Lecture 8

Consequences of Network Models of Cities

8.1 Predictive Consequences of Urban Scaling Theory

IUS 3.3

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Many quantitative predictions + general consequences

Urban scaling relation	Exponent prediction $D = 2, H_m = 1$	Exponent prediction General D, H_m
Land area $A = aN^{\alpha}$	$\alpha = 2/3$	$\alpha = \frac{D}{D + H_m}$
Network volume $A_n = A_0 N^{\nu}$	$\nu = 5/6$	$\nu = 1 - \delta$
Network Length $L_n = L_0 N^{\lambda}$	$\lambda = 2/3$	$\lambda = \alpha$
Interactions/capita $k = k_0 N^{\delta}$	$\delta = 1/6$	$\delta = \frac{H}{D(D + H_m)}$
Social outputs $Y = Y_0 N^{\beta}$	$\beta = 7/6$	$\beta = 1 + \delta$
Power dissipation $W = W_0 N^{\omega}$	$\omega = 7/6$	$\omega = 1 + \delta$
Land rents ($\$/m^2$) $P_L = P_0 N^{\beta_L}$	$\beta_L = 4/3$	$\beta_L = 1 + 2\,\delta$

Summary of Urban Scaling relations and exponent predictions for various important quantities. Note that agglomeration effects vanish when $H_m \to 0$ because then people remain spatially separated social networks fail to emerge (we will look at internet quantities later).

Besides predictions for scaling of all these quantities…

There are a number of very interesting combinations and ratios:

- The ratio of built volume to total area of cities
- The depth of social networks in cities vs the size of the entire population
- The “price” of land (land rents): or the rate of money exchanged per land area
- The ratio of land rents and incomes and building heights

Landscapes of Infrastructure

$$A_n/A \sim N^{\delta}$$

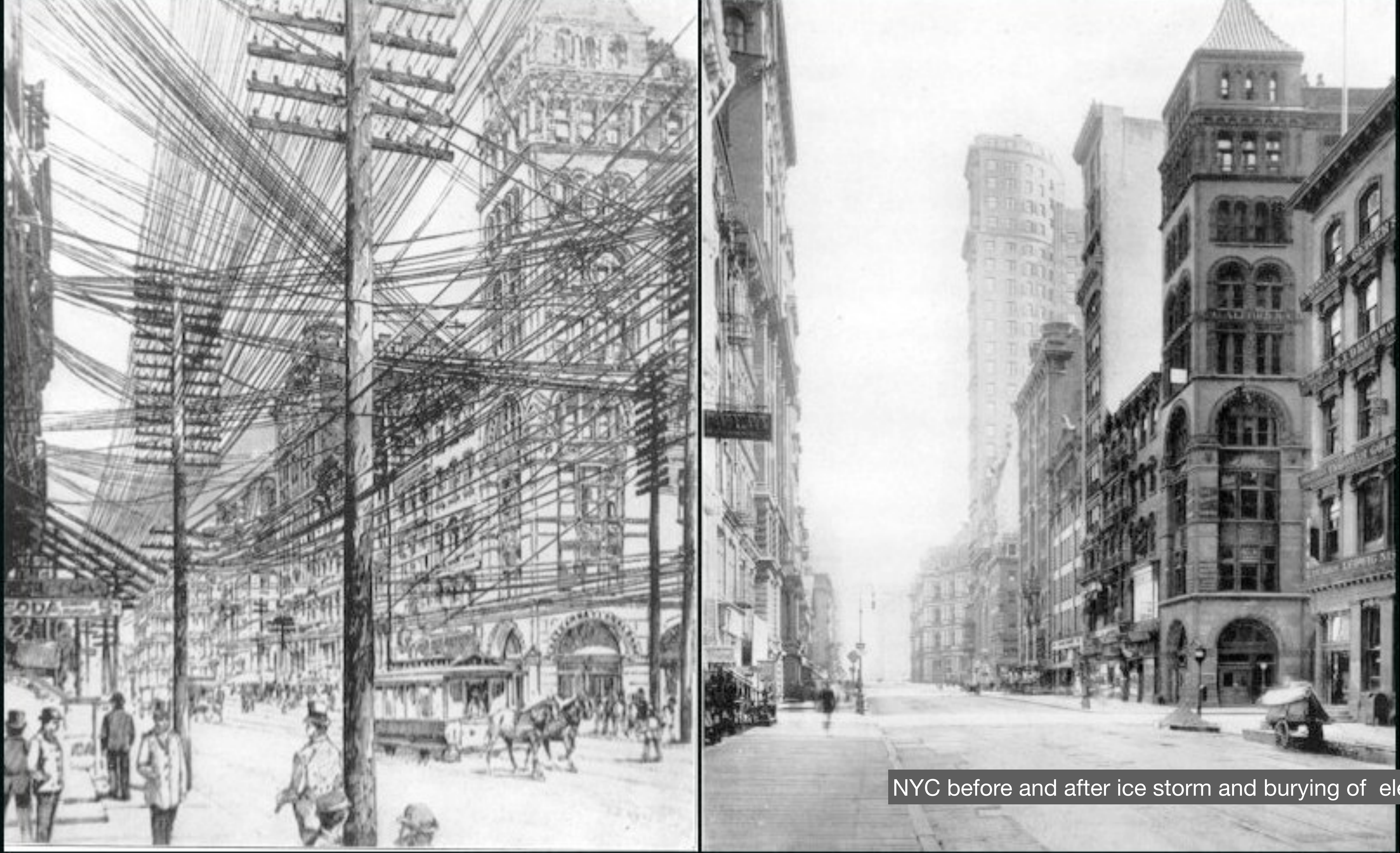
Greater infrastructure network volume per unit area with city size, especially in city centers

Master/Trunk infrastructure gets enormous


infrastructure networks must push
into the third dimension
credit: MacLean

infrastructure networks take over many urban spaces

credit: Robert Stone



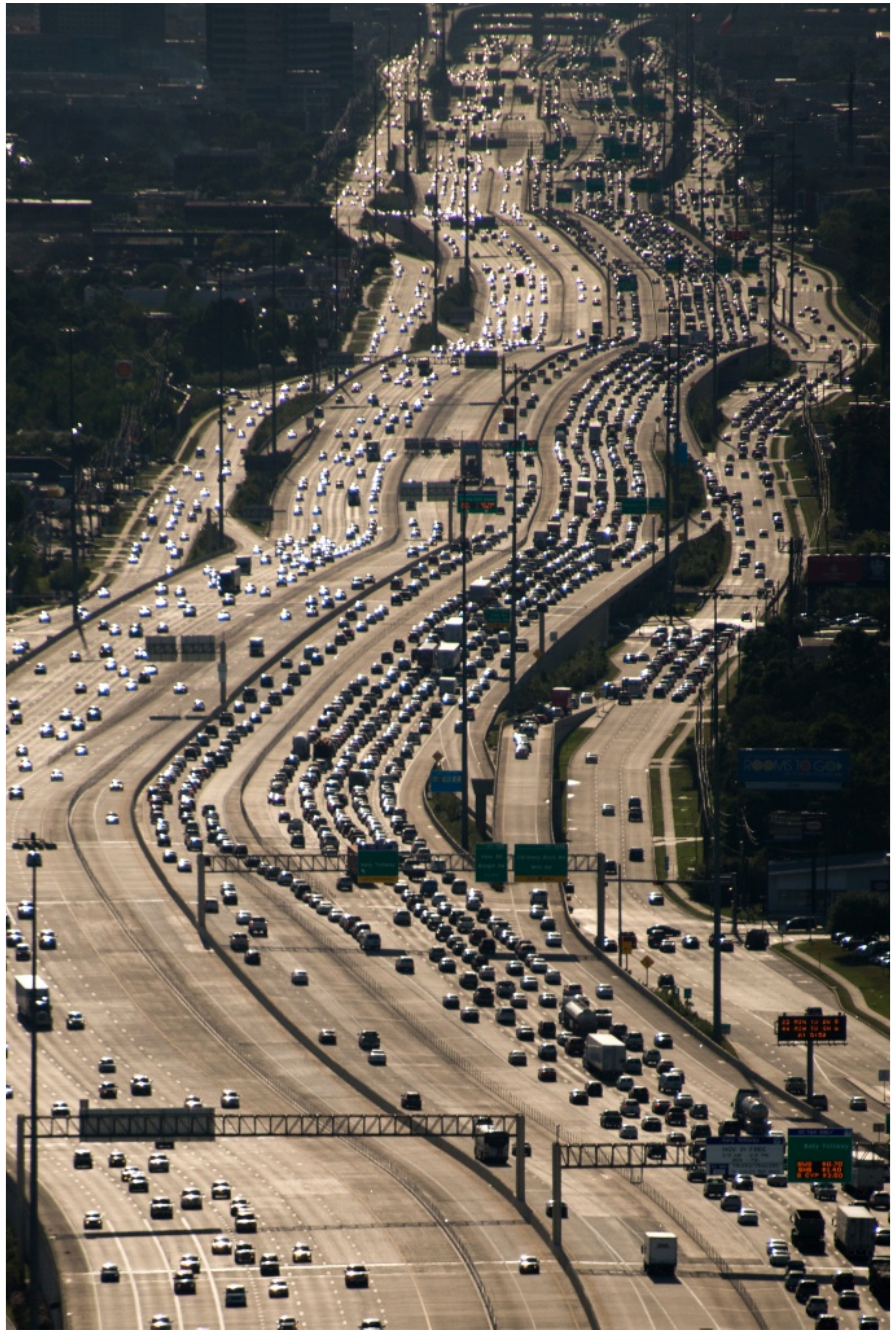
NYC before and after ice storm and burying of electrical cables

1890s New York City
credit: www.loper-os.org

And must go into the third dimension, above or below ground to leave space for people

World’s Widest Highways

G4 Beijing-Hong Kong-Macau Expressway (Image source: Reuters/China Daily)



IH-10 in Houston TX

what happens to width when speeds are lower?

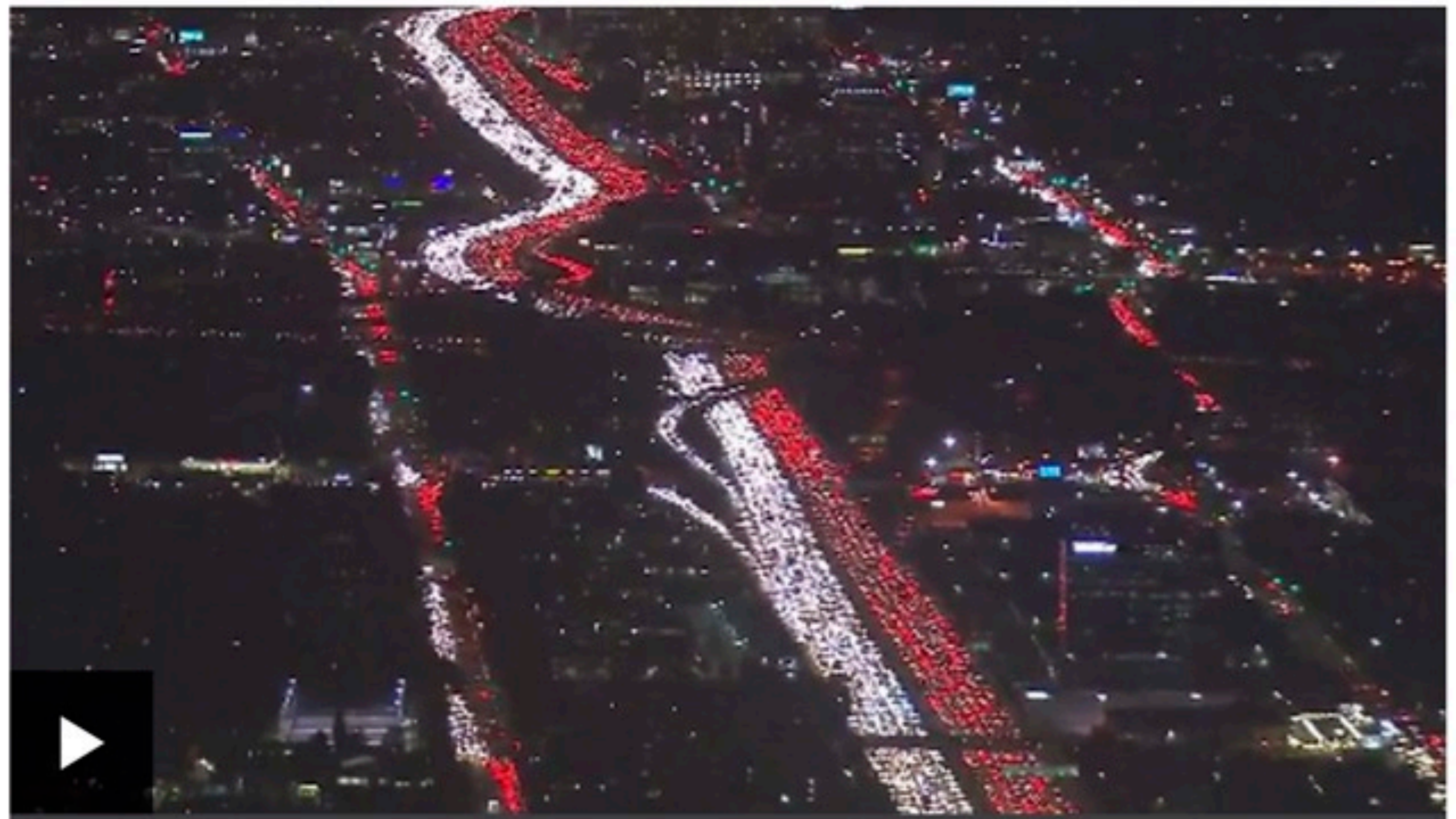
World’s Worst Traffic Jams

mostly in large developing cities

US & Canada

Thanksgiving traffic jam in Los Angeles is 'most epic'

23 November 2016



Thanksgiving traffic jam is 'most epic'

Aerial footage has gone viral of a massive traffic jam, captured during the great Thanksgiving getaway in southern California.

A news helicopter filmed the miles-long gridlock on the 405 motorway in the Los Angeles area on Tuesday.

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China traffic jam stretches 'nine days, 100km'

24 August 2010

A woman caught up in the jam describes her ordeal

A massive traffic jam in China has slowed vehicles to a crawl for nine days near Beijing, local media say.

Vehicles, mostly lorries bound for Beijing, are in a queue for about 100km (62 miles) because of heavy traffic, road works and breakdowns.

The drivers have complained that locals were over-charging them for food and drink while they were stuck.

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Sao Paulo: A city with 180km traffic jams

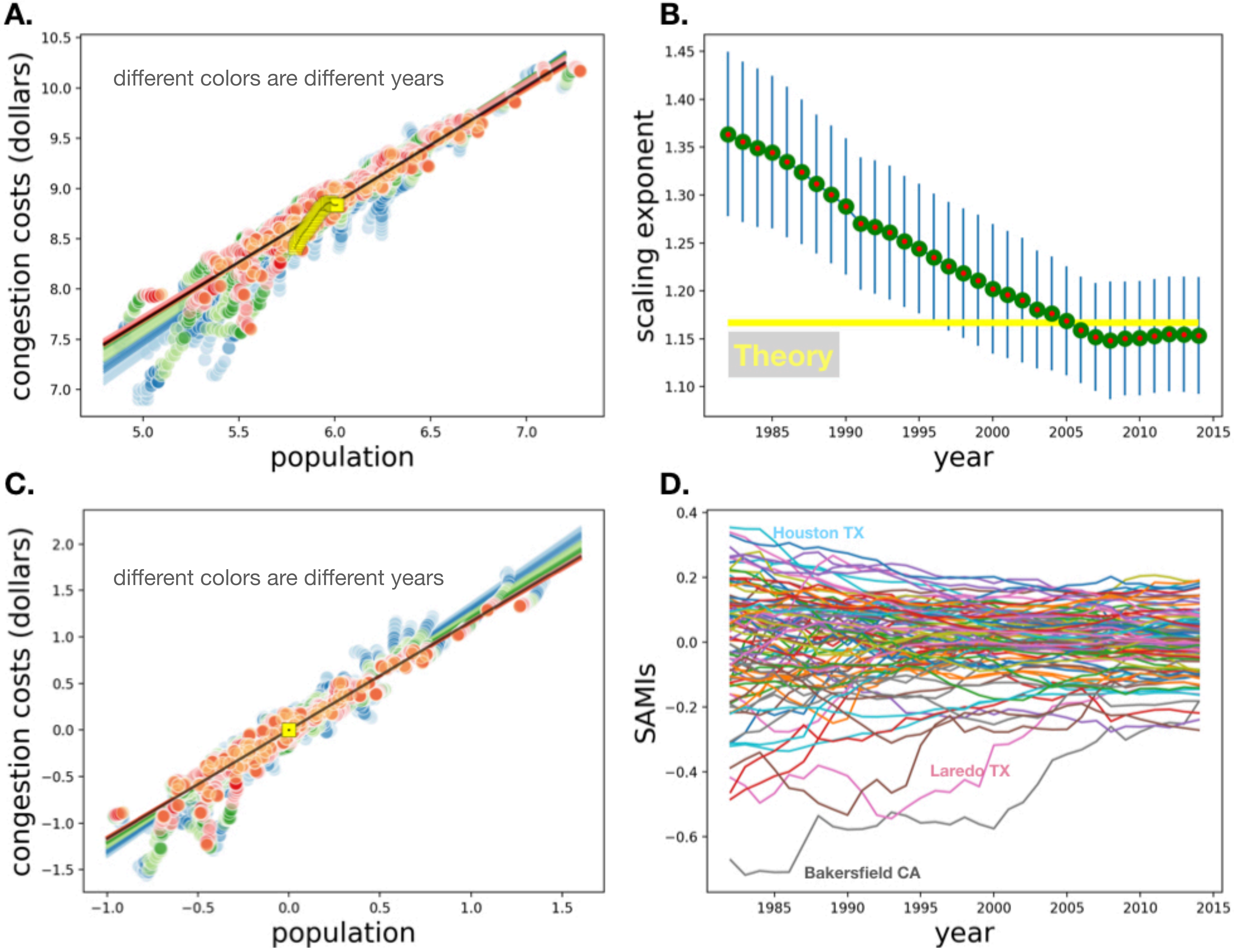
By Paulo Cabral
BBC News, Sao Paulo

25 September 2012

Next time you complain about being stuck in traffic, spare a thought for the drivers in Brazil's biggest city, which has some of the worst congestion problems in the world.

Friday evenings are a commuter's worst nightmare in Sao Paulo.

That's when all the tailbacks in and out of the city extend for a total of 180km (112 miles), on average, according to local traffic engineers, and as long as



https://royalsocietypublishing.org/doi/pdf/10.1098/rsif.2019.0846

building heights

$GDP/A_n \sim N^{2\delta}$ Land rents increase faster than incomes

building heights $\sim N^{\delta}$ larger cities get rising skylines

why?

Hong Kong
credit:Guardian

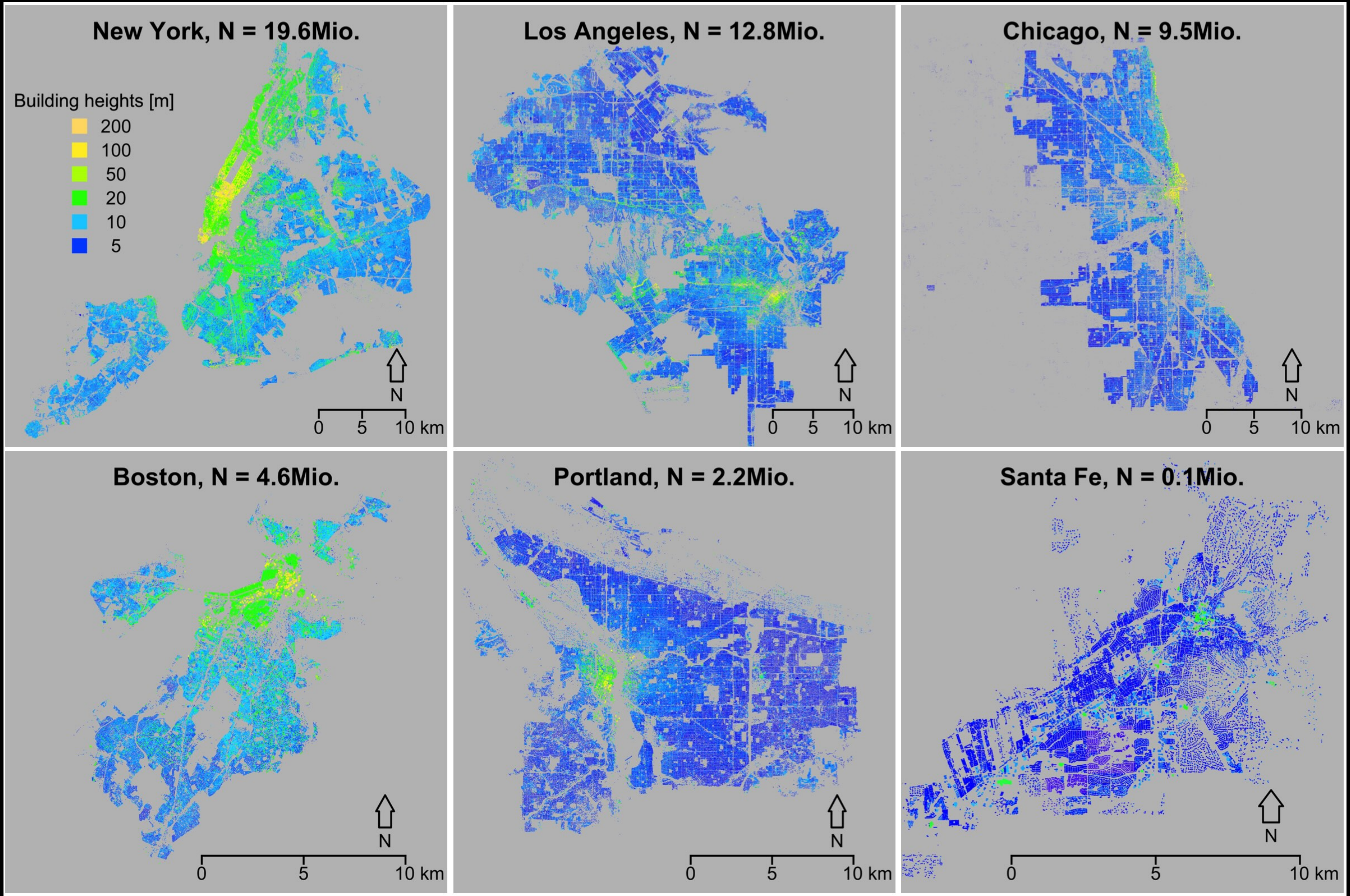

1876
1932

2839

1988
2013

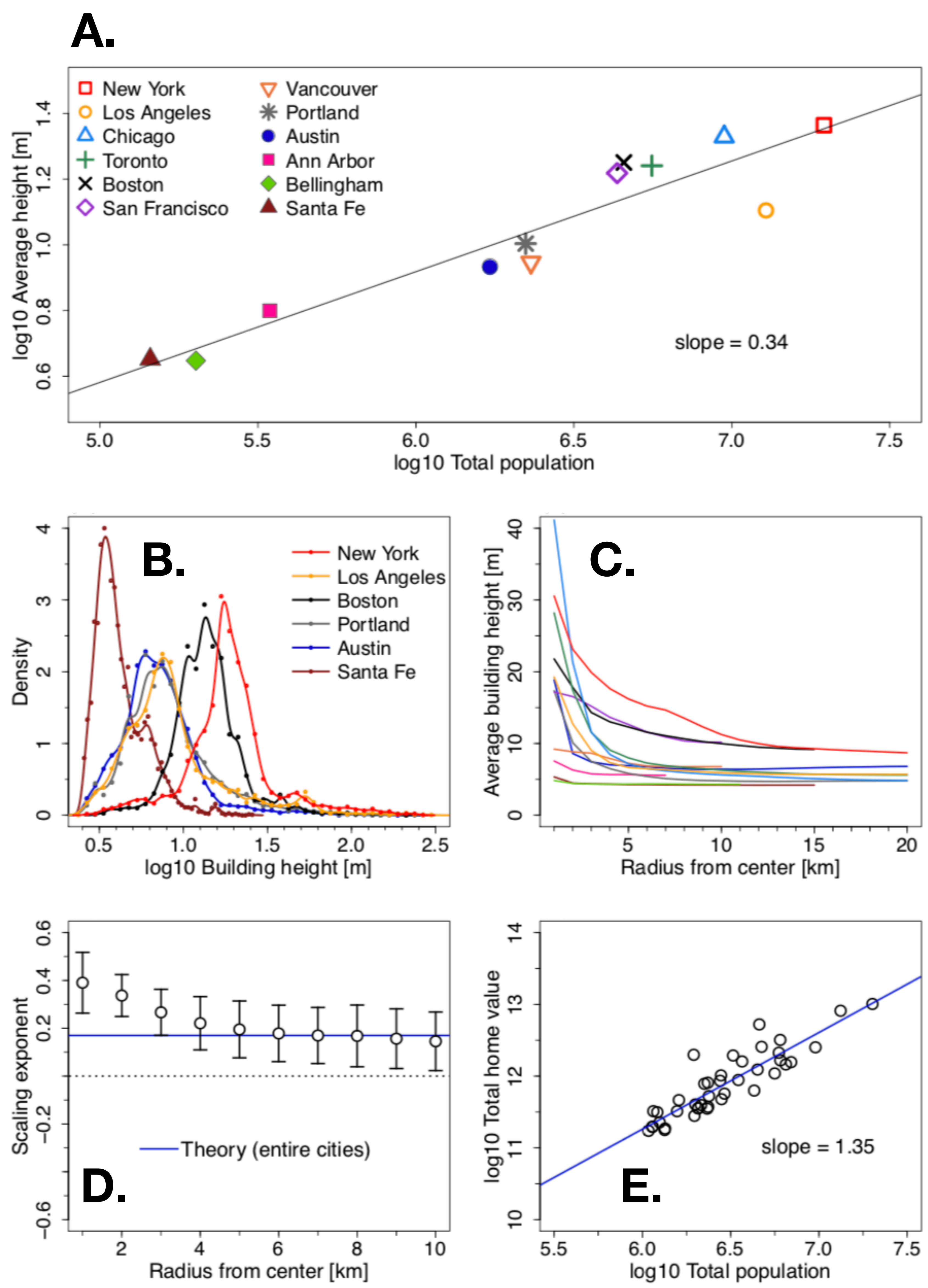
credit: telegraph

credit: Obinna Okerekeocha

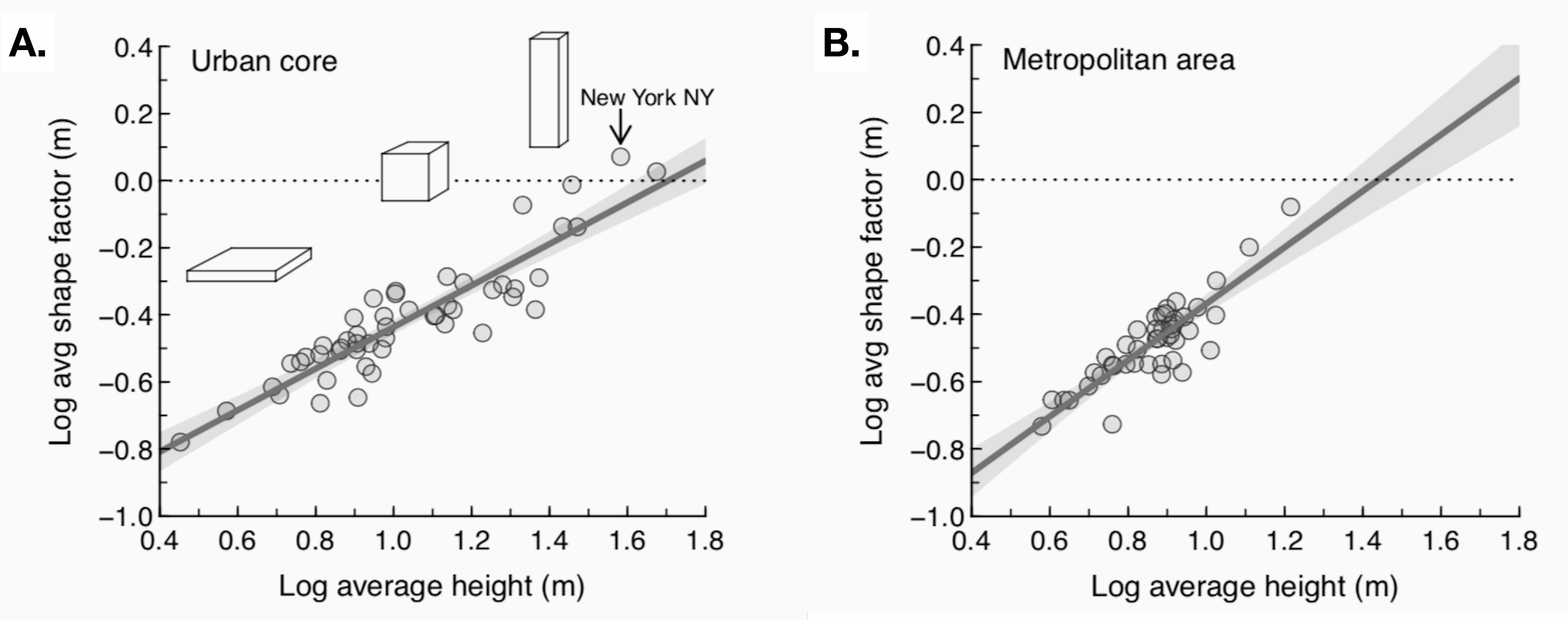


data from LiDAR

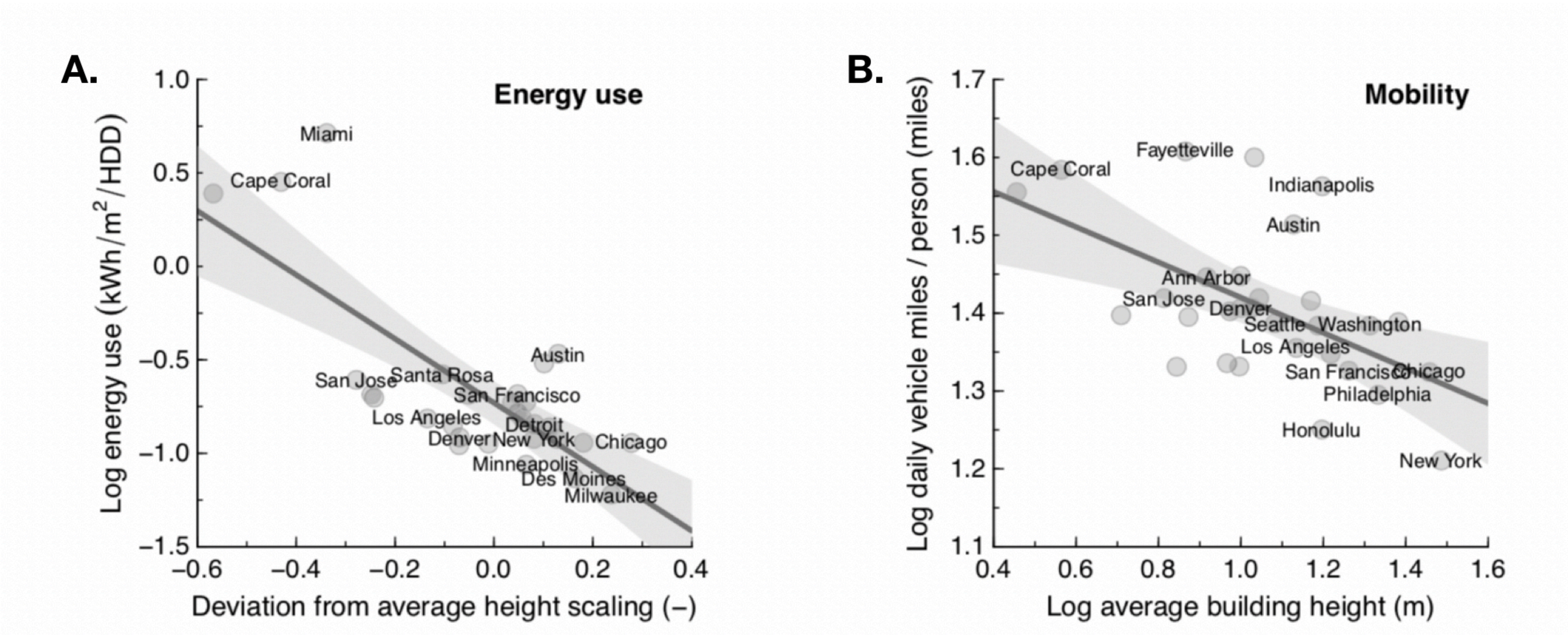
Schlaepfer, Lee, Bettencourt (2016)
Urban Skylines: building heights and shapes as measures of city size



A.
New York
Los Angeles
Chicago
Toronto
Boston
San Francisco
Vancouver
Portland
Austin
Ann Arbor
Bellingham
Santa Fe
slope = 0.34
log10 Average height [m]
log10 Total population
B.
New York
Los Angeles
Boston
Portland
Austin
Santa Fe
Density
log10 Building height [m]
C.
Average building height [m]
Radius from center [km]
D.
Theory (entire cities)
Scaling exponent
Radius from center [km]
E.
slope = 1.35
log10 Total home value
log10 Total population

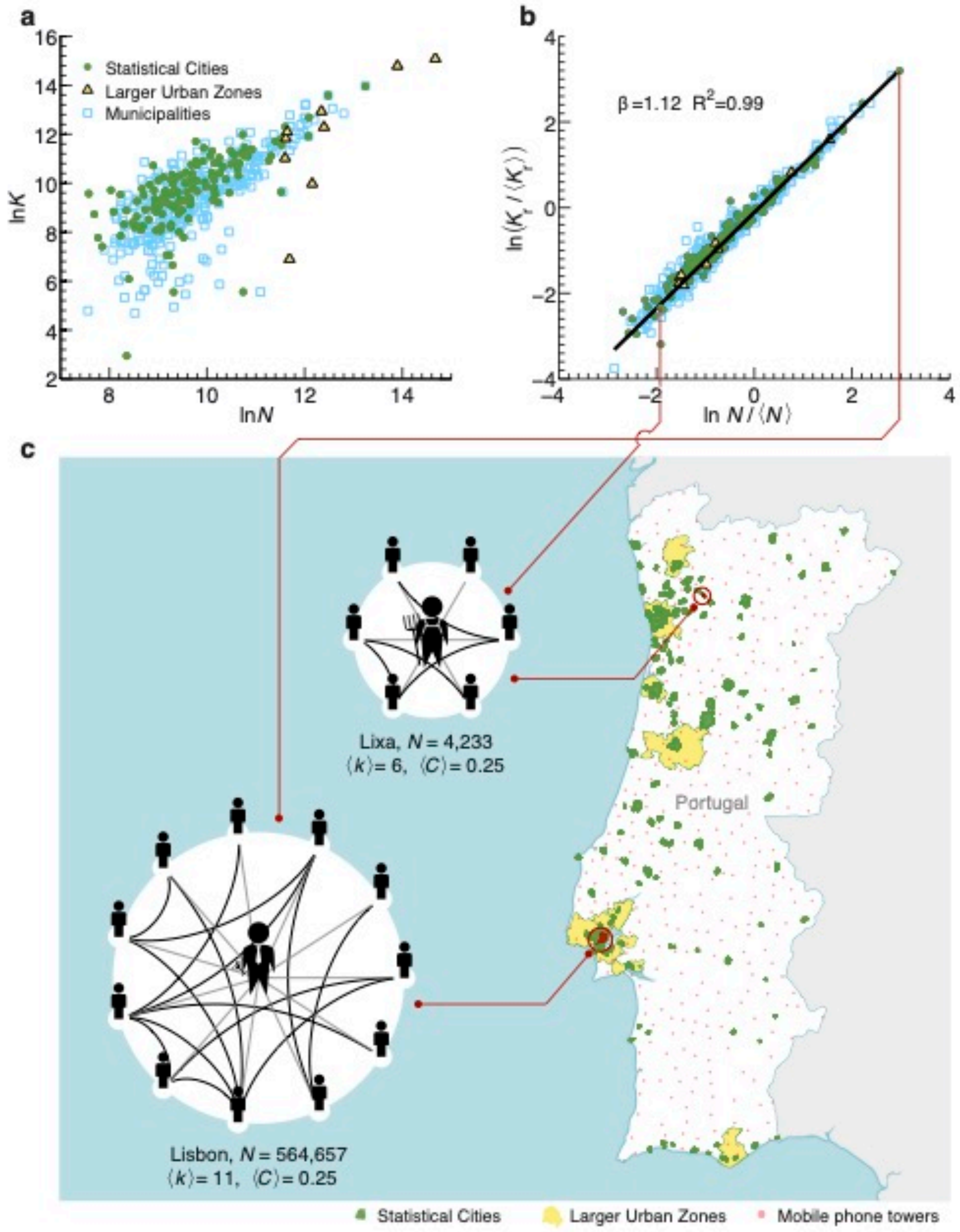

A.
Urban core
New York NY
Log avg shape factor (m)
Log average height (m)
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
B.
Metropolitan area
Log avg shape factor (m)
Log average height (m)

Higher buildings lead to savings in energy use and mobility



Social Networks get denser

average connectivity per capita: $\sim N^{\delta}$



Urban cellphone networks

β = 1.12-1.19

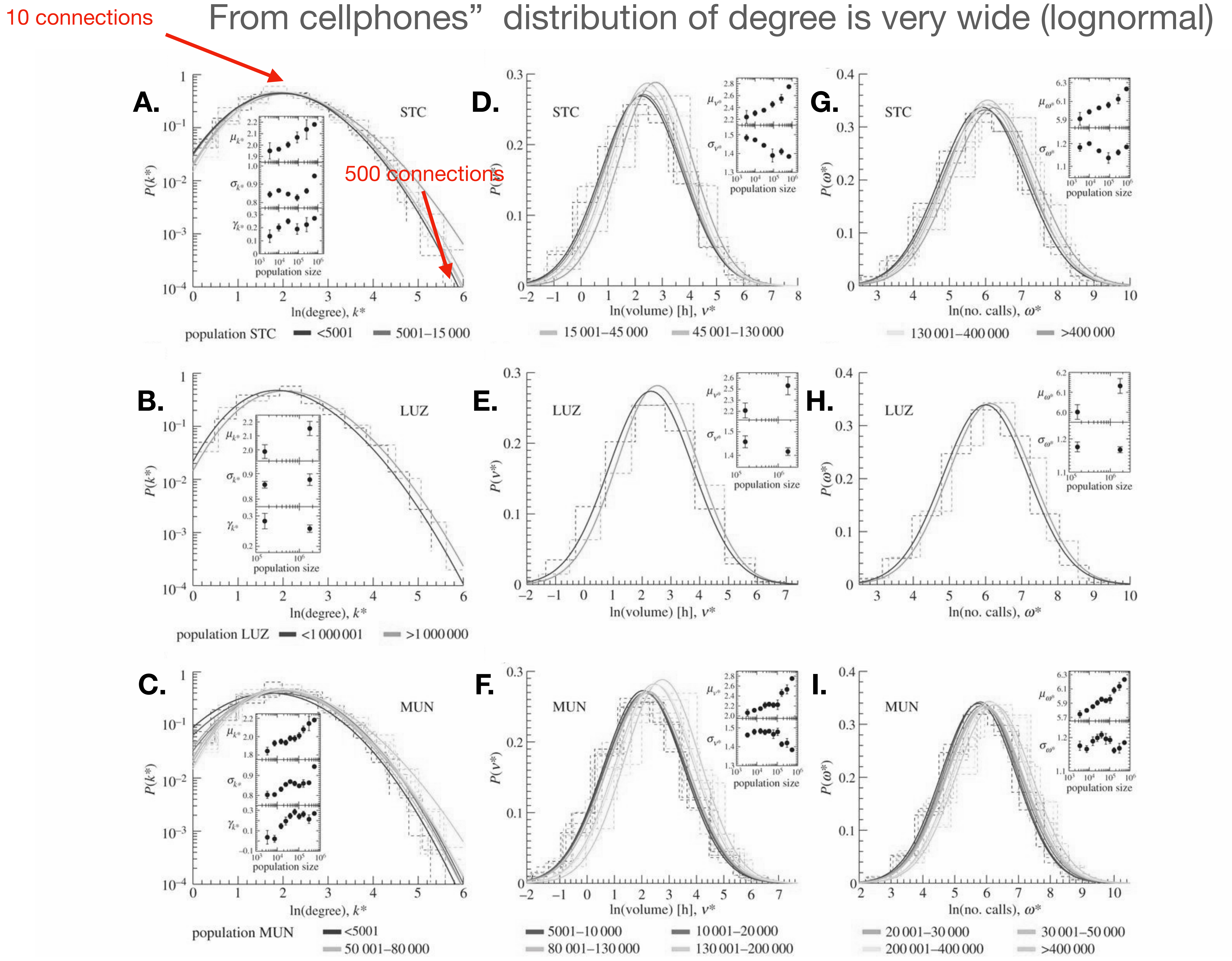
in agreement with theory.

Network clustering is preserved:

same sense of community in town and country!

Schläpfer et al, 2014

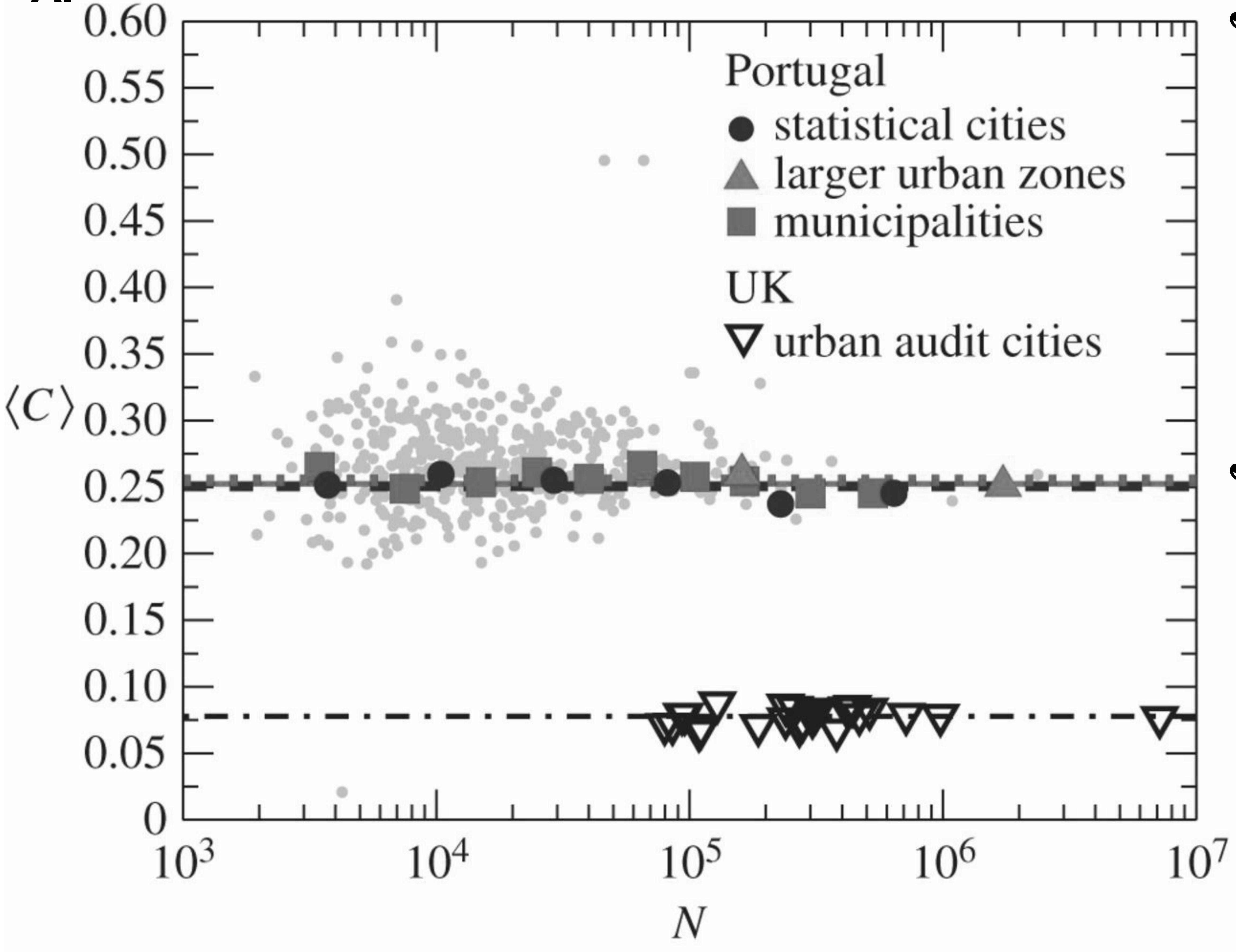
From cellphones” distribution of degree is very wide (lognormal)



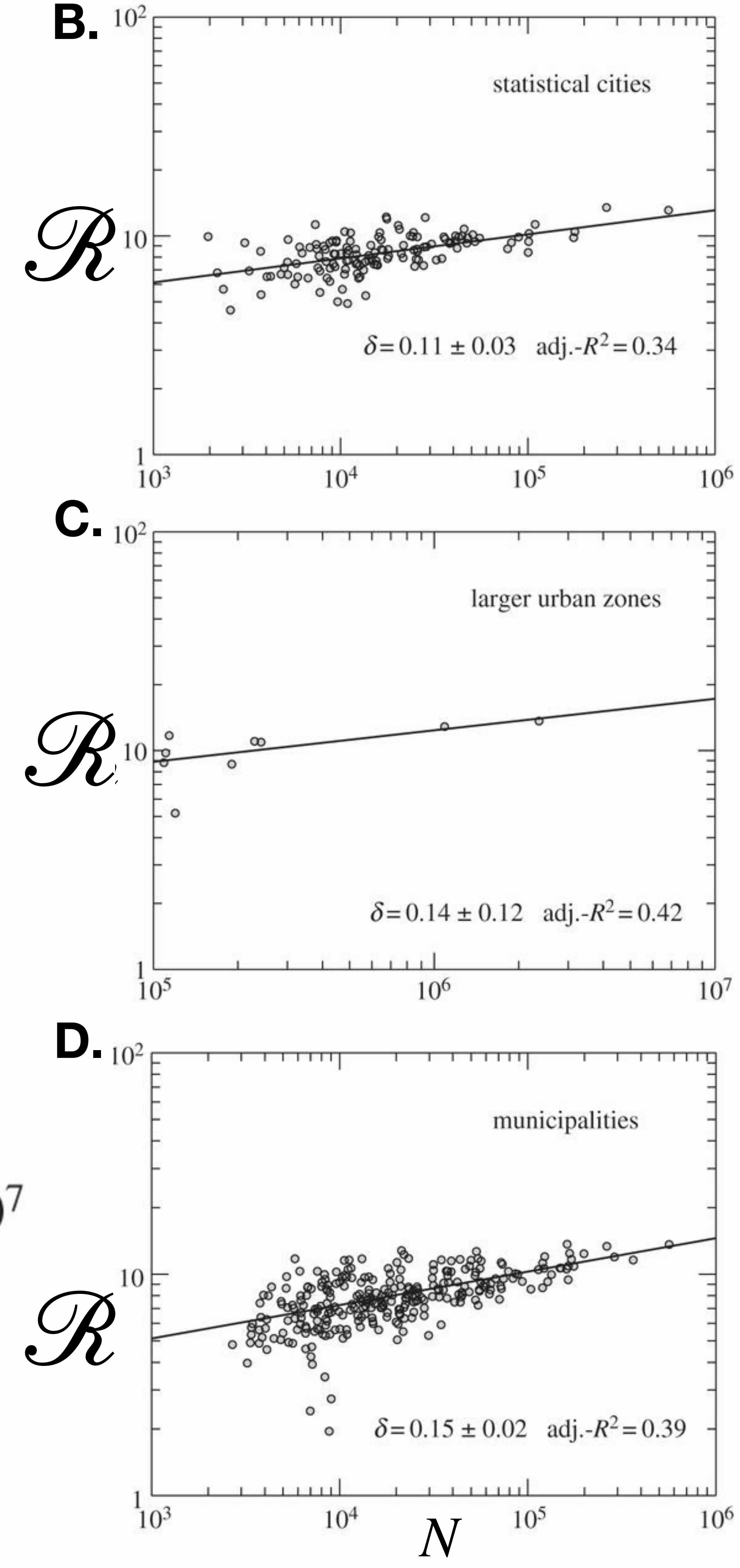
How many of your friends are mutual friends ?

clustering coefficient

A.



B. C. D.



Contagion Dynamics

scales **superlinearly**

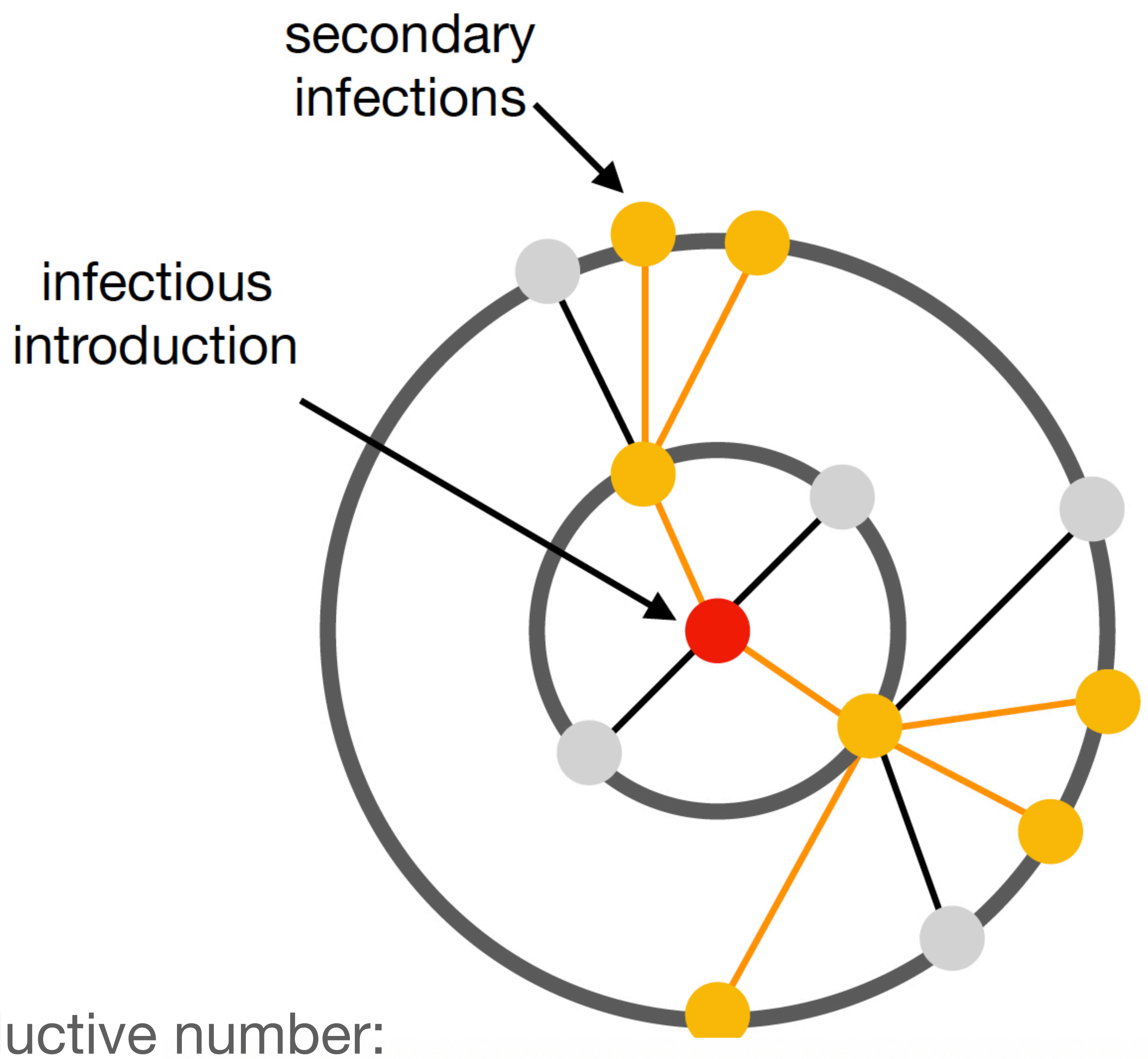
with population size

https://royalsocietypublishing.org/doi/full/10.1098/rsif.2013.0789

Contagious Diseases and Information spread faster in larger cities

average connectivity per capita: $k(N) \sim N^{\delta}$

Contagious Processes on Networks



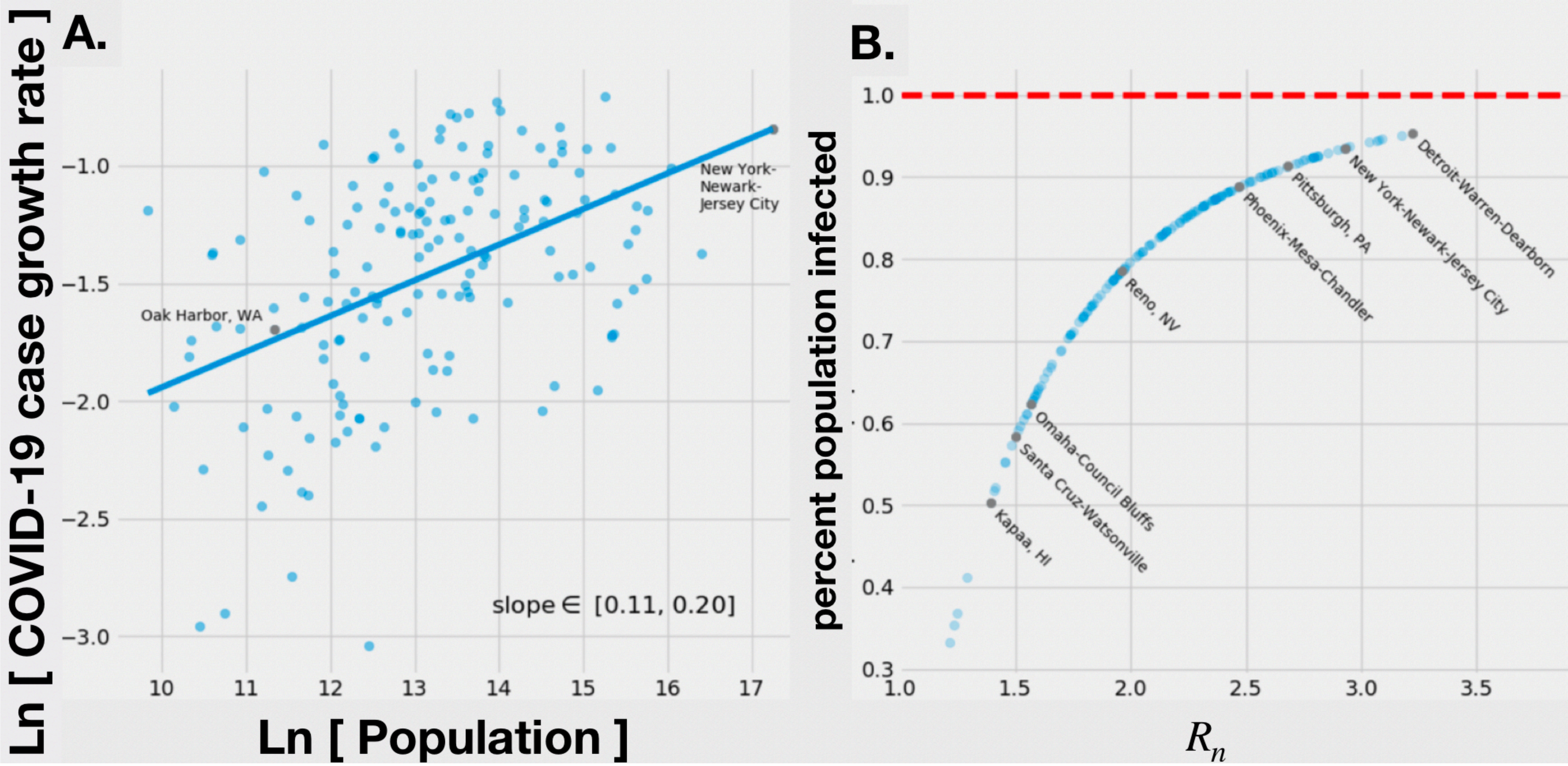
Reproductive number:

$$\mathcal{R} = P_I \frac{\langle k^2 \rangle}{\langle k \rangle} = P_I \langle k \rangle \left(1 + \frac{\sigma_k^2}{\langle k \rangle^2}\right)$$

$$k = \langle k \rangle = e^{\mu + \frac{\sigma^2}{2}}, \qquad \sigma_k^2 = \left(e^{\sigma^2} - 1\right) e^{2\mu + \sigma^2}$$

$$\mathcal{R}(N) = P_I\, e^{\sigma^2} k(N) \simeq P_I\, k_0\, e^{\sigma^2} N^{\delta}$$

For COVID-19:



size of the outbreak $S_\infty = S_0\, e^{-\mathcal{R}\left(1 - \frac{S_\infty}{N}\right)}$

vaccination rate: $P_v = 1 - 1/\mathscr{R}$

Mental Health

Evidence and theory for lower rates of depression in larger US urban areas

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Edited by William A. V. Clark, University of California, Los Angeles, CA, and approved June 18, 2021 (received for review October 27, 2020)

It is commonly assumed that cities are detrimental to mental health. However, the evidence remains inconsistent and at most, makes the case for differences between rural and urban environments as a whole. Here, we propose a model of depression driven by an individual's accumulated experience mediated by social networks. The connection between observed systematic variations in socioeconomic networks and built environments with city size provides a link between urbanization and mental health. Surprisingly, this model predicts lower depression rates in larger cities. We confirm this prediction for US cities using four independent datasets. These results are consistent with other behaviors associated with denser socioeconomic networks and suggest that larger cities provide a buffer against depression. This approach introduces a systematic framework for conceptualizing and modeling mental health in complex physical and social networks, producing testable predictions for environmental and social determinants of mental health also applicable to other psychopathologies.

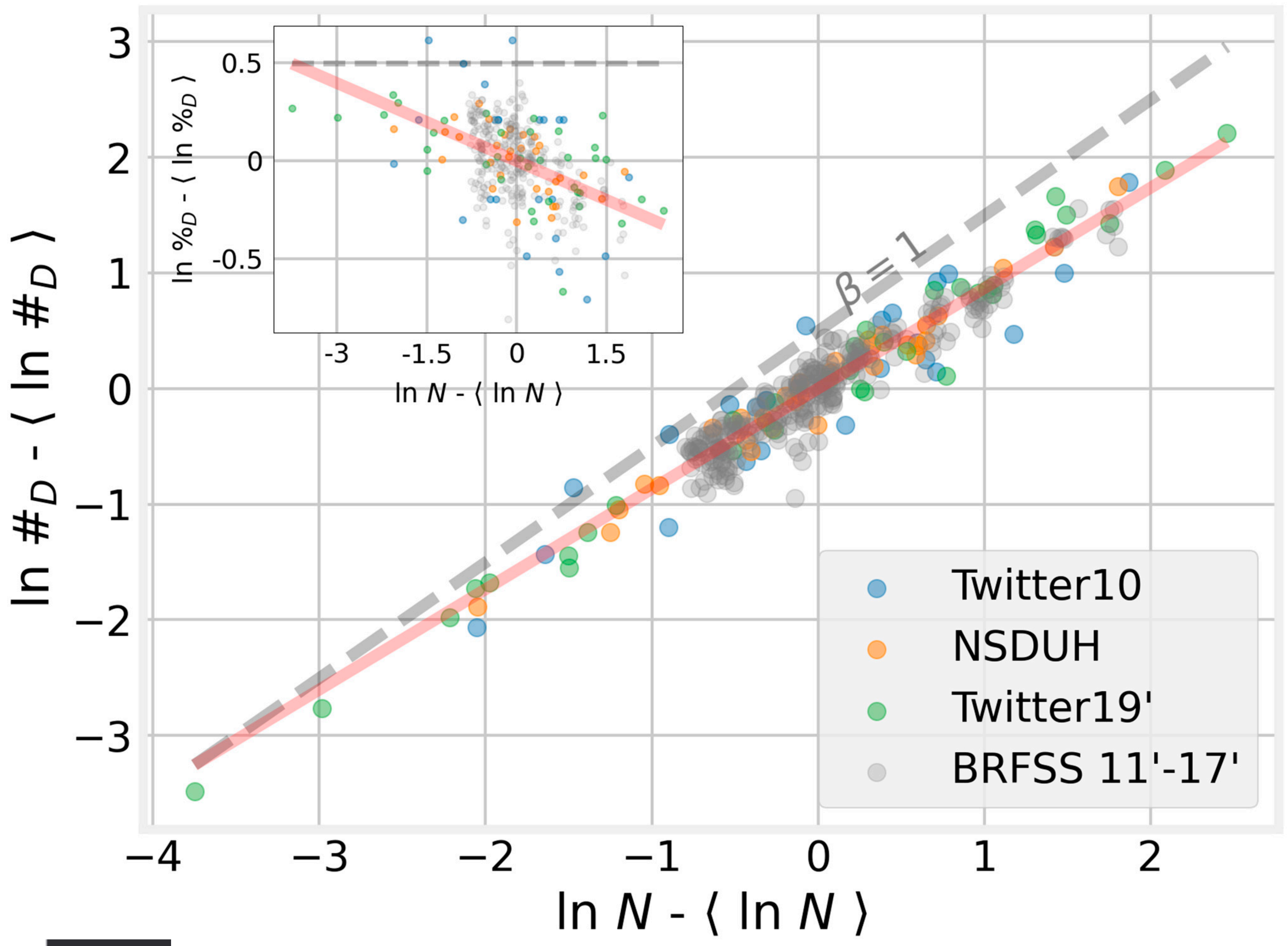
cities | depression | social networks | built environment | complex systems

Living in cities changes the way we behave and think (1–3). Over a century ago, the social changes associated with mas- mental health in cities vs. rural areas (7, 8). However, this evidence and that linking SWB and cities (15–18) have remained mixed and often explicitly inconsistent (19, 20) due to differences in 1) reporting (e.g., surveys vs. medical records); 2) types of measurement (e.g., surveys vs. interviews); 3) definitions of what constitutes urban; and 4) the mental disorders studied (e.g., schizophrenia vs. depression).

For these reasons, it is desirable to create a systematic framework that organizes this diverse body of research and interrogates how varying levels of urbanization influence mental health across different sets of indicators. Here, we begin to build this framework for depression in US cities. We show that, surprisingly, the per capita prevalence of depression decreases systematically with city size.

Like earlier classic approaches, our strategy frames the effects of city size on mental health through the lens of the individual experience of urban physical and socioeconomic environments. Crucial to our purposes, many characteristics of cities have been recently found to vary predictably with city population size. These systematic variations in urban indicators are explained by denser built environments and their associated increases in the intensity of human interactions and resulting adaptive behaviors (21).

https://www.pnas.org/doi/10.1073/pnas.2022472118



ECOLOGY

PSYCHOLOGICAL AND COGNITIVE SCIENCES

The pace of life accelerates

average rates of production and exchange per capita: $y(N) \sim N^{\delta}$

speeds $[y] \sim 1/time$

times between events "shrink" : $\sim N^{-\delta}$

quantifies some measures of overload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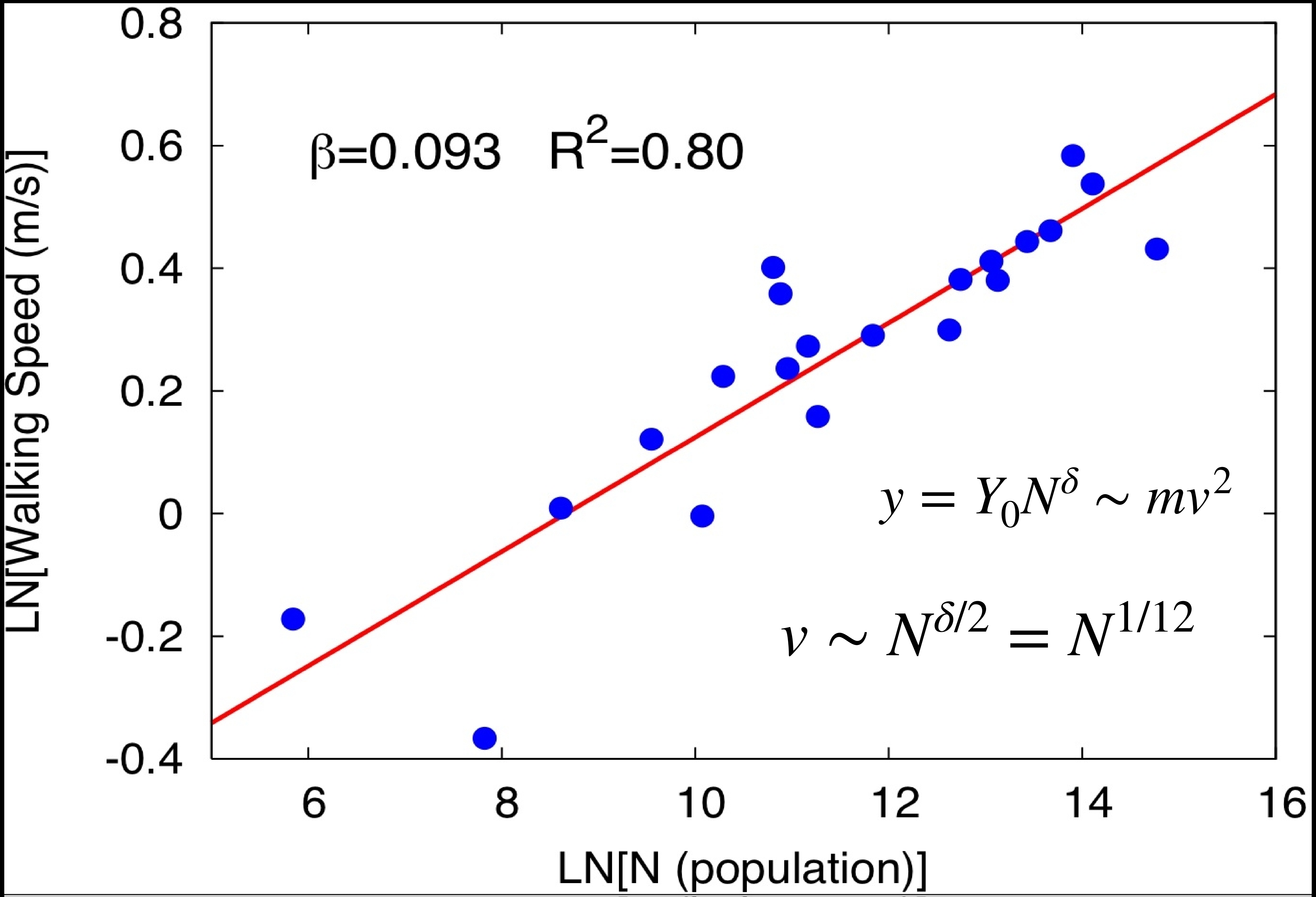
Walking Speed vs Population Size



NYC Tourists Are 'Like Walking Dead,' Anger Fast-Paced New Yorkers During Holiday Season

By JAKE PEARSON 12/12/13 01:07 PM ET EST AP

"They're like the walking dead, real slow," griped Dennis Moran, 46, a fire safety officer at a building in Times Square and a native New Yorker. "They have this unnatural habit of stopping in the middle of the sidewalk."

credit: Huffington Post

Fractal Dimension of Built Spaces

Shapes of built spaces of cities
1990s

Fractal Dimension

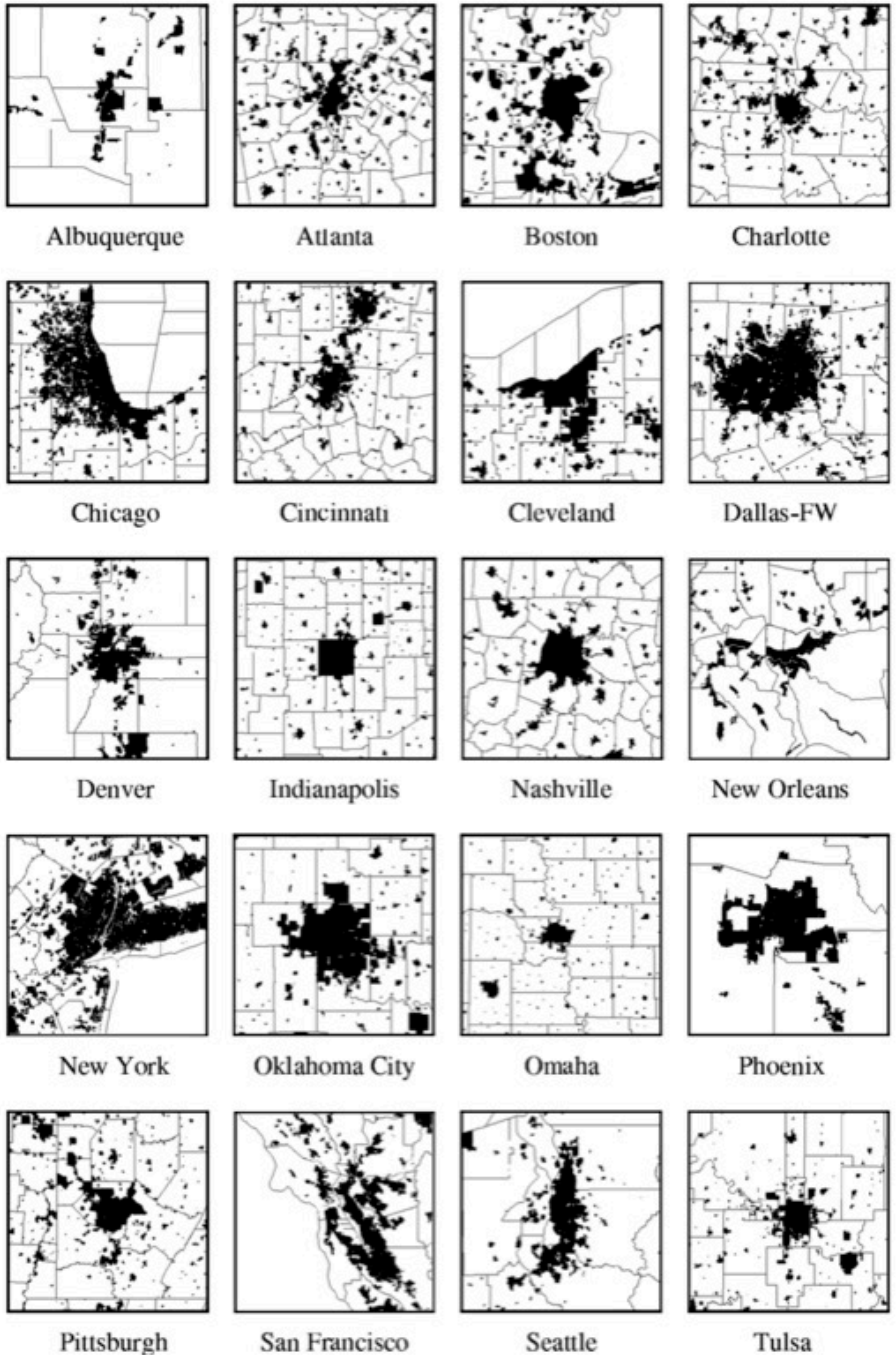
$$M(R) = M_0 R^{D_f} \qquad D_f = \frac{\log \frac{M(R)}{M_0}}{\log \frac{R}{R_m}}$$

Use it for built area and population

$$D_f^{\ N} = \frac{\log \frac{N}{N_0}}{\log \frac{R}{R_m}} \qquad D_f^{\ A_n} = \frac{\log \frac{A_n}{A_0}}{\log \frac{R}{R_m}}$$

$$\frac{D_f^{\ A_n}}{D_f^{\ N}} = \frac{\log A_n - \log A_0}{\log N - \log N_0} = \frac{\Delta \log A_n}{\Delta \log N} = \frac{5}{6}$$

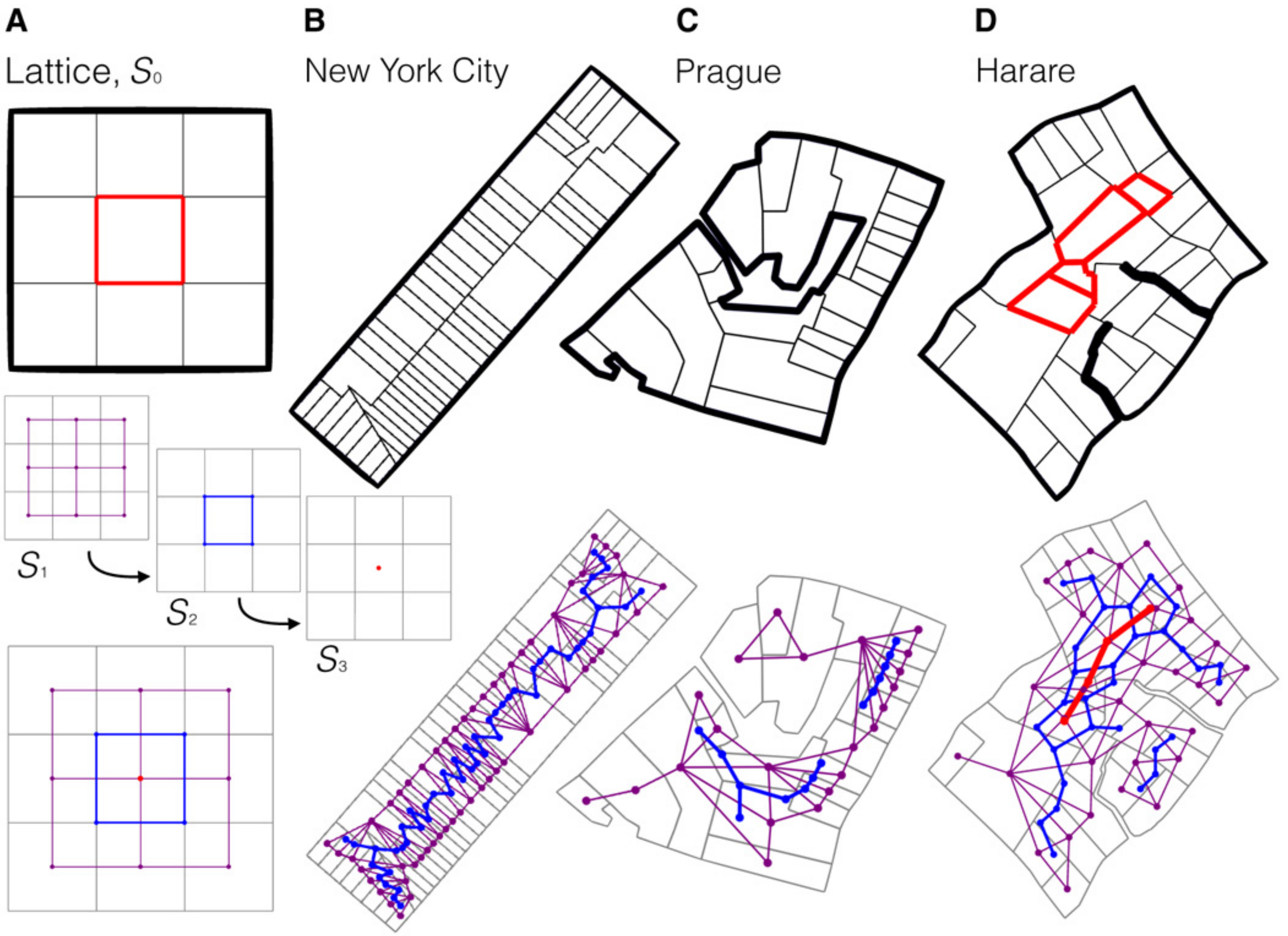
another way to measure urban scaling exponents



Slums and Informal Settlements

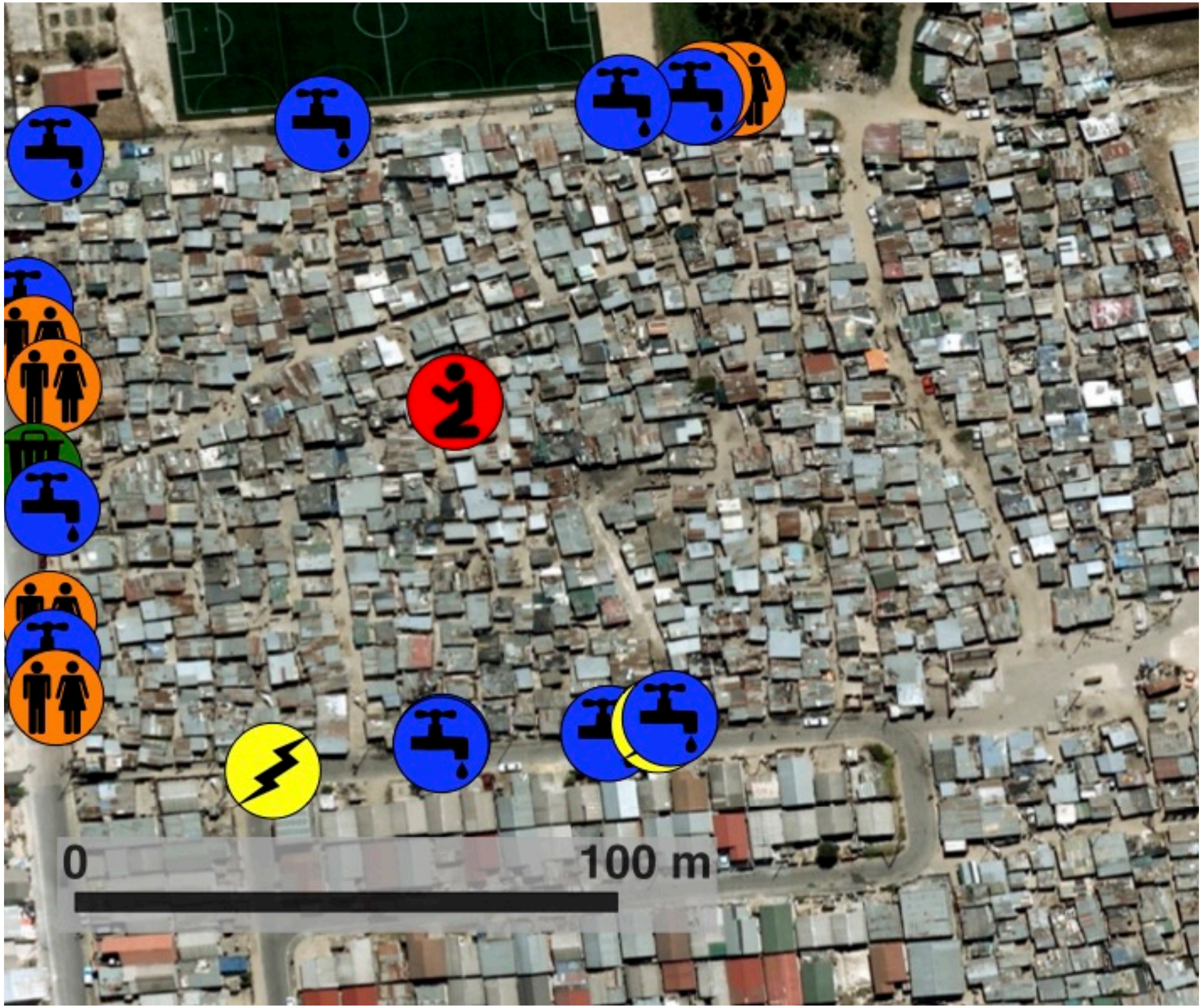
Have incomplete infrastructure networks, can use these ideas to identify where and how much to do

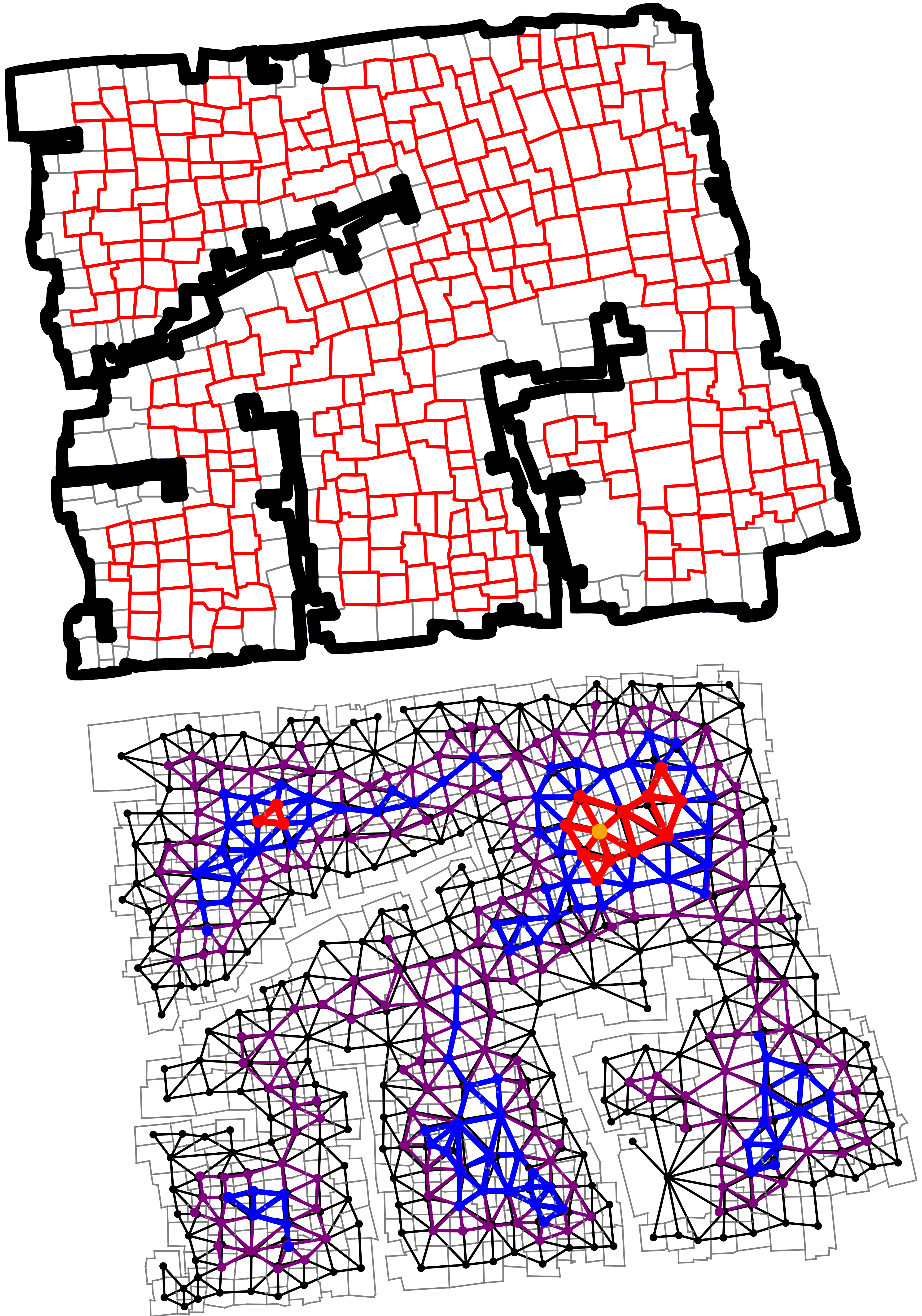
A network (graph theory) model to identify disconnected parcels and underserviced city blocks

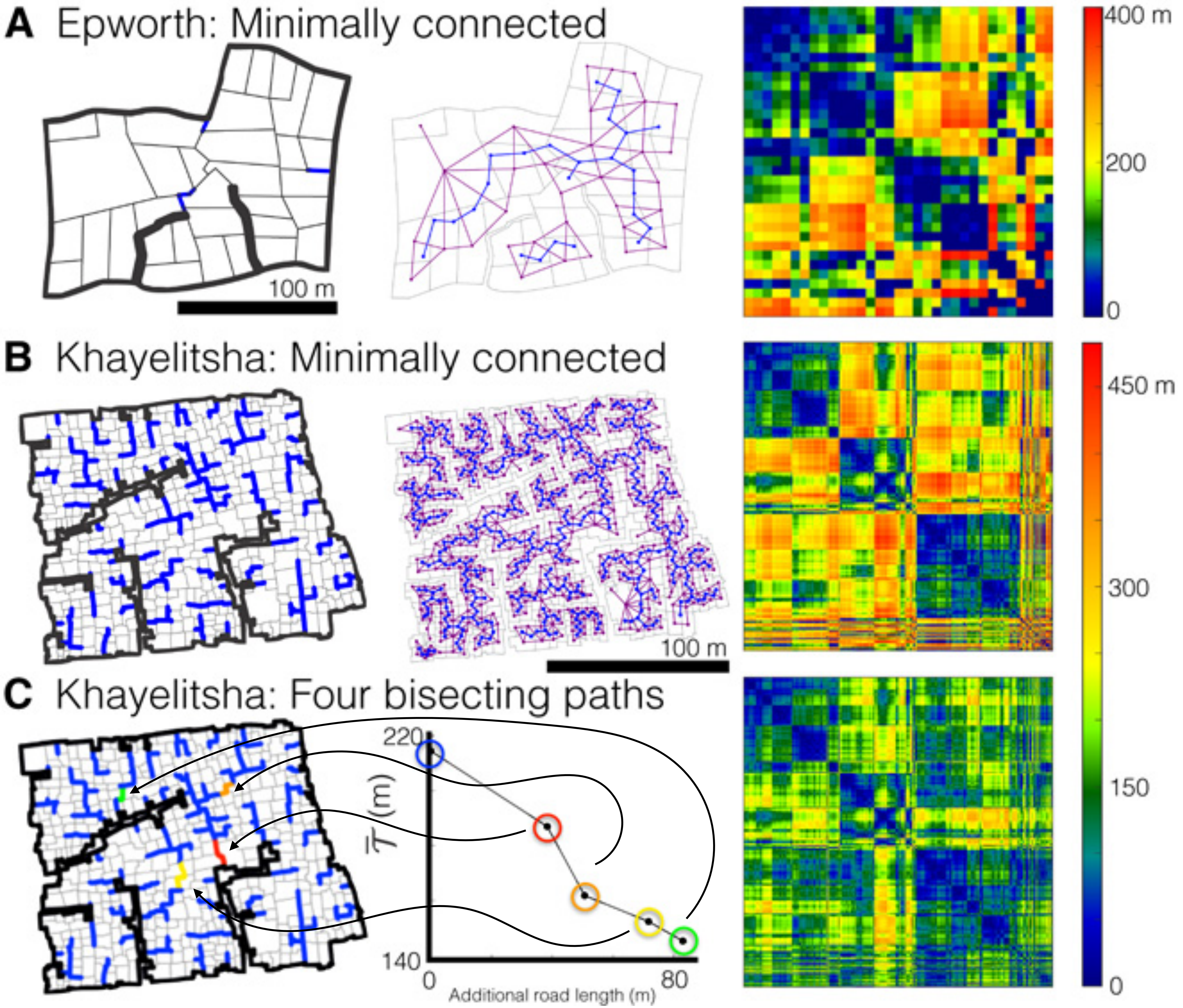


https://www.science.org/doi/10.1126/sciadv.aar4644

A disconnected block in a South African Township







A Epworth: Minimally connected
100 m
400 m
200
0
B Khayelitsha: Minimally connected
100 m
450 m
300
150
0
C Khayelitsha: Four bisecting paths
220
140
$\overline{T}$ (m)
0
80
Additional road length (m)

Million Neighborhoods

Continue explainer (6/8) | Play video

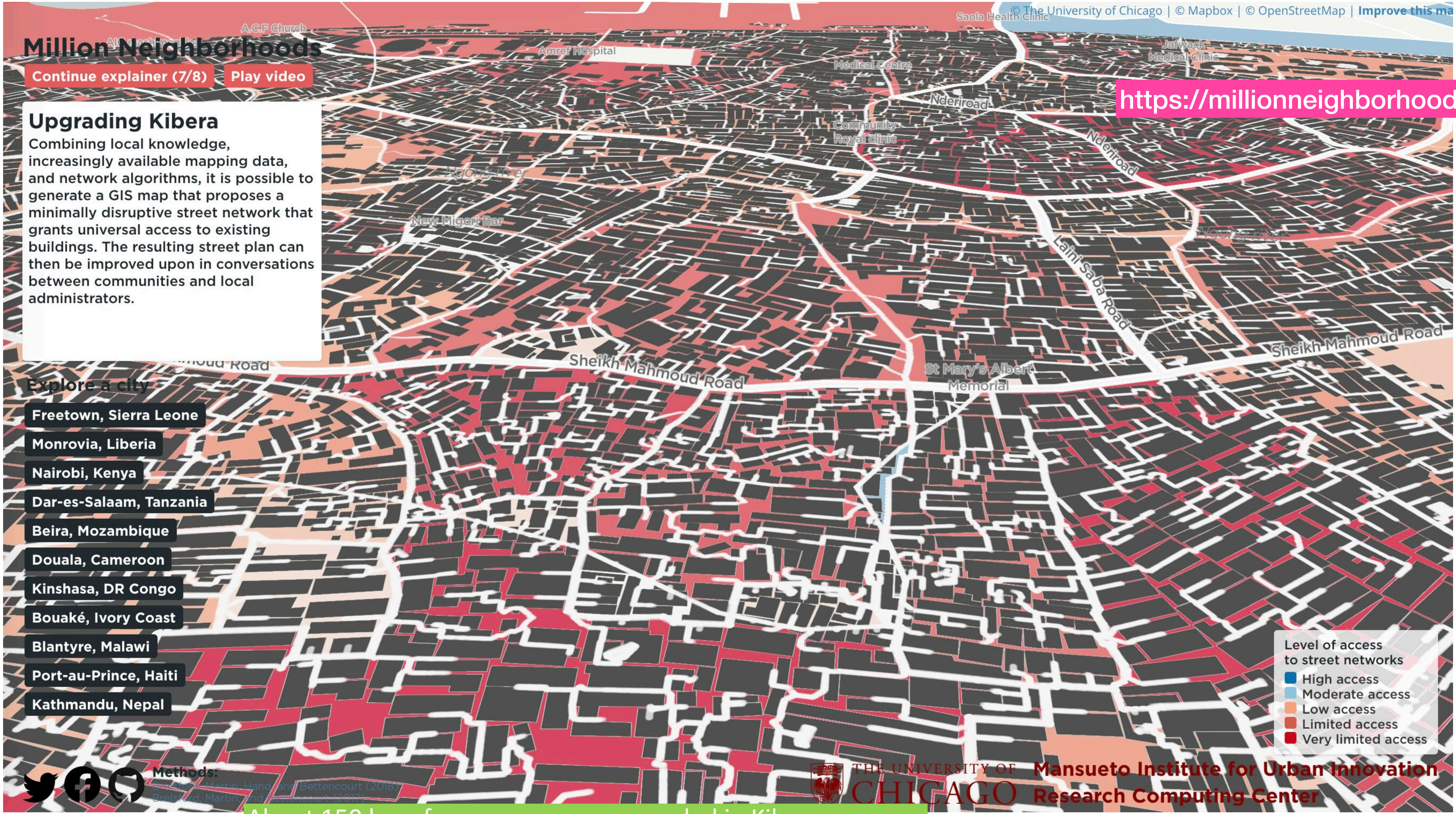
Kibera

Kibera is a large informal settlement near the city center, it has long held the reputation of being one of Africa's largest urban slums. The neighborhood is very dense; most services are only available to people in buildings along the few existing streets.

A street network that expands public access can facilitate service delivery and create an open-ended process of neighborhood development.

Explore a city

- Freetown, Sierra Leone
- Monrovia, Liberia
- Nairobi, Kenya
- Dar-es-Salaam, Tanzania
- Beira, Mozambique
- Douala, Cameroon
- Kinshasa, DR Congo
- Blantyre, Malawi
- Port-au-Prince, Haiti
- Petare, Venezuela
- Kathmandu, Nepal



https://millionneighborhoods.org

About 150 km of new accesses are needed in Kibera.

A large number of interconnected phenomena

From behavior and cognition

To infrastructure

To socioeconomic performance

Can be understood and predicted by a theory of cities as complex networks

This kind of theory will allow us to predict characteristics of cities throughout history and across diverse contexts

What about exceptions? Inequality? Growth? Information?