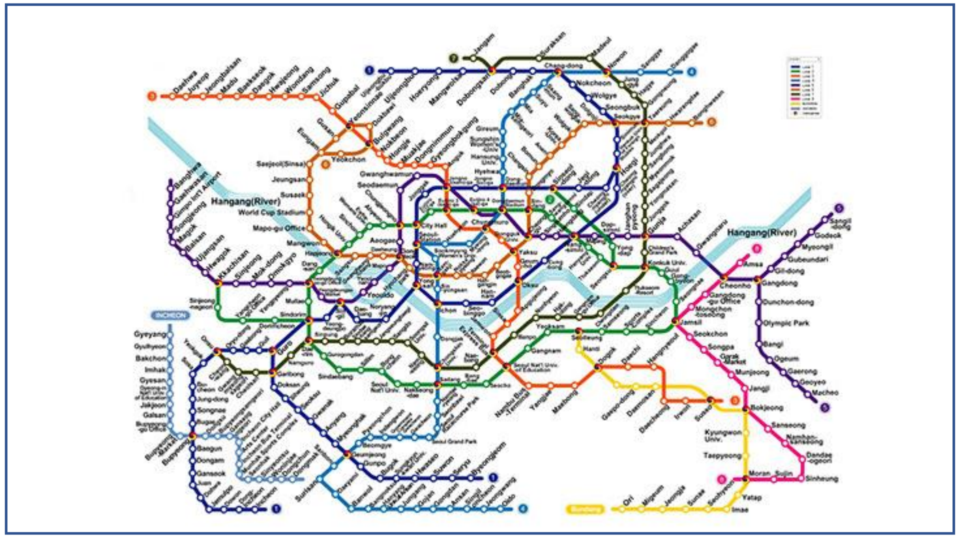

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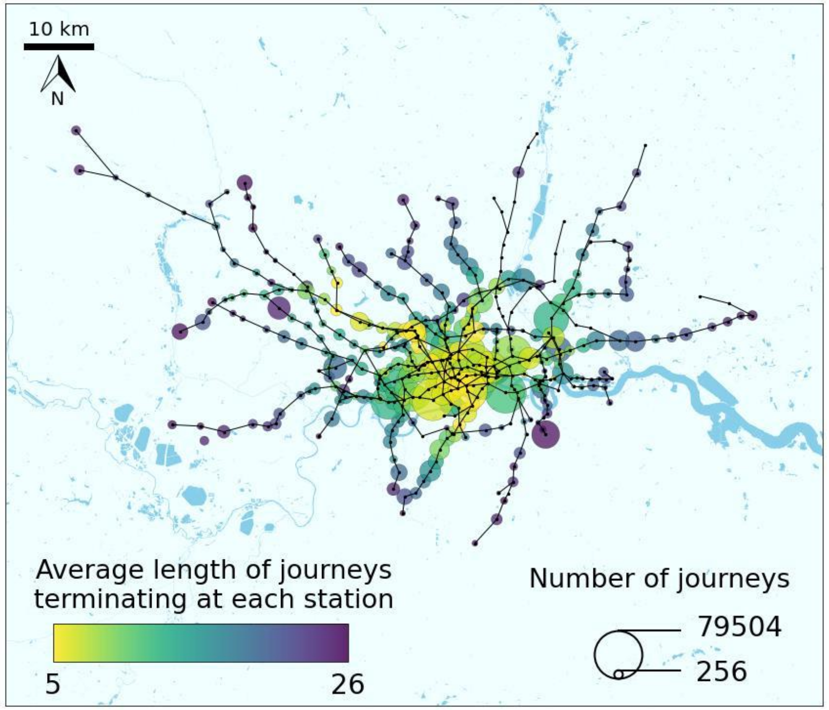
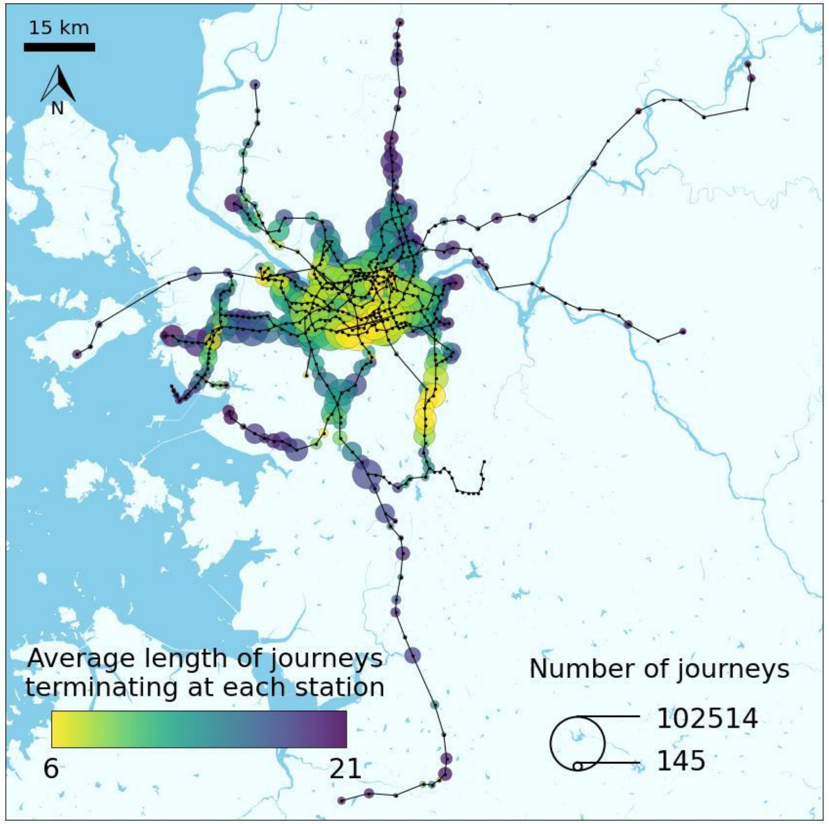


Seoul



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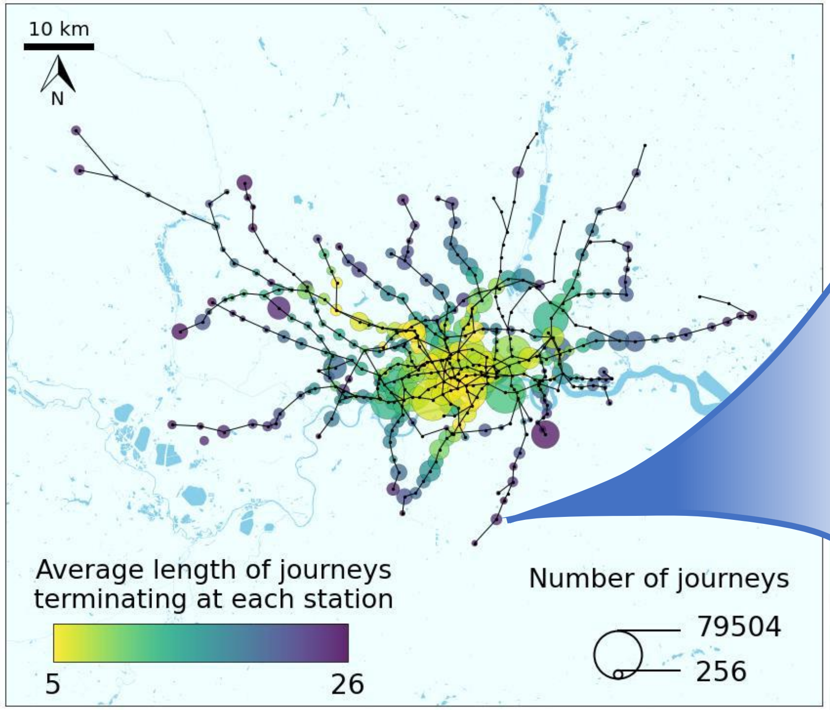
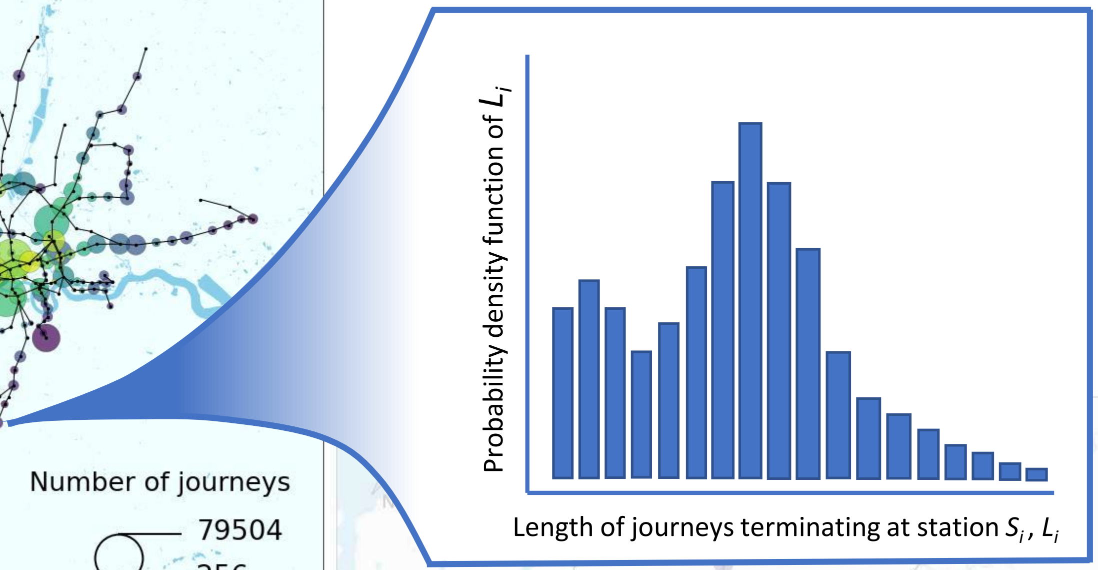
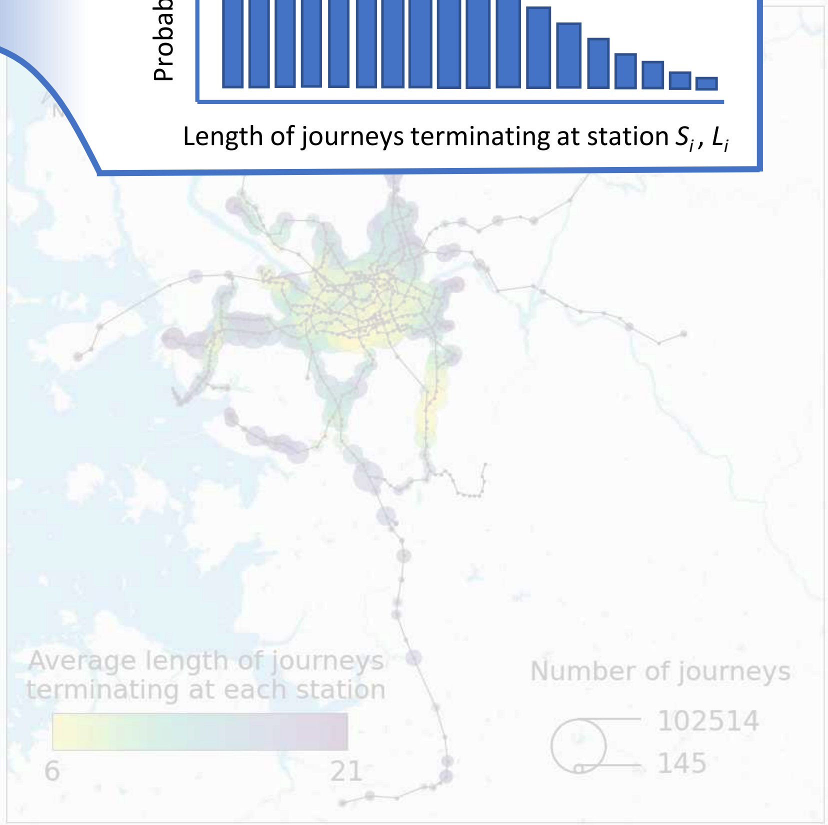


(Empirical) Probability density function for the length of the journeys terminating at station S_i





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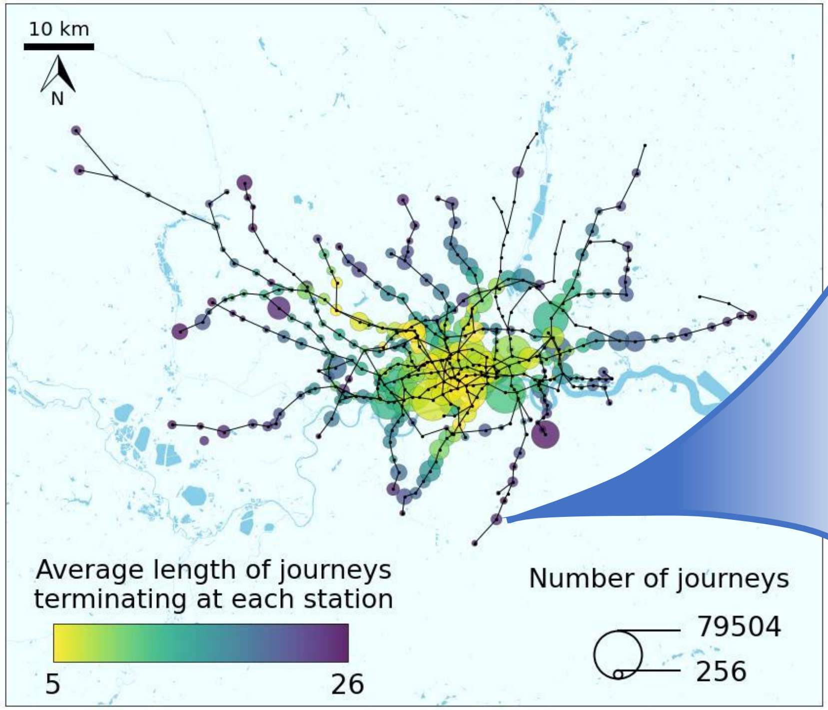

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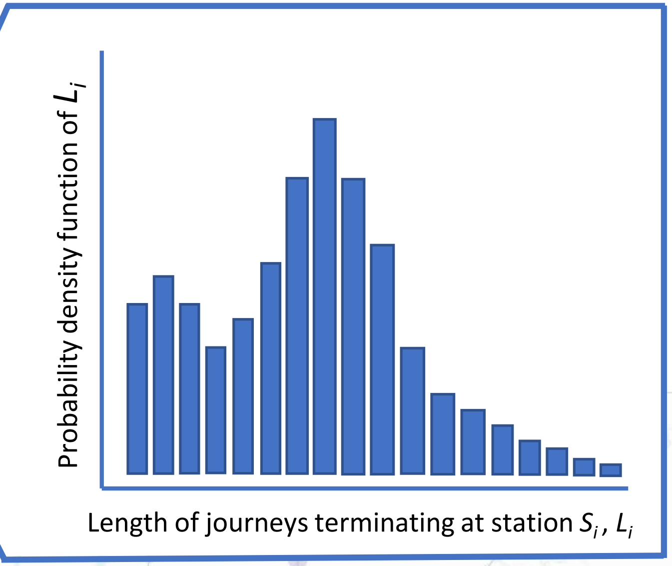
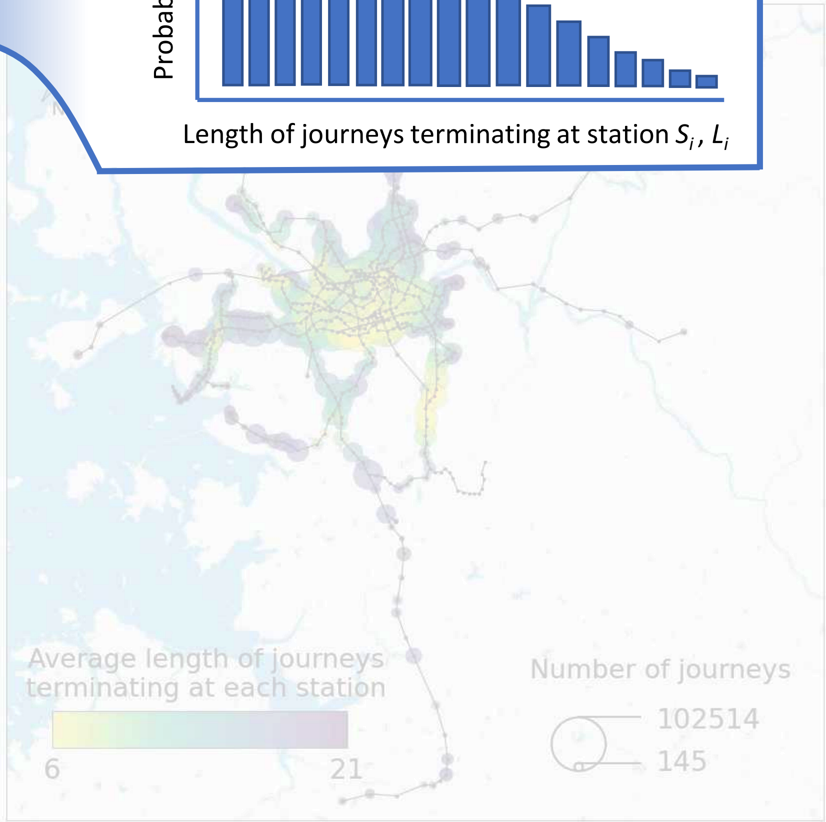




- Define the "most central" node in the network, call it **nucleus** and denote it by S_1
- We choose **Piccadilly Circus** in London & **City Hall** in Seoul (somewhat arbitrary choice)
- But then, we perform a sensitivity analysis

Methods – the *monocentric hypothesis*

MONOCENTRIC HYPOTHESIS

If a city was perfectly monocentric, the expected length of the journeys terminating at a station (except for the nucleus itself) would be equal to the network distance between the nucleus and the destination station

Mathematically,

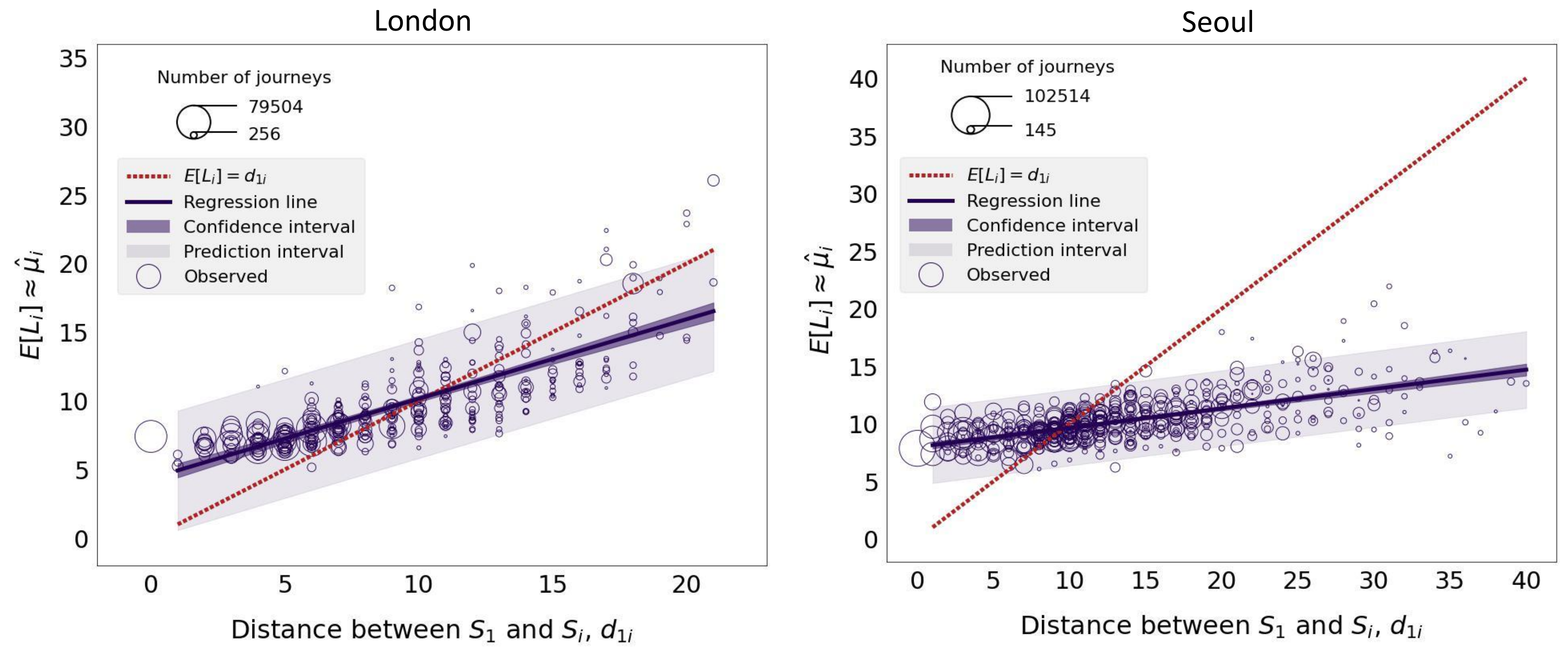
$$E[L_i] = d_{1i}$$

for $i = 2,\ldots,N$

IN REALITY

$E[L_i]$ (estimated as $\hat{\mu}_i$, i.e. the arithmetic mean of the observations for L_i) do not fall on the $E[L_i] = d_{1i}$ line

Can we further explore these deviations?



Methods – probabilistic approach, mixture models

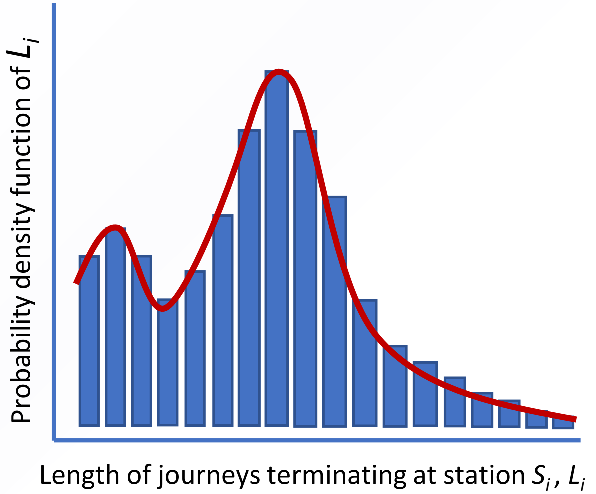
- In order to describe the deviations from the hypothesised monocentric behaviour in more detail, we introduce Poisson mixture models

$$f_i(L_i = h|\vec{w}_i, \vec{\mu}_i) = \sum_{j=1}^{K} w_i^j p_i^j (L_i = h|\mu_i^j)$$

We set p_i^j to be a Poisson distribution with parameter μ_i^j,

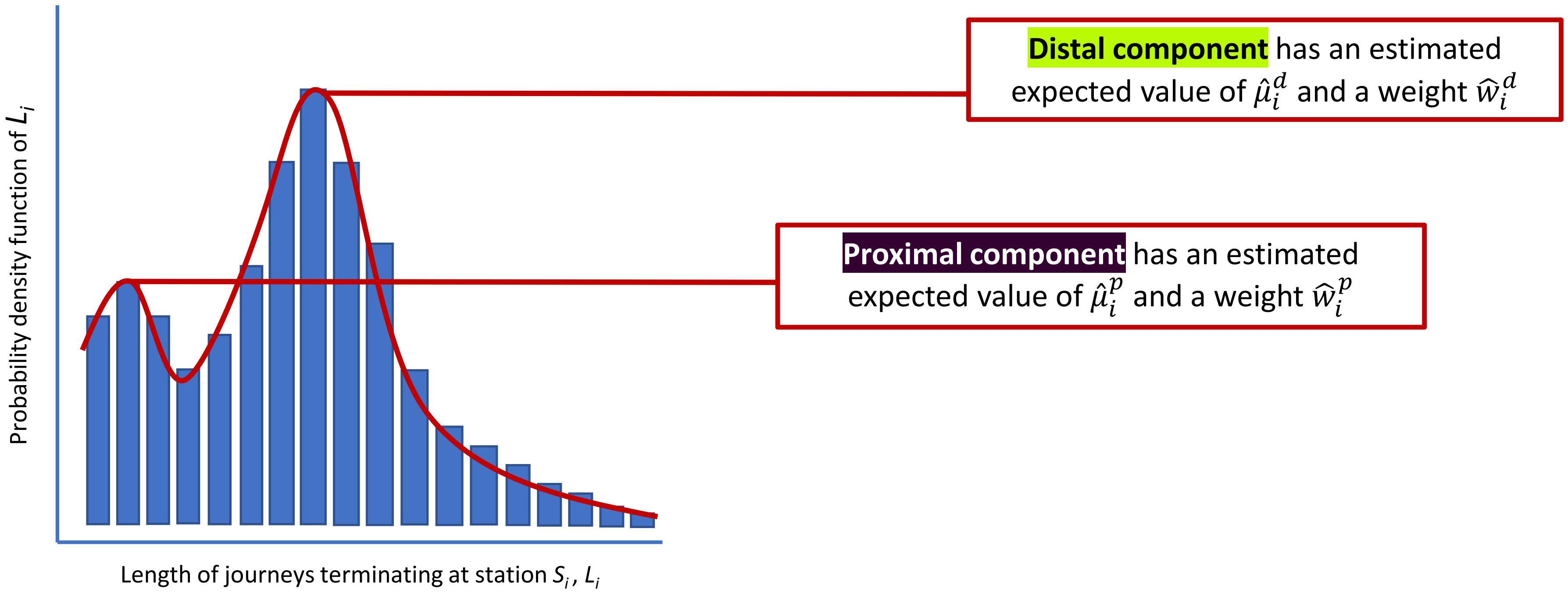
so that $p_i^j(L_i = h|\mu_i^j) = \frac{1}{h}(\mu_i^j)^h \exp(-\mu_i^j)$

for $i = 1, \dots, N$ and $j = 1, \dots, K$



Results – two-component Poisson mixture model

- Let K=2, then, the mixture model turns into $f_i(L_i = h|\vec{w}_i, \vec{\mu}_i) = w_i^1 p_i^1(L_i = h|\mu_i^1) + w_i^2 p_i^2(L_i = h|\mu_i^2)$
- We refer to the component with the lowest estimated mean as the proximal component
- The other component is the distal component



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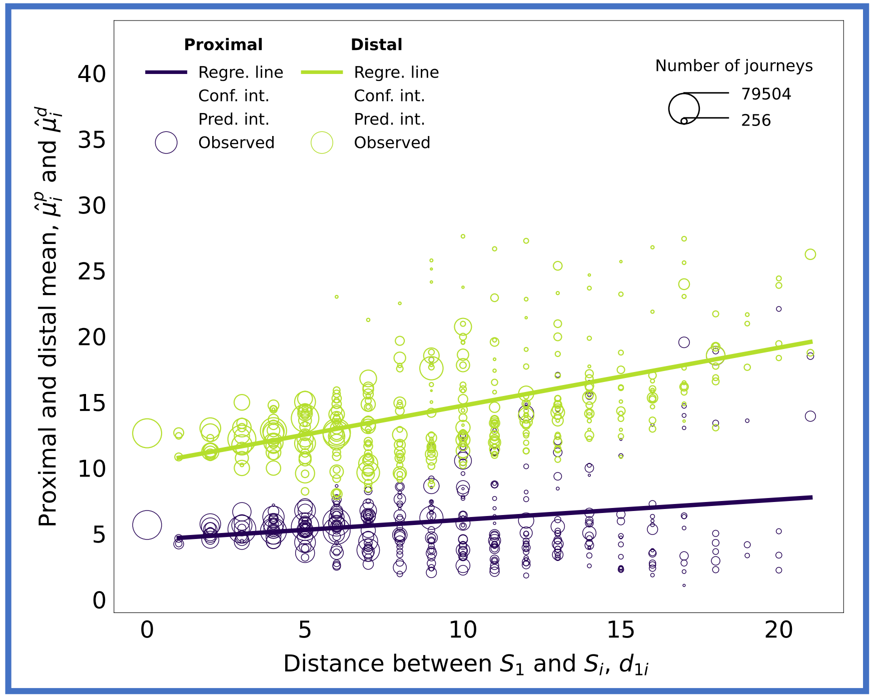
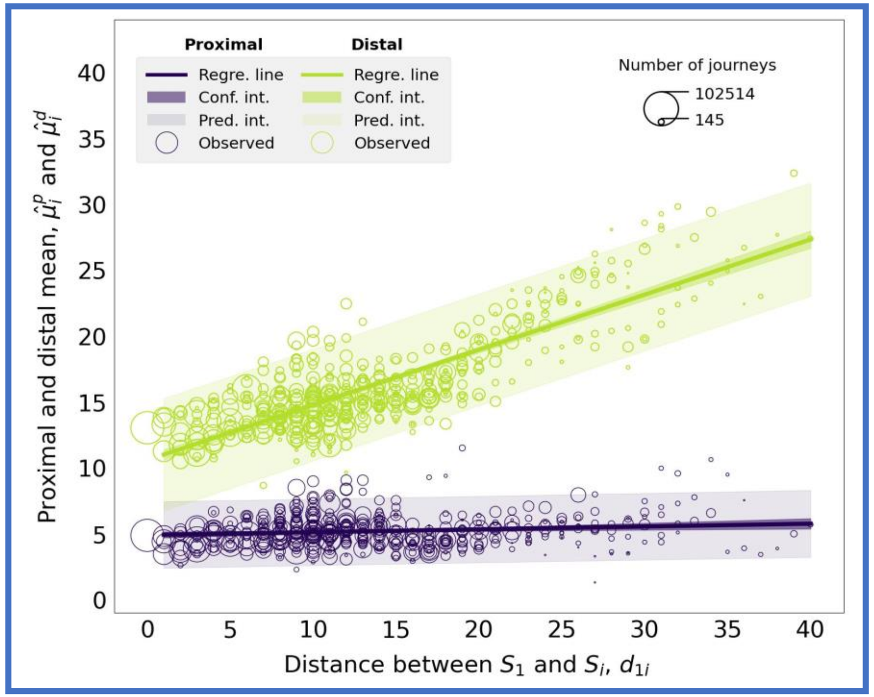
LONDON



Intercept	Slope	R	p
4.38 ± 0.43	0.17 ± 0.04	0.21	< 0.05
10.09 ± 0.45	0.46 ± 0.04	0.50	< 0.05

SEOUL



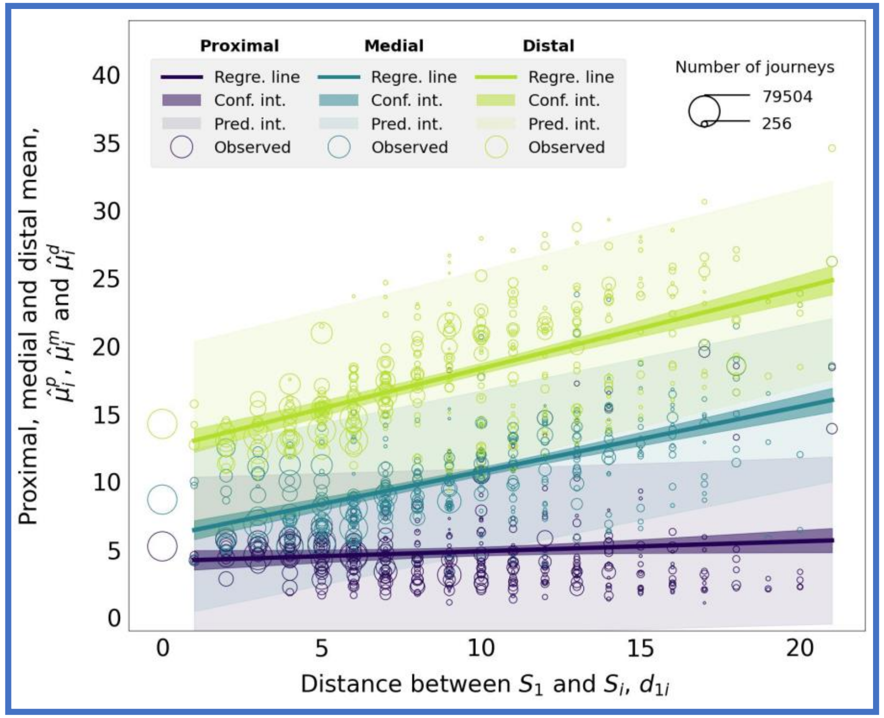
Intercept	Slope	R	p
4.90 ± 0.12	0.02 ± 0.01	0.13	< 0.05
10.59 ± 0.20	0.42 ± 0.01	0.84	< 0.05

- As d_{1i} becomes larger, there is no significant increase in the proximal mean $\hat{\mu}_i^p$
- Likely to be the consequence of the existence of other socioeconomic centres, closer to the destination station S_i, where passengers prefer to travel to carry out some socioeconomic activities at a more local level
- In contrast, the distal component significantly increases with d_{1i}
- The distal component captures long-distance, city-wide journeys from stations that are possibly close to the nucleus, to stations that are in the peripheral regions of the city

Results – three-component Poisson mixture model

- Let K=3, then, the mixture model turns into $f_i(L_i = h|\vec{w}_i, \vec{\mu}_i) = w_i^1 p_i^1(L_i = h|\mu_i^1) + w_i^2 p_i^2(L_i h|\mu_i^2) + w_i^3 p_i^3(L_i h|\mu_i^3)$
- We call the component proximal, medial and distal

LONDON



Intercept	Slope	R	p
4.05 ± 0.40	0.08 ± 0.04	0.11	< 0.05
6.08 ± 0.36	0.49 ± 0.03	0.62	< 0.05
12.80 ± 0.48	0.56 ± 0.05	0.57	< 0.05

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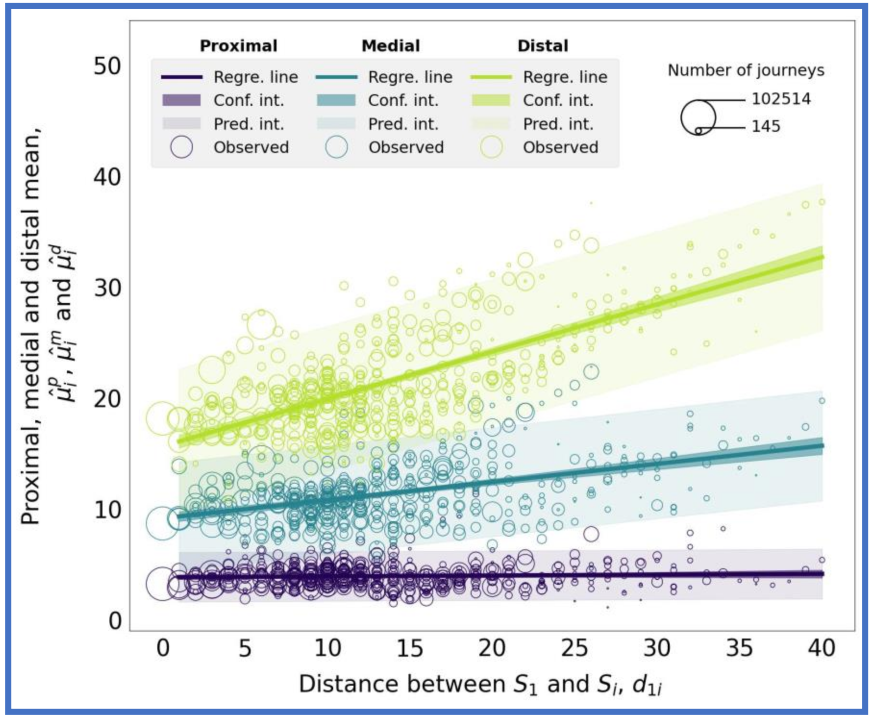

Intercept	Slope	R	p
3.83 ± 0.11	0.01 ± 0.01	0.05	0.26
9.15 ± 0.24	0.16 ± 0.01	0.46	< 0.05
15.64 ± 0.31	0.43 ± 0.02	0.71	< 0.05

- The behaviour of the proximal and distal components is analogous to the K = 2 case
- We recommend keeping K to 2 or 3

Discussion and conclusions

- The construction of London’s transport network started at the end of the 19th century while the construction of Seoul’s started in 1971
- **Assuming** that the layout of the transport network and the passengers’ travelling behaviour are a manifestation of urban structure, then the fact that our findings suggest that London is more monocentric than Seoul, should not come as a surprise
- But, does this **assumption** hold in general? **Has London’s early construction of a public transport network conditioned its urban structure** and slowed its transition towards a more polycentric arrangement?

Link to full paper

Cabrera-Arnau, C., Zhong, C., Batty, M. *et al.* Inferring urban polycentricity from the variability in human mobility patterns. *Sci Rep* **13**, 5751 (2023).