The Science of Cities as Complex Systems II

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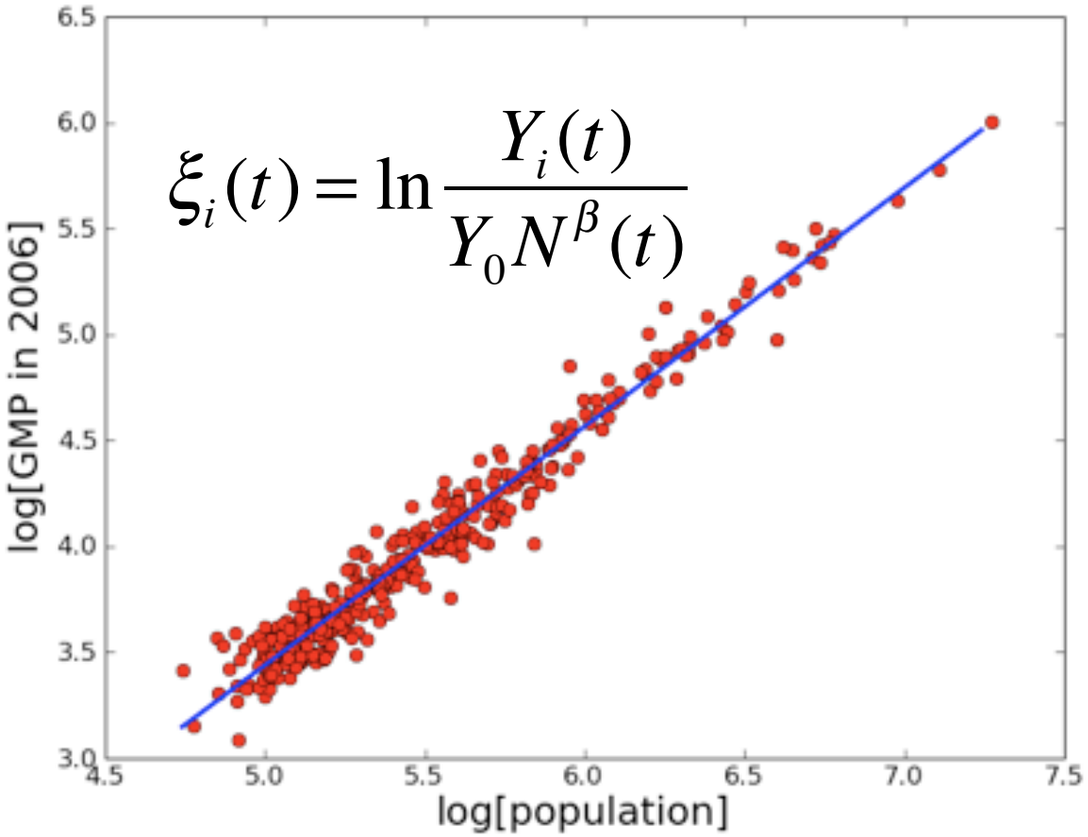
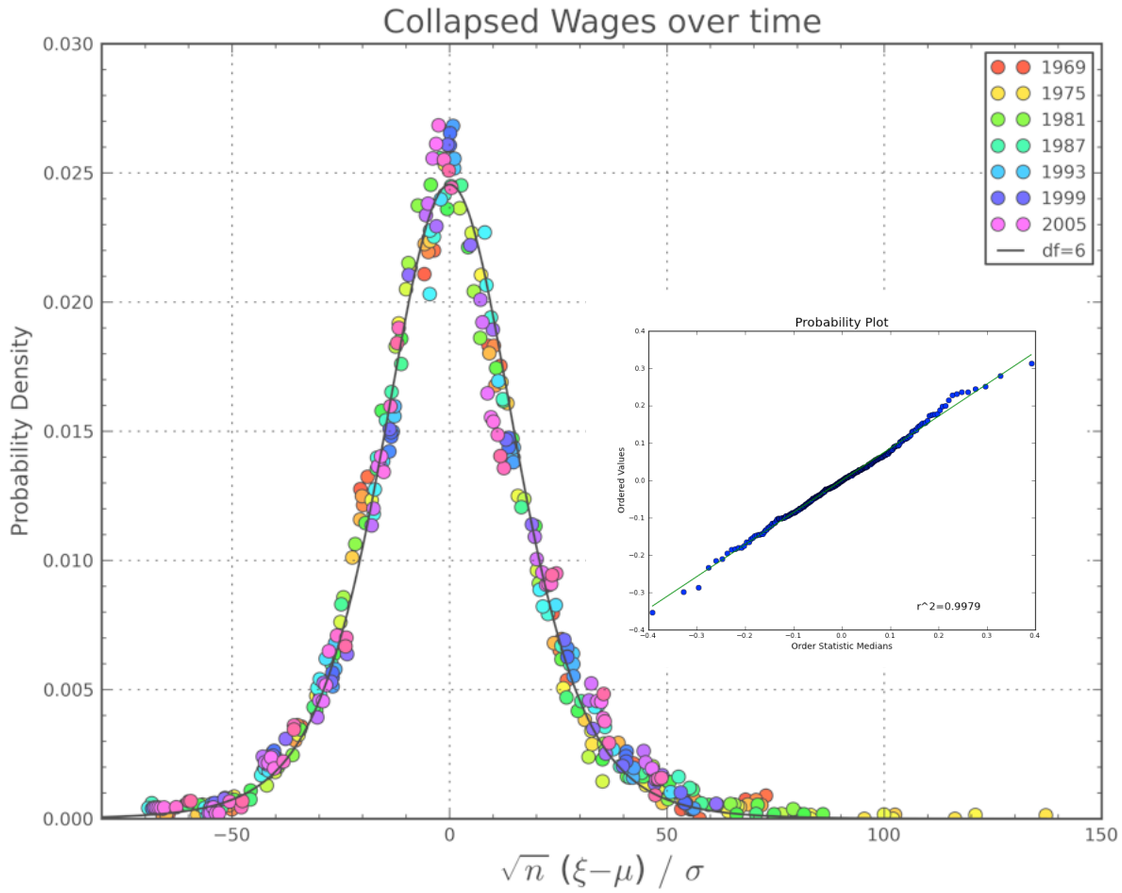
Deviations from Scaling

Scale **A**djusted **M**etropolitan **I**ndicator**s**: SAMIs

$$\xi_i(t) = \ln \frac{Y_i(t)}{Y_0 N^{\beta}(t)}$$





What is the structure of each city's deviation?

What is Its local flavor ...?

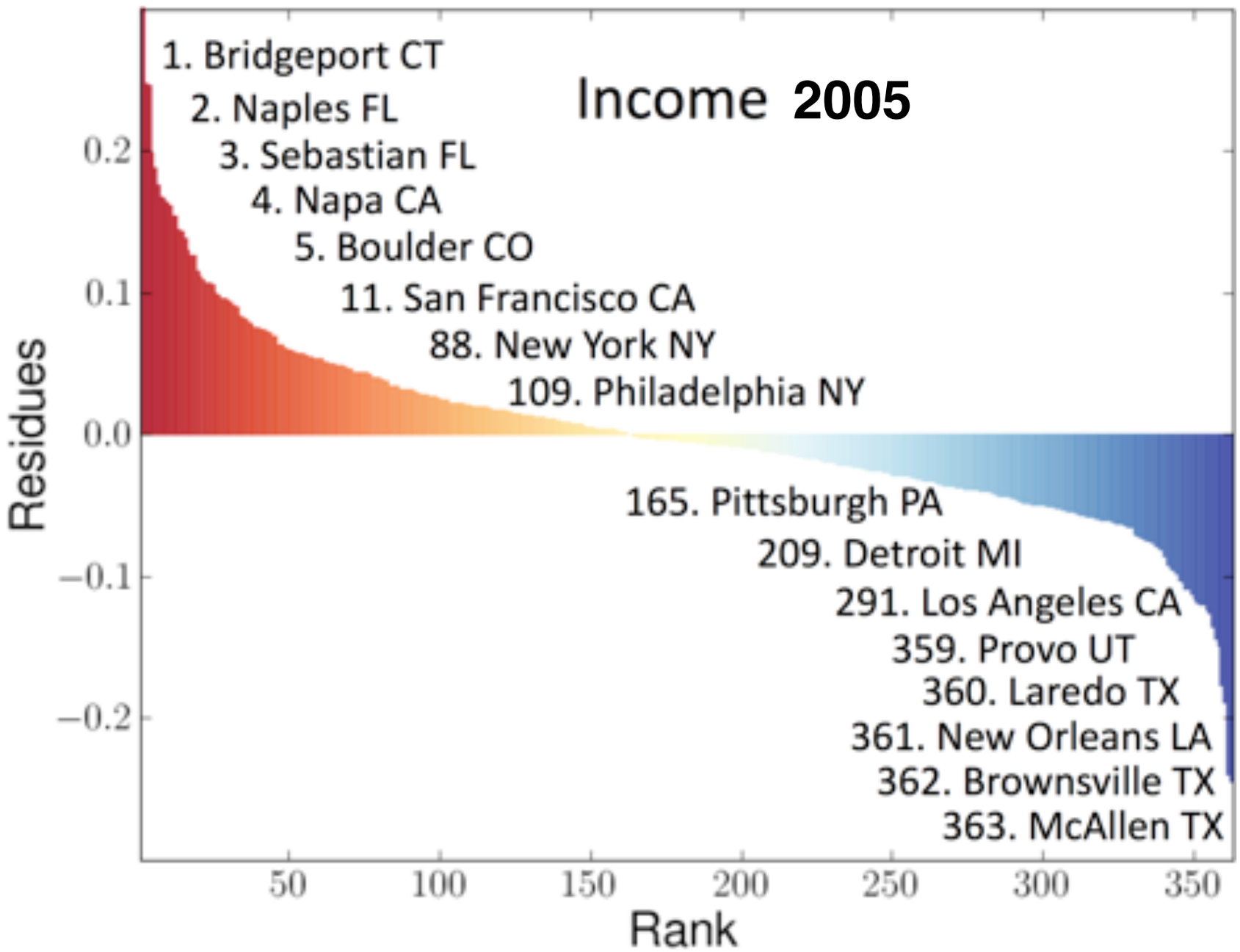
Urban Scaling and its Deviations,
Bettencourt, Lobo, Strumsky, West 2010

The differences **between** cities

how to measure the effects of **history** and **accident**?
how to build “performance” indices?

Ranking Cities

independently of their population size



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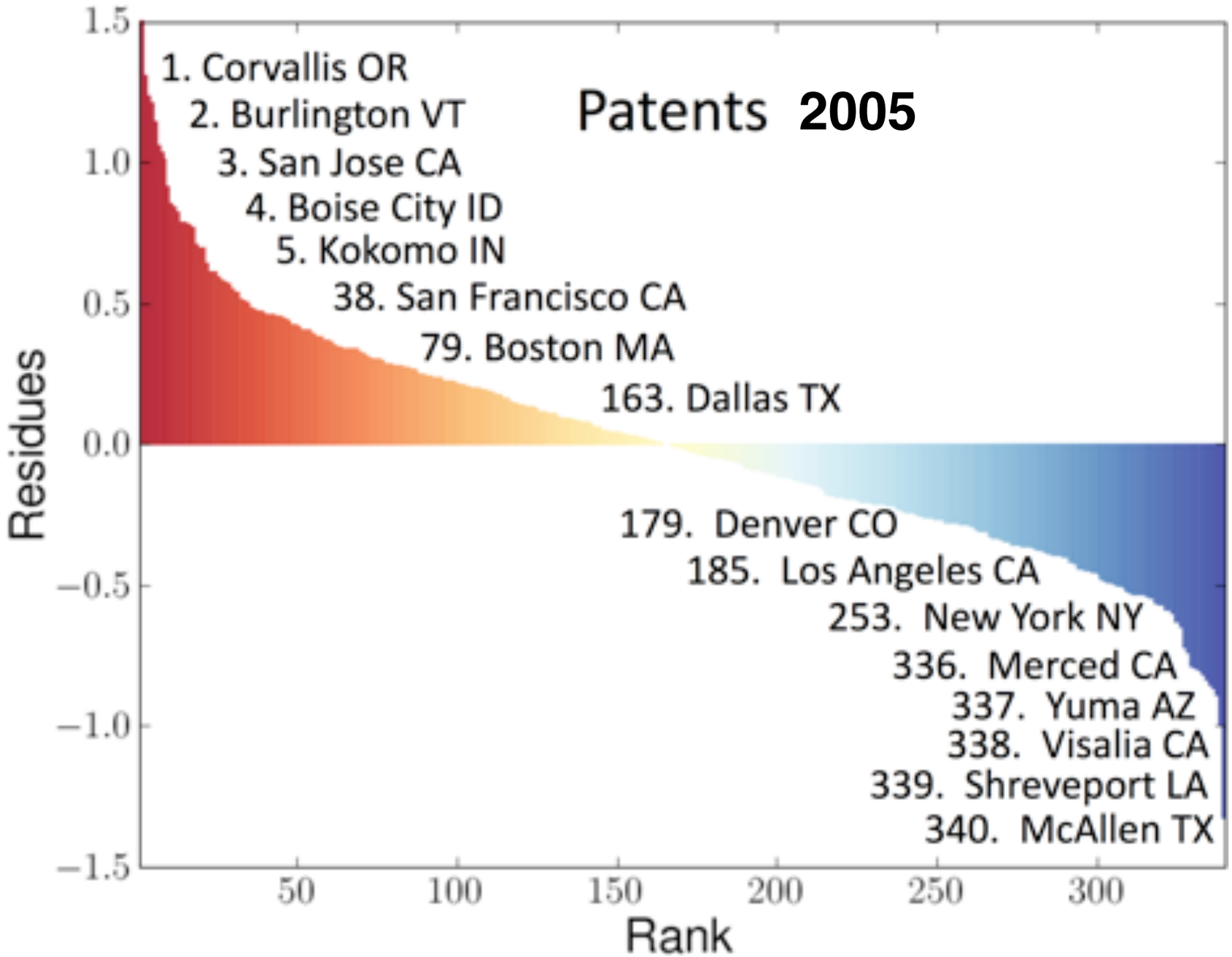
Ranking Cities

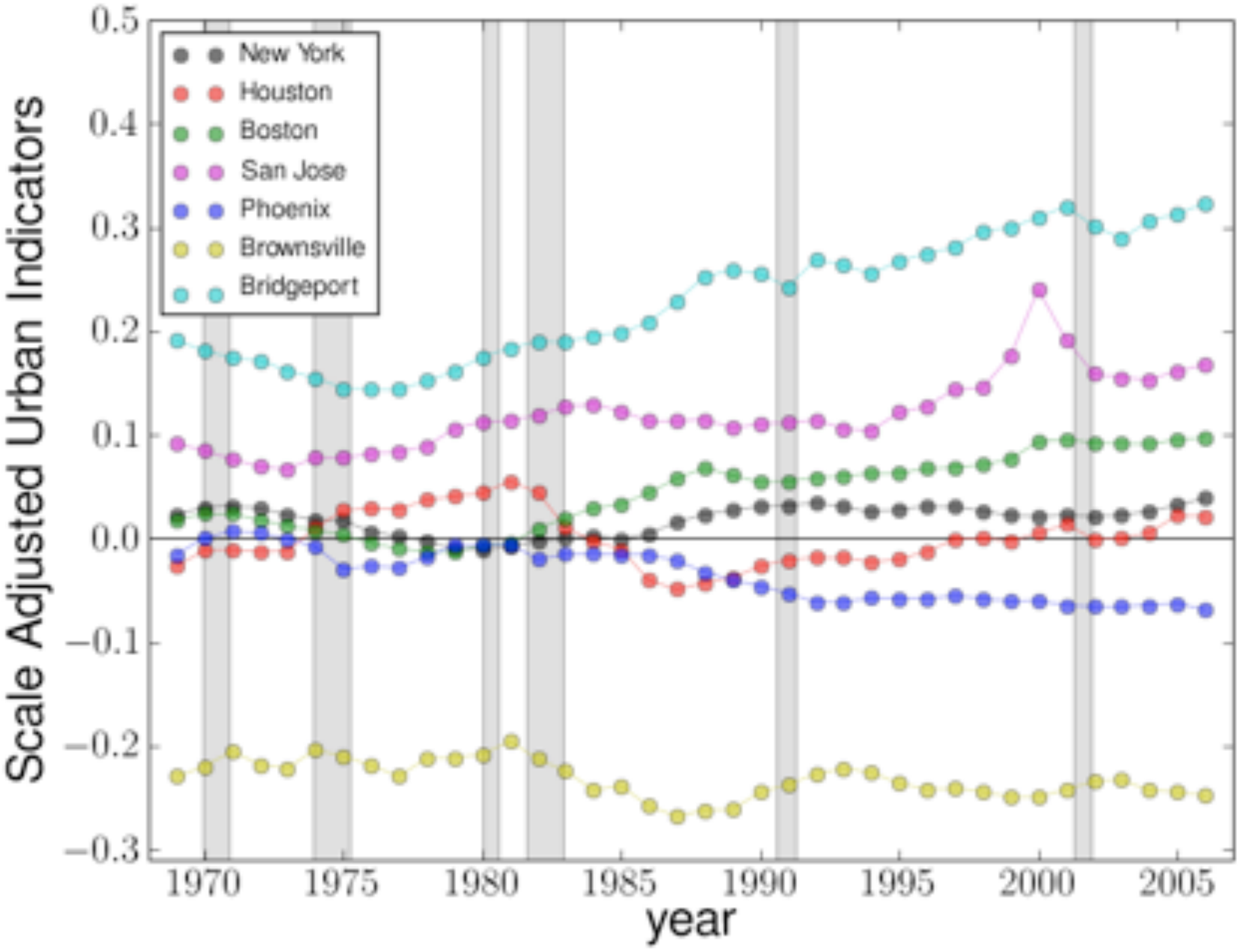
independently of their population size



Urban Scaling and its Deviations,
Bettencourt, Lobo, Strumsky, West 2010

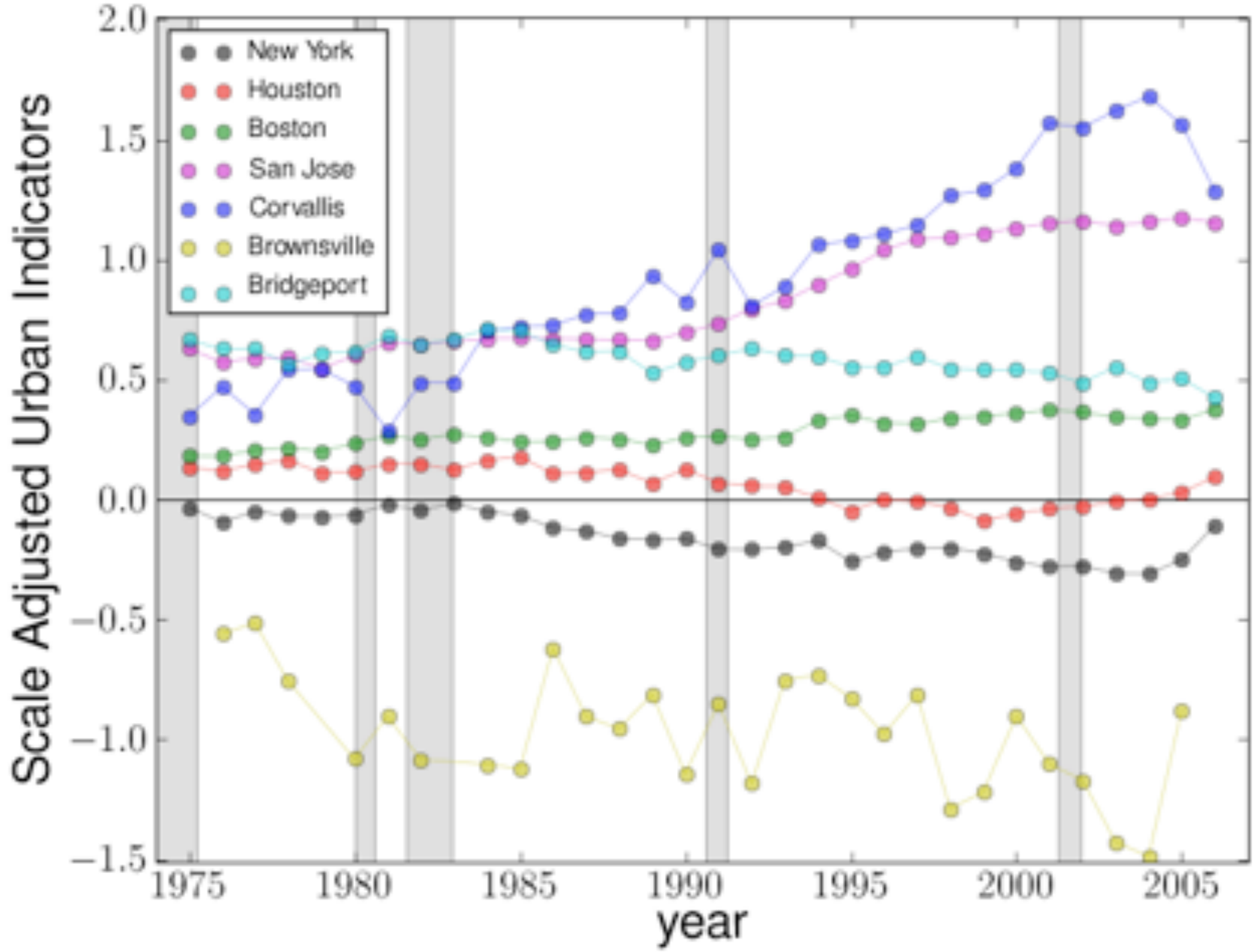
Temporal persistence

personal income



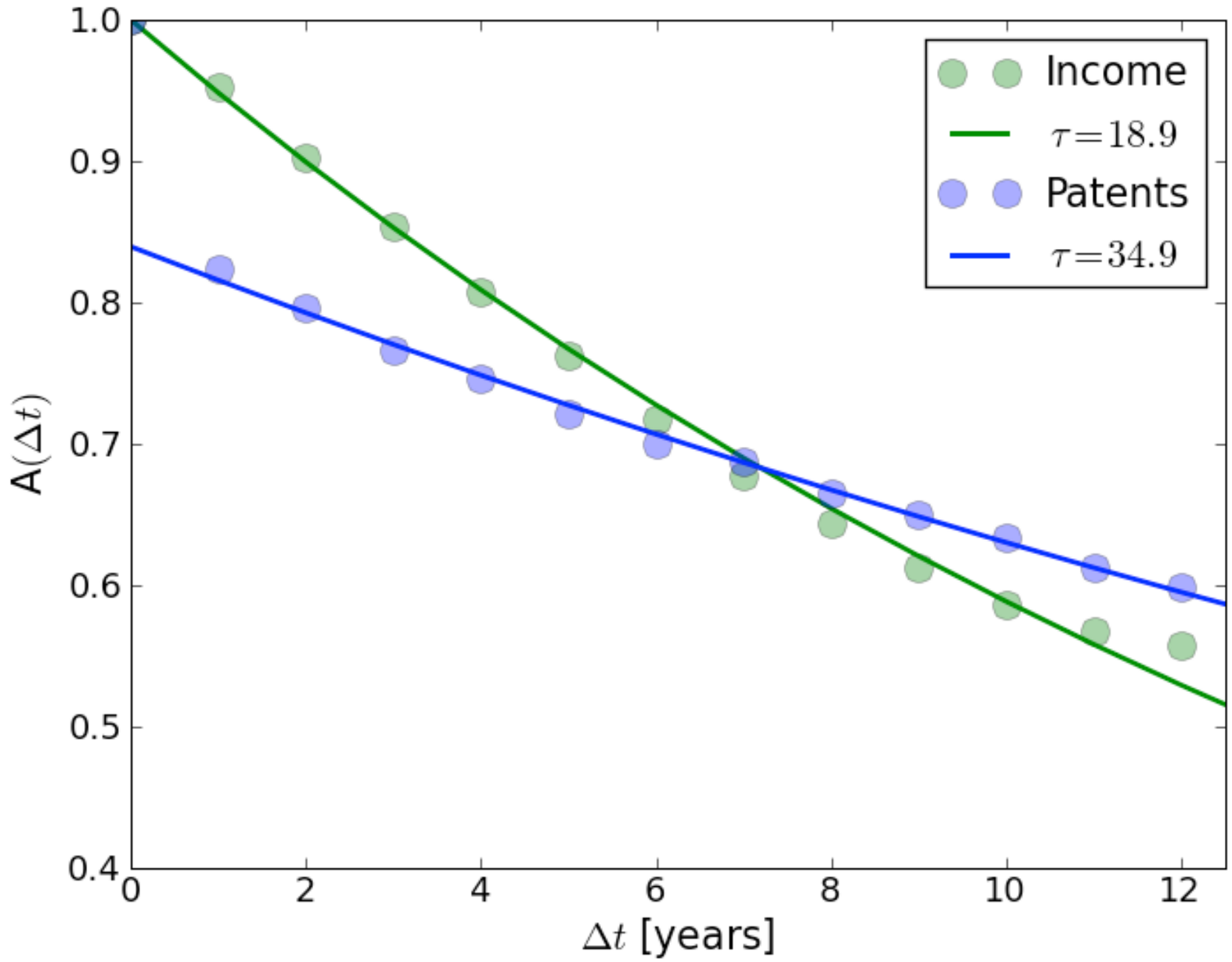
Temporal persistence

patents



Temporal persistence

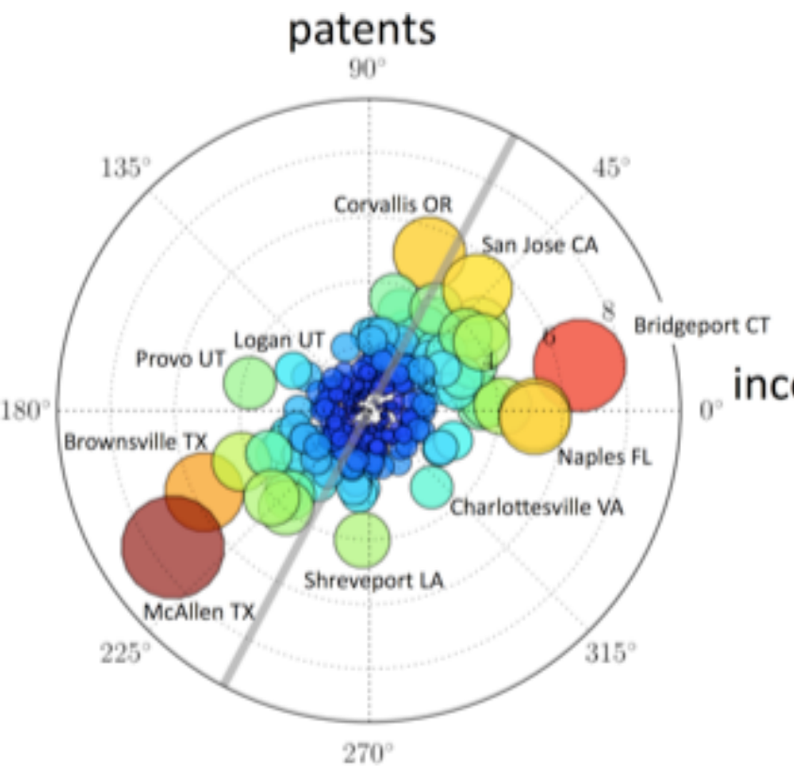
of scaling deviations

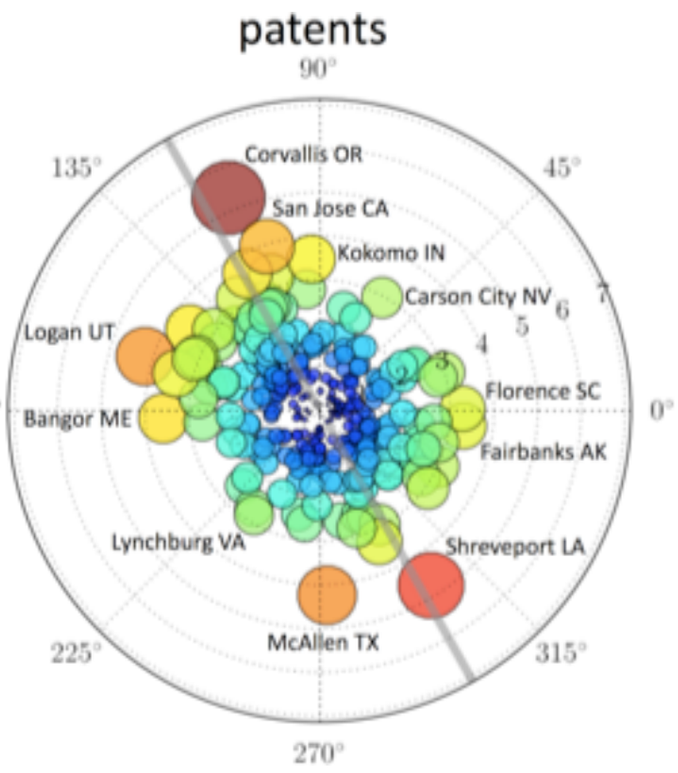


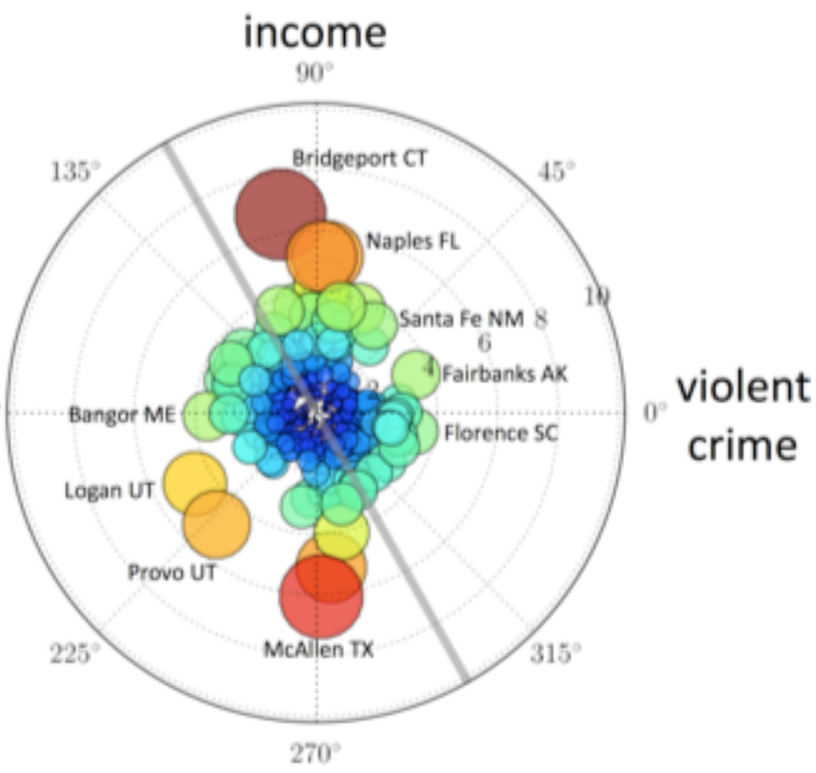
Persistence times are in the order of a few decades !

Beyond population size

are there correlations between





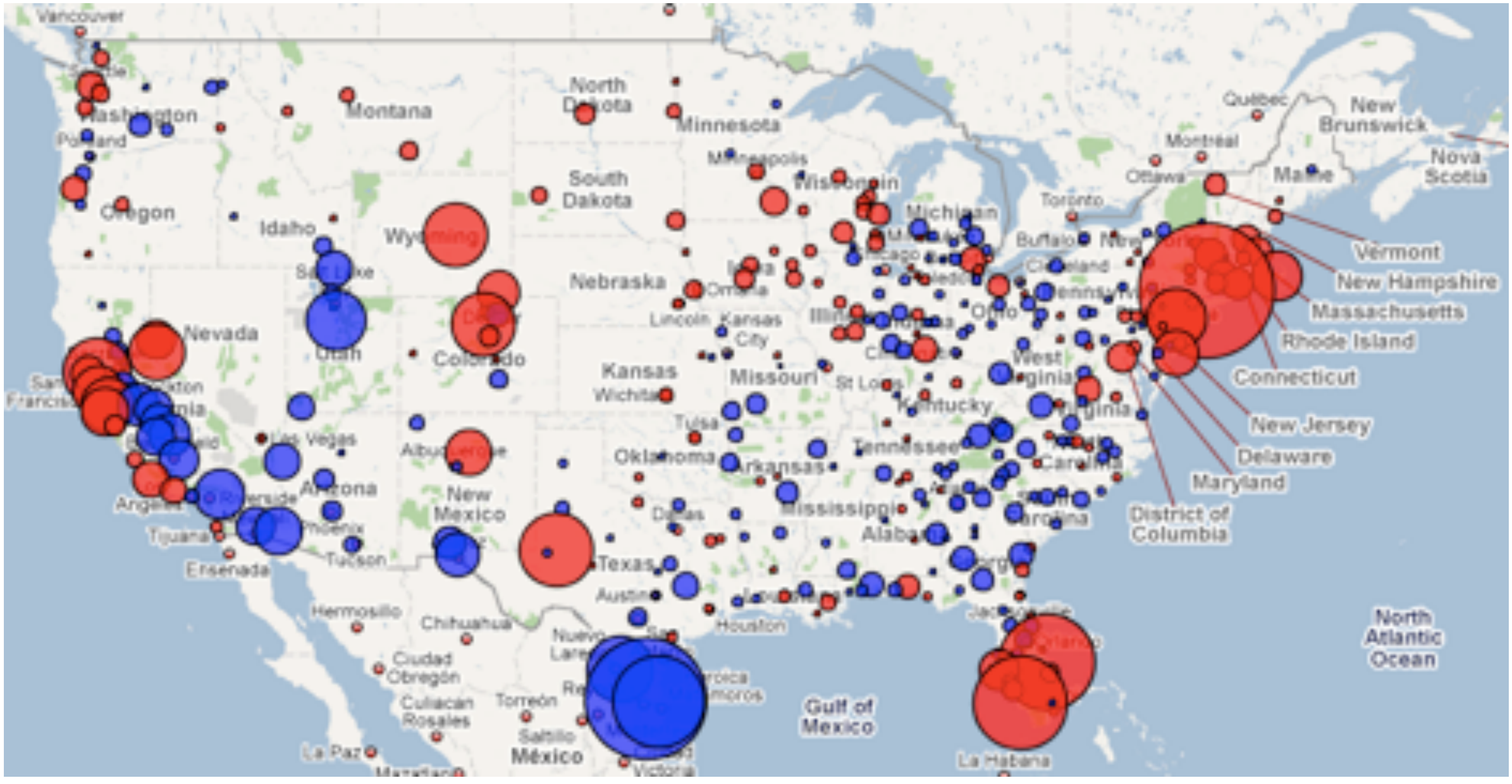


Population size accounts for most of the (co)-variation in these quantities.

Cross correlations explain only 5-15% of the variation.

spatial structure

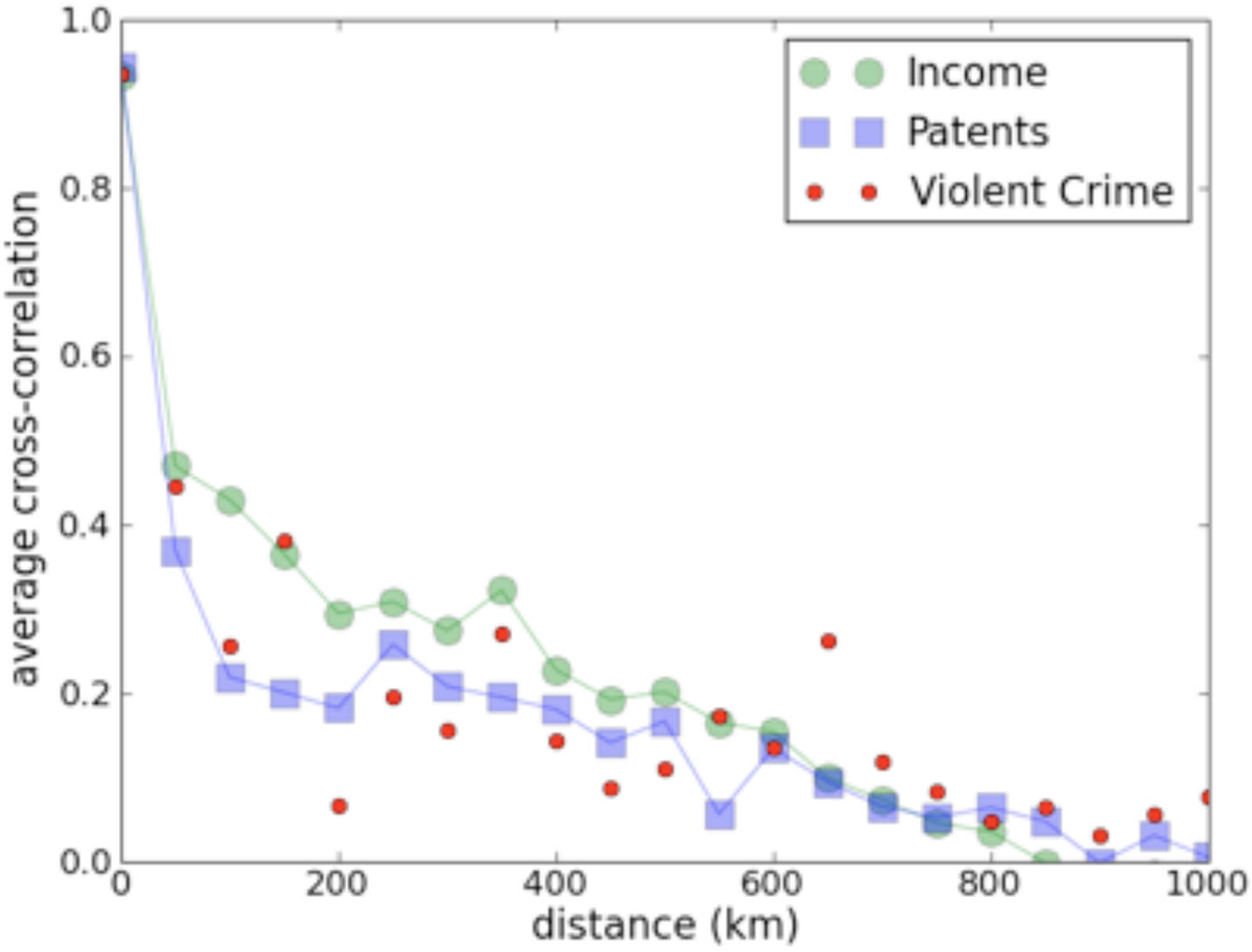
personal income



http://santafe.edu/urban_observatory/

spatial structure

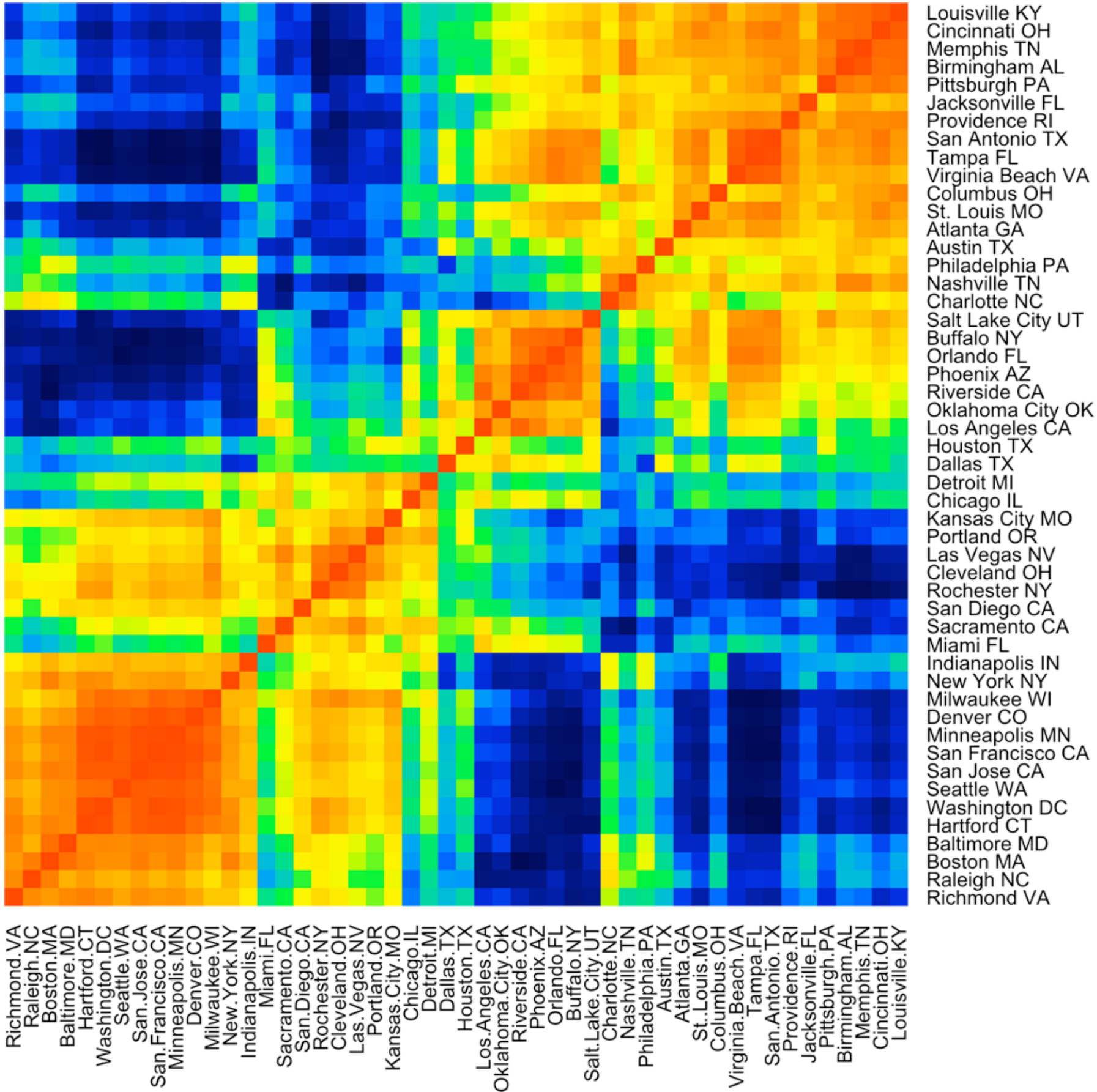
the death of distance

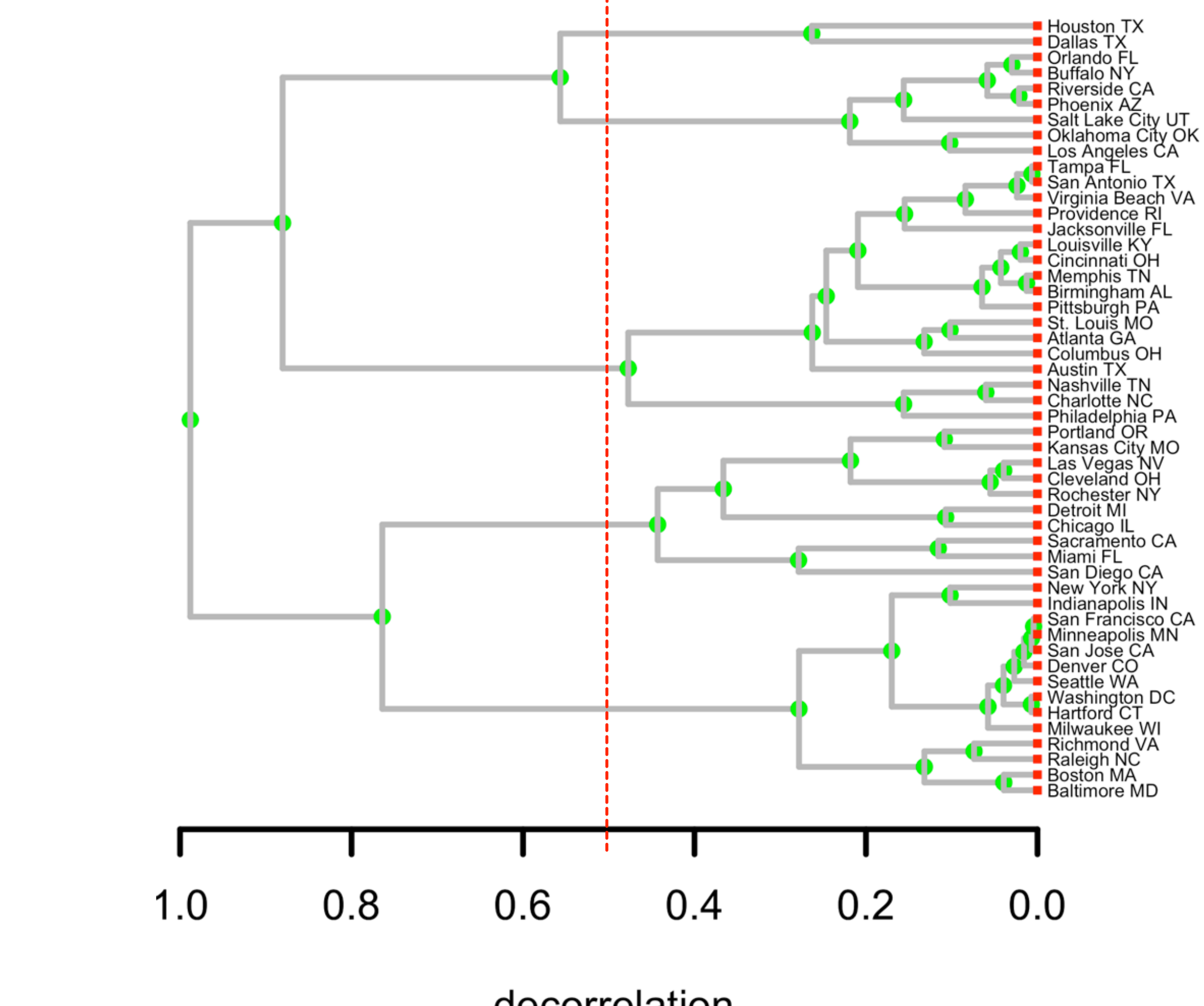


spatial correlations are not significant beyond 200 km

Urban Scaling and its Deviations,
Bettencourt, Lobo, Strumsky, West 2010

Heat maps from Urban History Clustering Analysis




Houston TX
Dallas TX
Orlando FL
Buffalo NY
Riverside CA
Phoenix AZ
Salt Lake City UT
Oklahoma City OK
Los Angeles CA
Tampa FL
San Antonio TX
Virginia Beach VA
Providence RI
Jacksonville FL
Louisville KY
Cincinnati OH
Memphis TN
Birmingham AL
Pittsburgh PA
St. Louis MO
Atlanta GA
Columbus OH
Austin TX
Nashville TN
Charlotte NC
Philadelphia PA
Portland OR
Kansas City MO
Las Vegas NV
Cleveland OH
Rochester NY
Detroit MI
Chicago IL
Sacramento CA
Miami FL
San Diego CA
New York NY
Indianapolis IN
San Francisco CA
Minneapolis MN
San Jose CA
Denver CO
Seattle WA
Washington DC
Hartford CT
Milwaukee WI
Richmond VA
Raleigh NC
Boston MA
Baltimore MD
1.0
0.8
0.6
0.4
0.2
0.0
decorrelation

The differences **within** cities

neighborhoods and individual heterogeneity

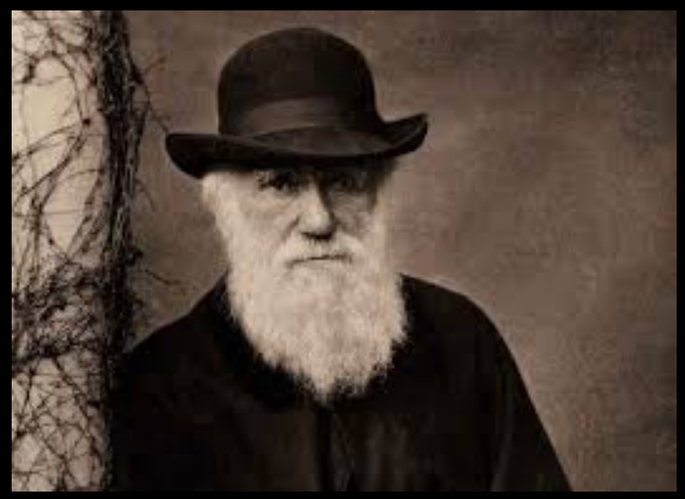
There are over 800 languages spoken in New York City

credit: Mark Turin/BBC News Magazine

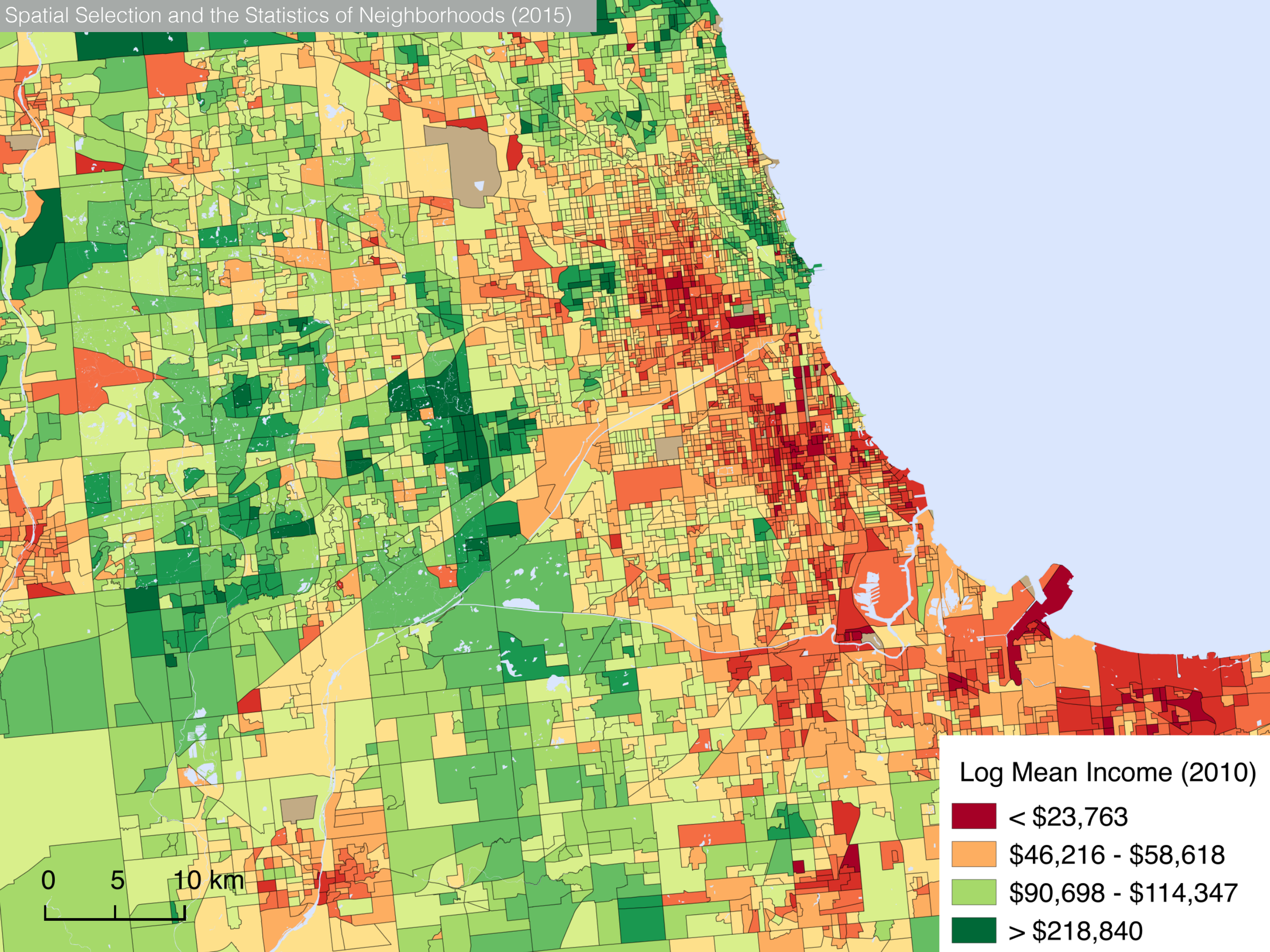
“If every one were cast in the same mould,

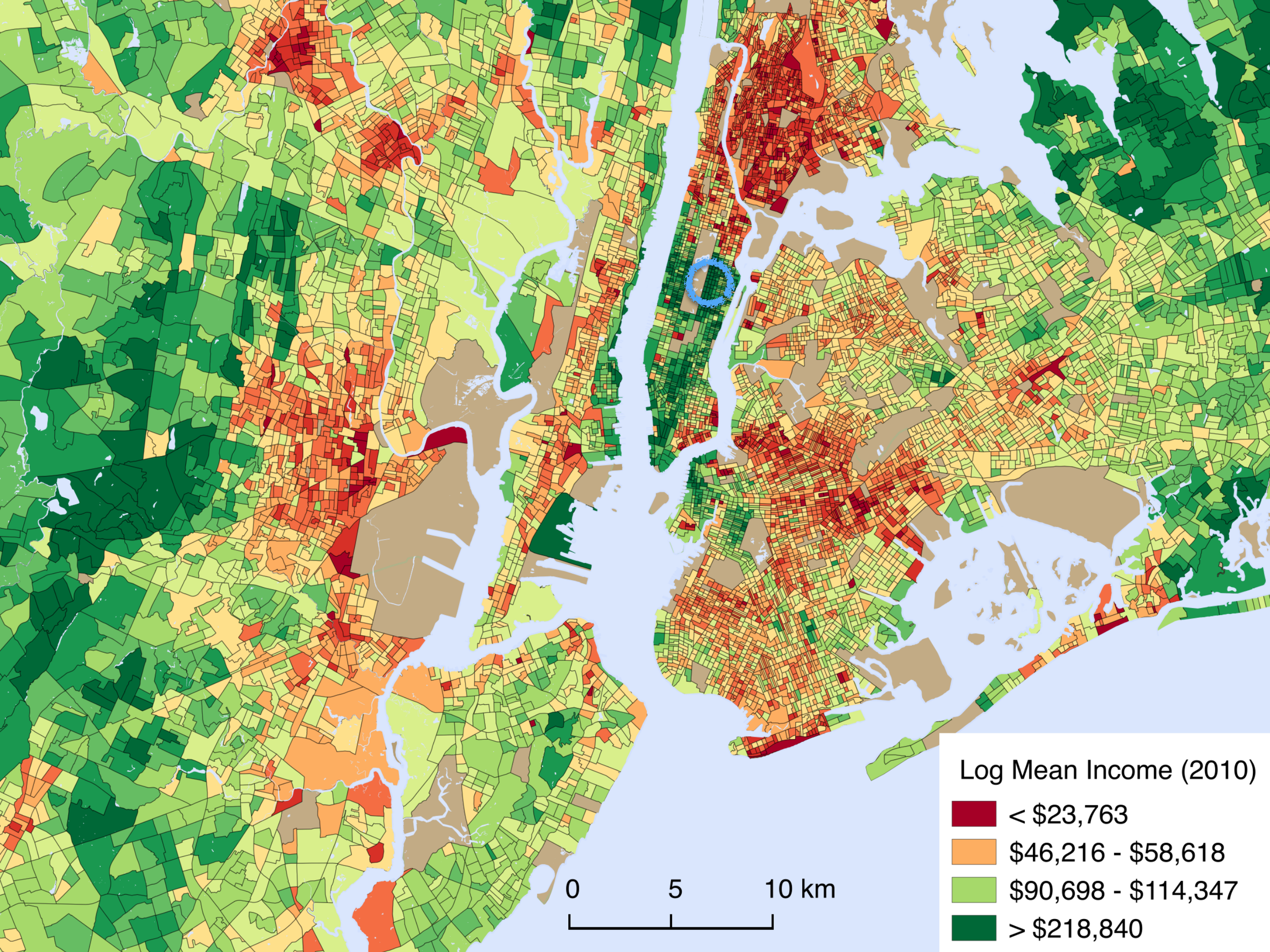
there would be no such thing as beauty.

Charles Darwin



Spatial Selection and the Statistics of Neighborhoods (2015)




Log Mean Income (2010)
< $23,763
$46,216 - $58,618
$90,698 - $114,347
> $218,840
0
5
10 km

740 PARK AVENUE: Inside The Most Powerful Apartment Building In New York

JULIE ZEVELOFF

DEC. 29, 2011, 3:46 PM | 815,377 | 17

FACEBOOK LINKEDIN TWITTER GOOGLE+ PRINT EMAIL

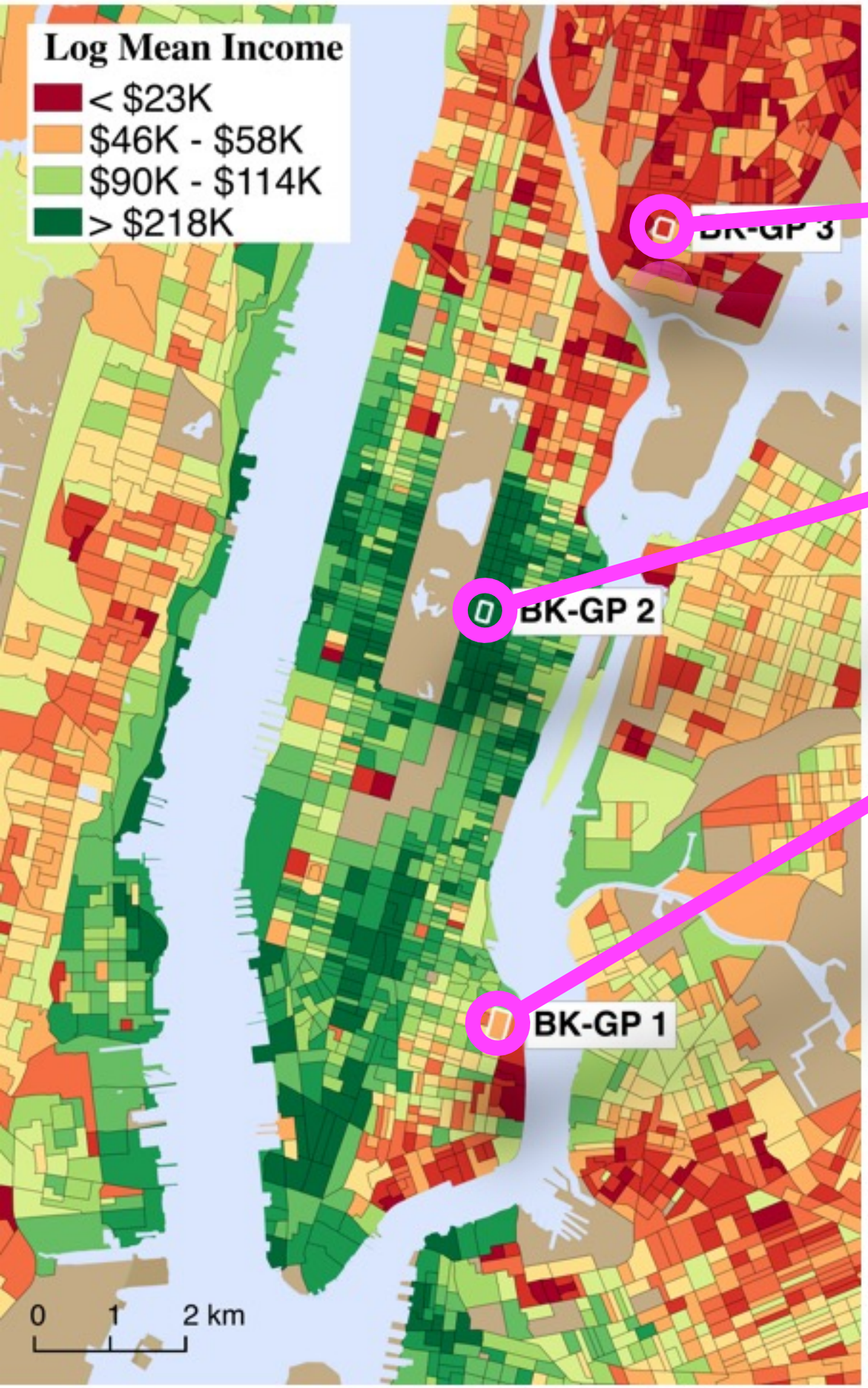
740 Park Avenue is a legendary address, at one time considered (and still thought to be by some) the most luxurious and powerful residential building in New York City.

Bing Maps/Wikipedia

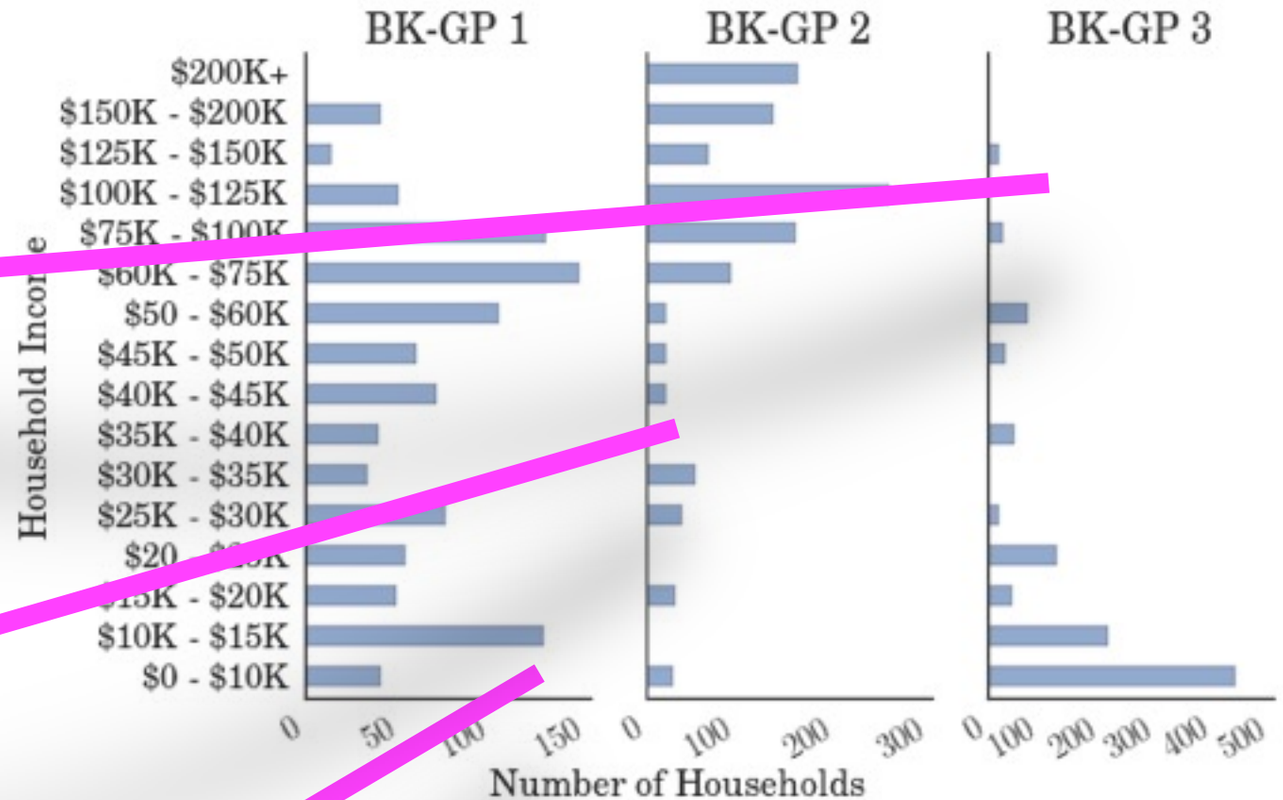
The co-op, on the corner of 71st Street and Park Avenue, has an impressive past.

Built in 1929 by the grandfather of Jacqueline Kennedy Onassis--who lived there as a child--740 Park has just 31 residences that have, over time, commanded some of the highest real estate prices in New York history.

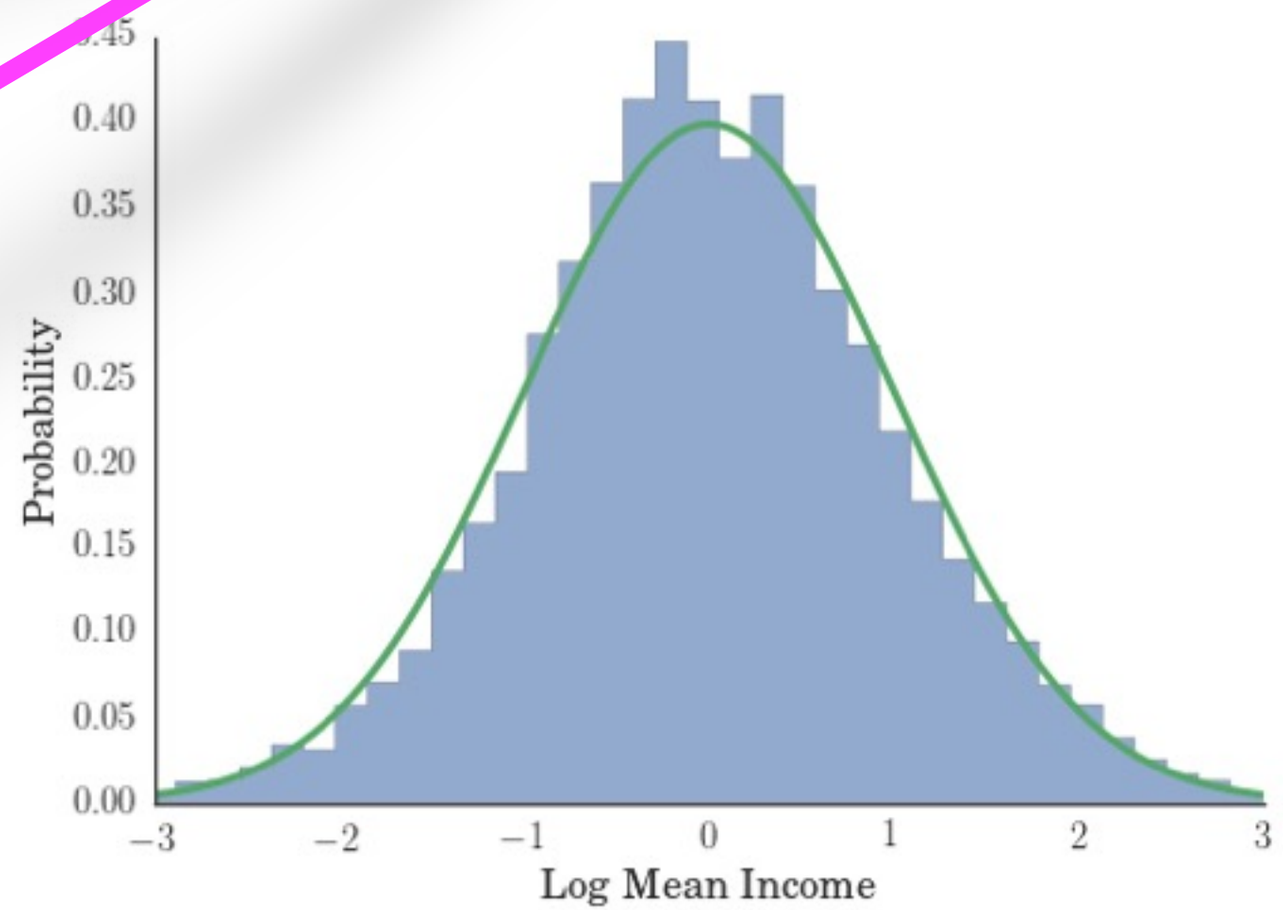
A.


Log Mean Income
< $23K
$46K - $58K
$90K - $114K
> $218K
BK-GP 3
BK-GP 2
BK-GP 1
0
1
2 km

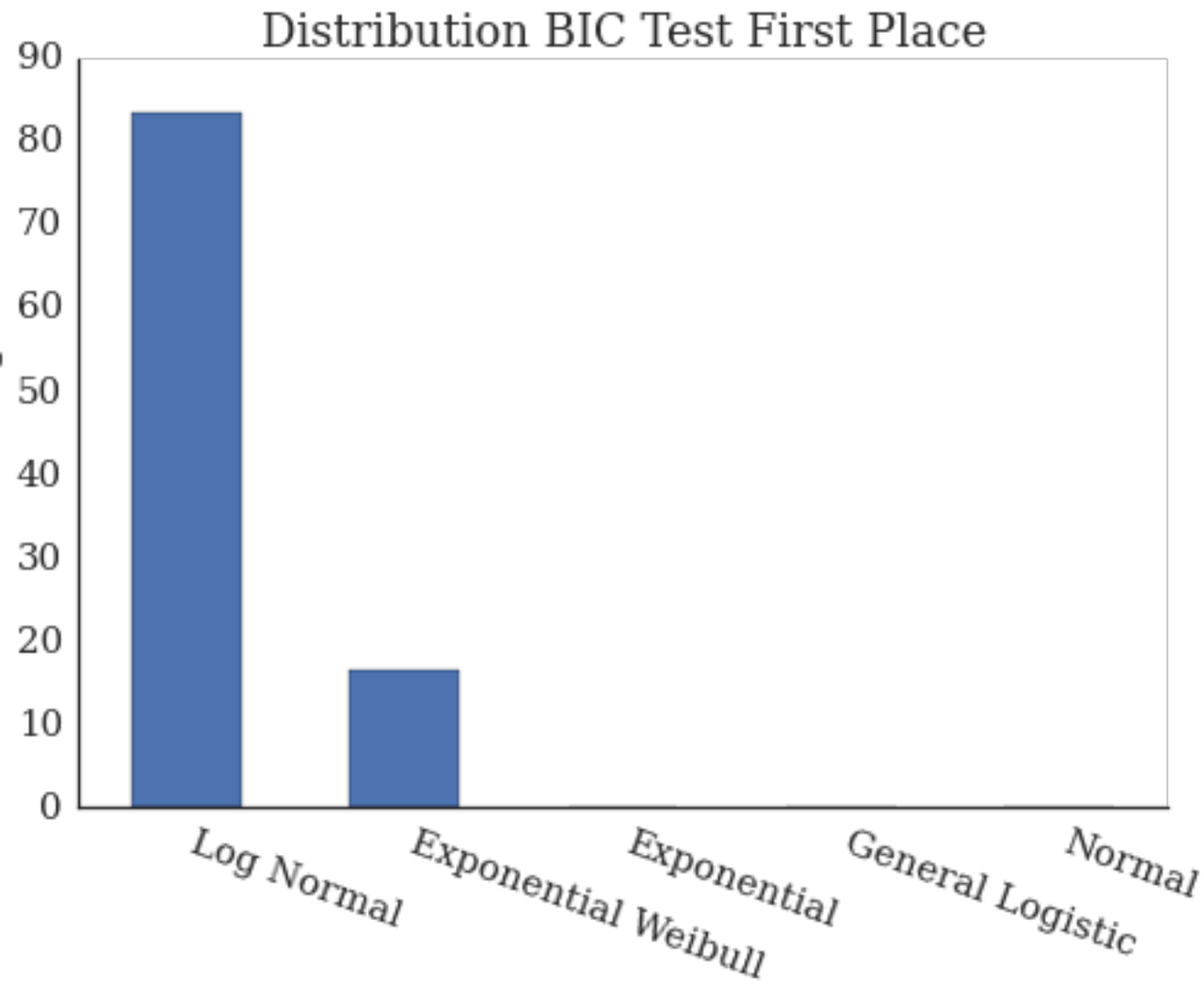
B.

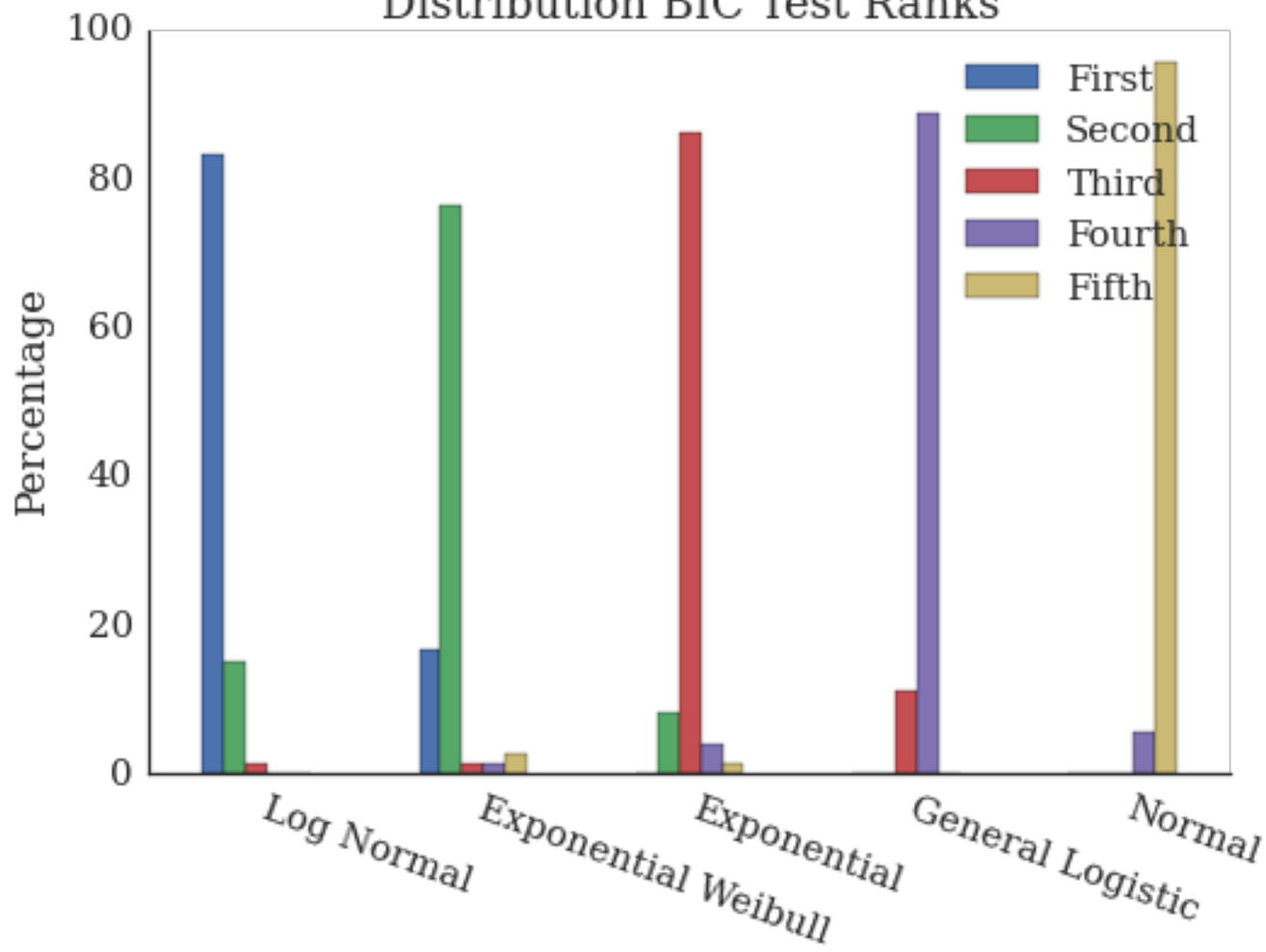

BK-GP 1
BK-GP 2
BK-GP 3
$200K+
$150K - $200K
$125K - $150K
$100K - $125K
$75K - $100K
$60K - $75K
$50 - $60K
$45K - $50K
$40K - $45K
$35K - $40K
$30K - $35K
$25K - $30K
$10K - $15K
$0 - $10K
Household Income
0
50
100
150
0
100
200
300
0
100
200
300
400
500
Number of Households

C.

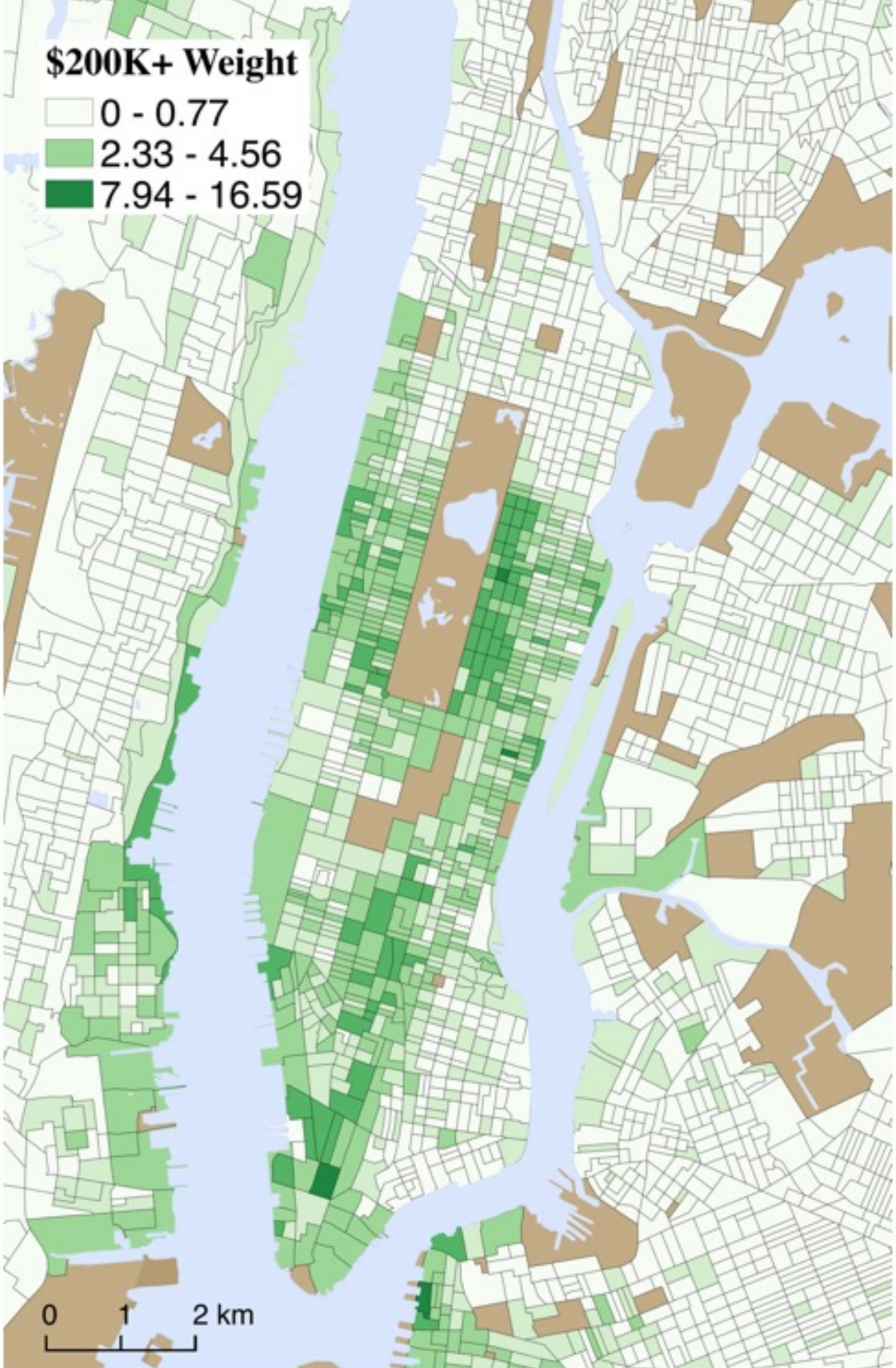

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Probability
−3
−2
−1
0
1
2
3
Log Mean Income

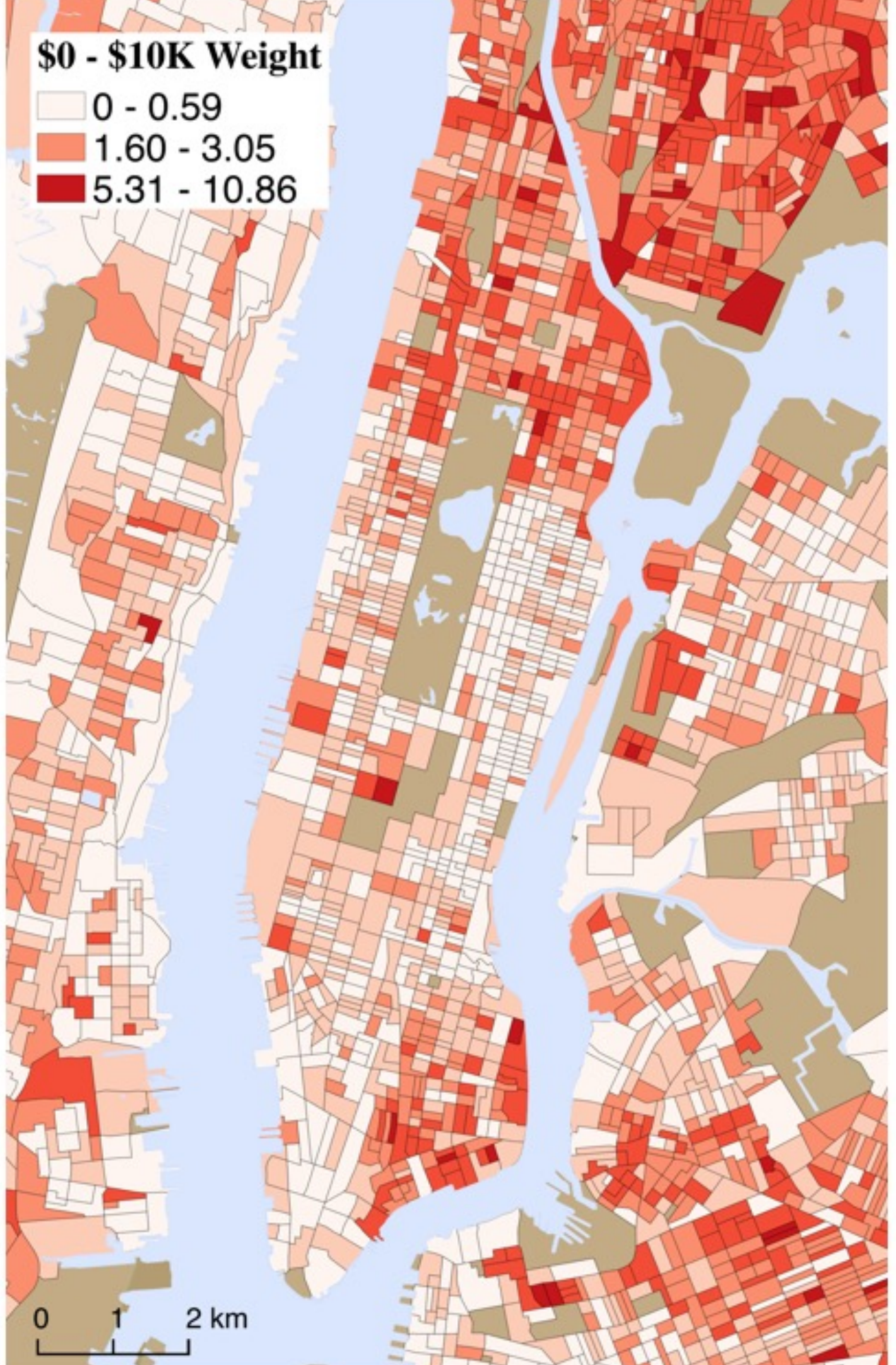
Universality of City-Wide Distribution





Spatial Selection and the Statistics of Neighborhoods (2015)


$200K+ Weight
0 - 0.77
2.33 - 4.56
7.94 - 16.59
0
1
2 km


$0 - $10K Weight
0 - 0.59
1.60 - 3.05
5.31 - 10.86
0
1
2 km

Information & Spatial Selection

$$p(y_\ell|n_j) = w_{\ell,j}\, p(y_\ell)$$

neighborhood i income distribution

city-wide income distribution

$$p(y_\ell|n_j) = \frac{p(n_j|y_\ell)p(y_\ell)}{p(n_j)} \rightarrow w_{\ell,j} = \frac{p(n_j|y_\ell)}{p(n_j)} = \frac{p(y_\ell|n_j)}{p(y_\ell)} = \frac{p(n_j, y_\ell)}{p(y_\ell)\, p(n_j)}$$

Bayes' Theorem

$$\langle \ln w_j \rangle = \sum_\ell p(y_\ell|n_j) \ln \frac{p(y_\ell|n_j)}{p(y_\ell)} = D_{\mathrm{KL}}\left[p(y_\ell|n_j)||p(y_\ell)\right]$$

Information to explain neighborhood j

$$\langle \ln w \rangle = \sum_{i,l} p(n_i, y_\ell) \ln w_{i,l} = I(n;y).$$

Information between neighborhoods and income for a city

Spatial Selection and the Statistics of Neighborhoods (2015)

Log DKL Income (2010)

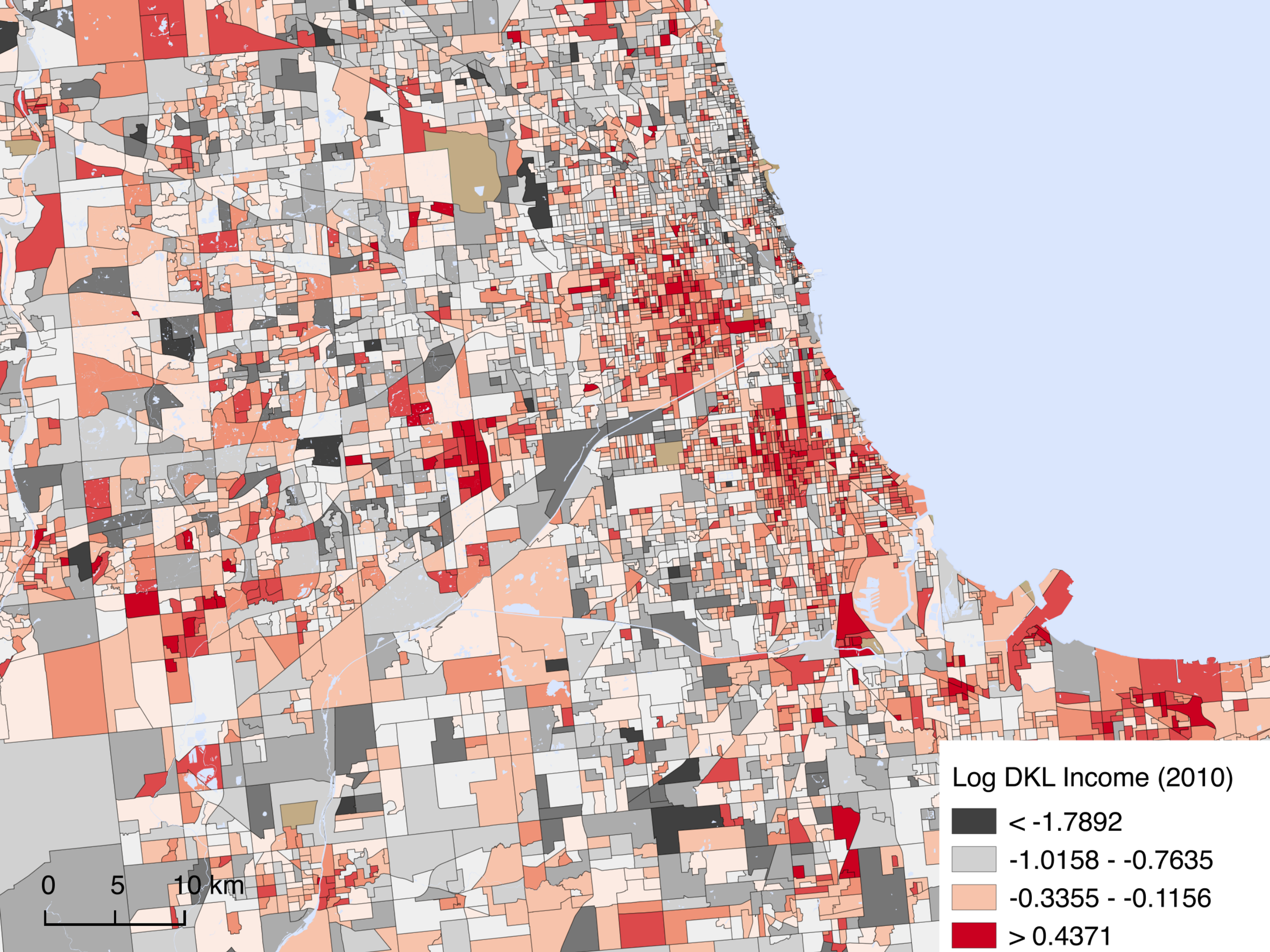
< -1.7892

-1.0158 - -0.7635

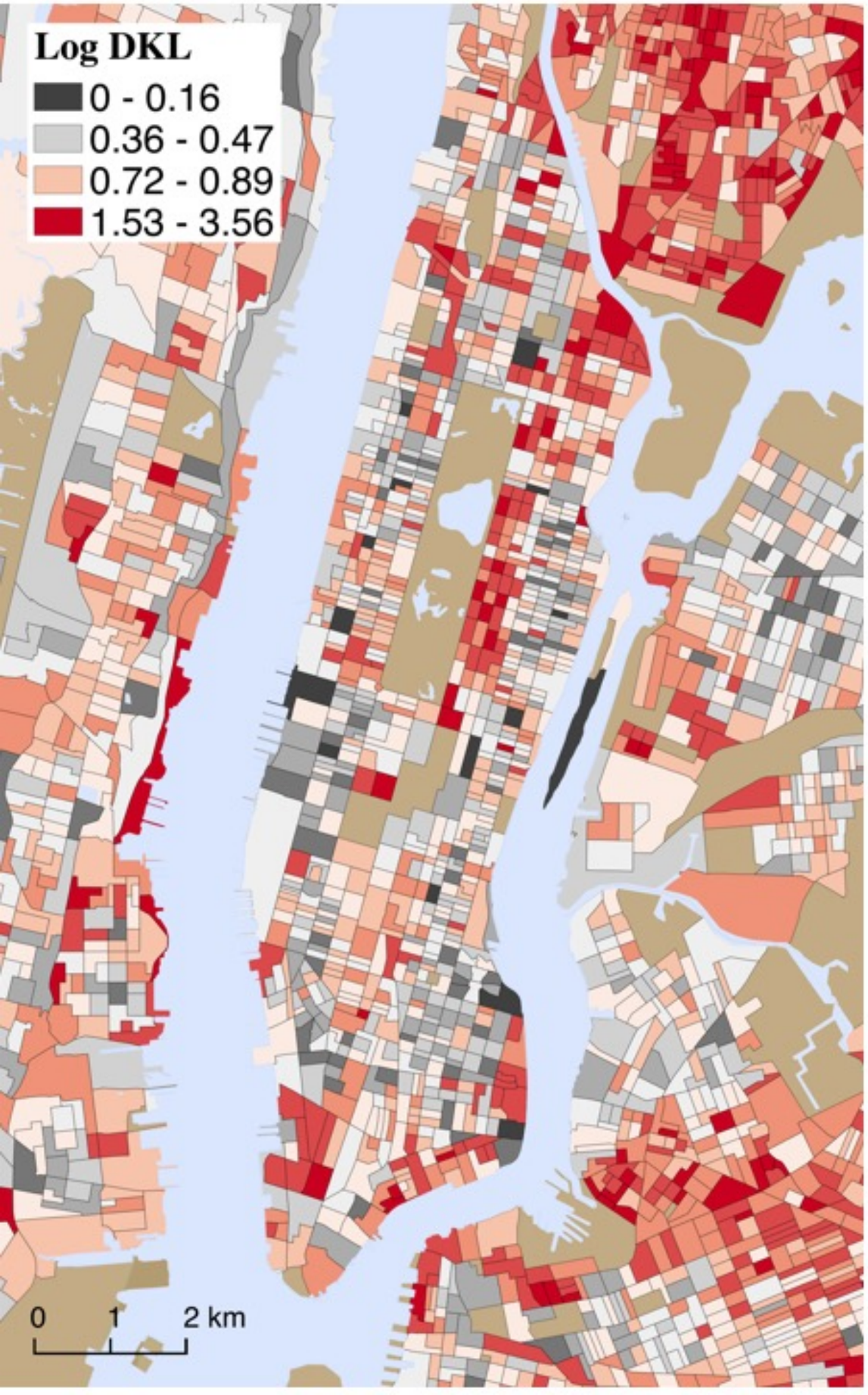
-0.3355 - -0.1156

> 0.4371

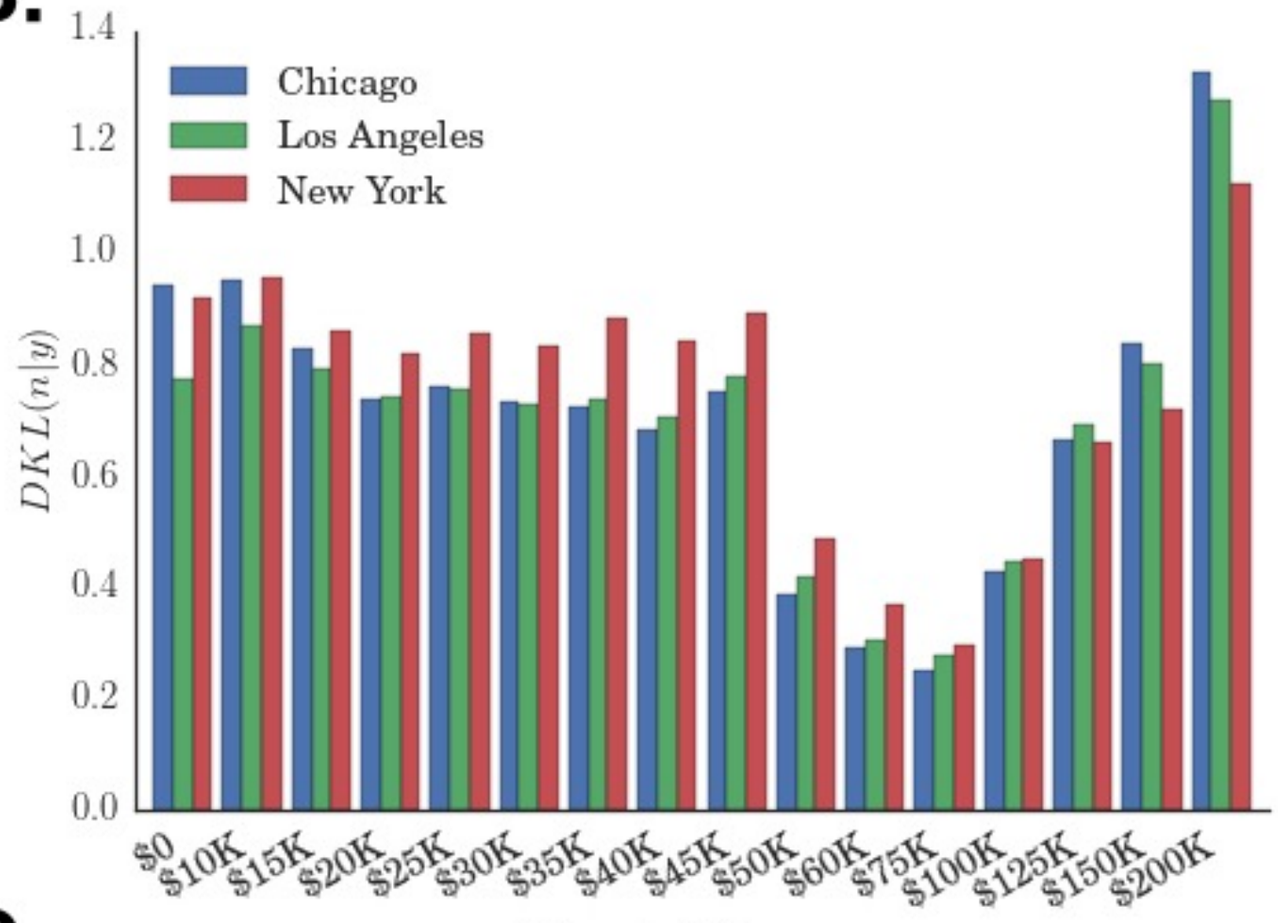
0 5 10 km


Log DKL Income (2010)
< -1.7892
-1.0158 - -0.7635
-0.3355 - -0.1156
> 0.4371
0
5
10 km

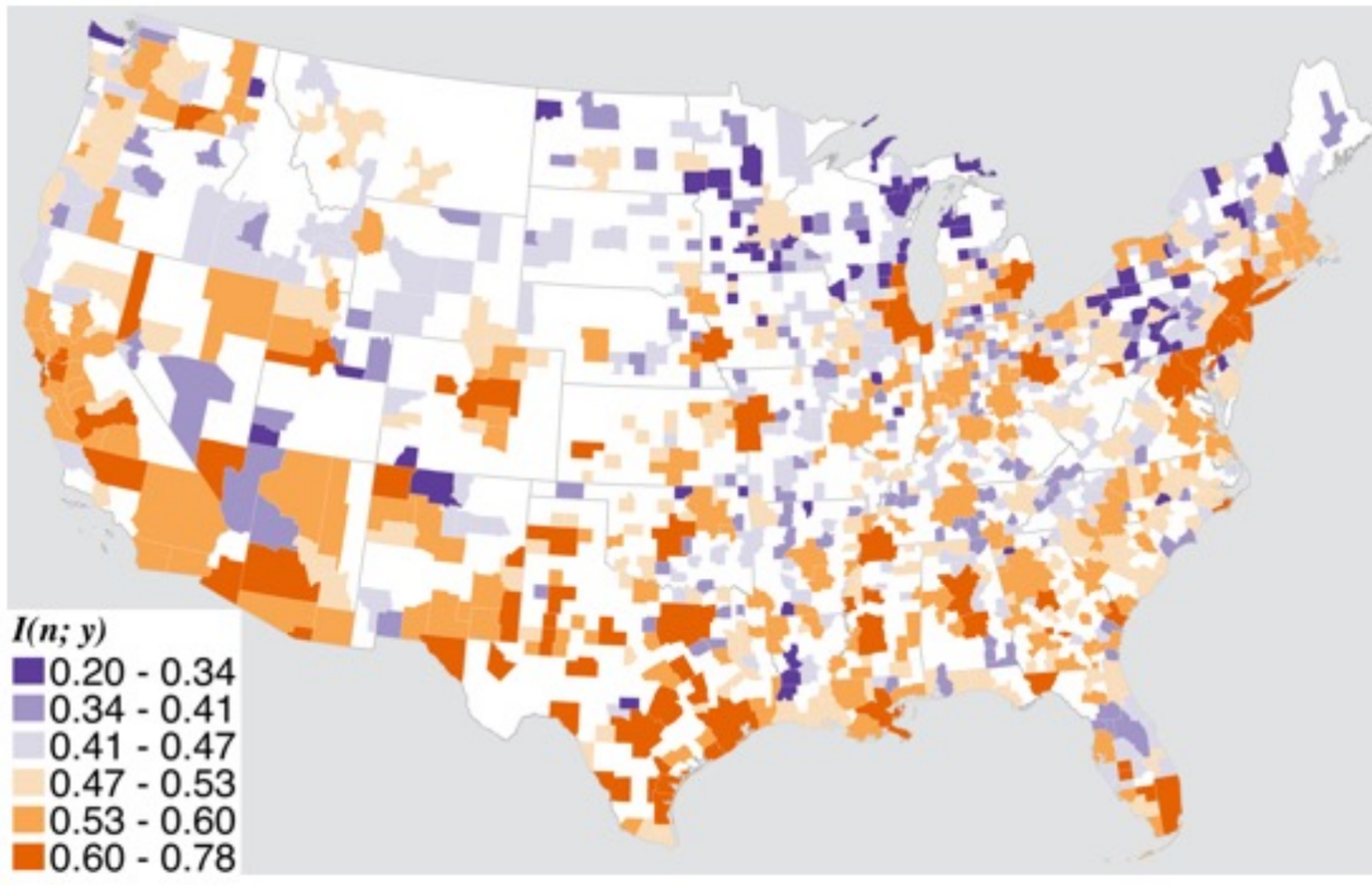
A.


Log DKL
0 - 0.16
0.36 - 0.47
0.72 - 0.89
1.53 - 3.56
0
1
2 km

B.


Chicago
Los Angeles
New York
$DKL(n|y)$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
$0
$10K
$15K
$20K
$25K
$30K
$35K
$40K
$45K
$50K
$60K
$75K
$100K
$125K
$150K
$200K
Household Income

C.

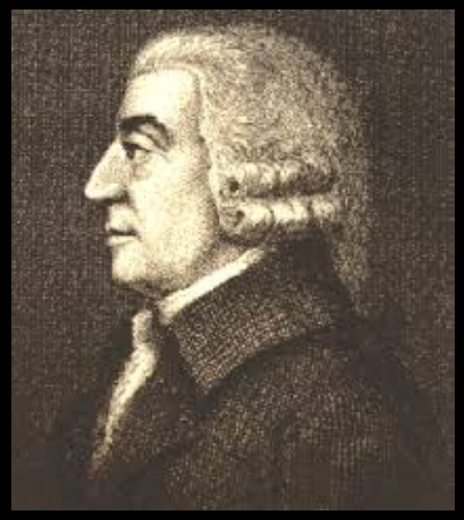

I(n; y)
0.20 - 0.34
0.34 - 0.41
0.41 - 0.47
0.47 - 0.53
0.53 - 0.60
0.60 - 0.78

What is the Ultimate Function of Cities?

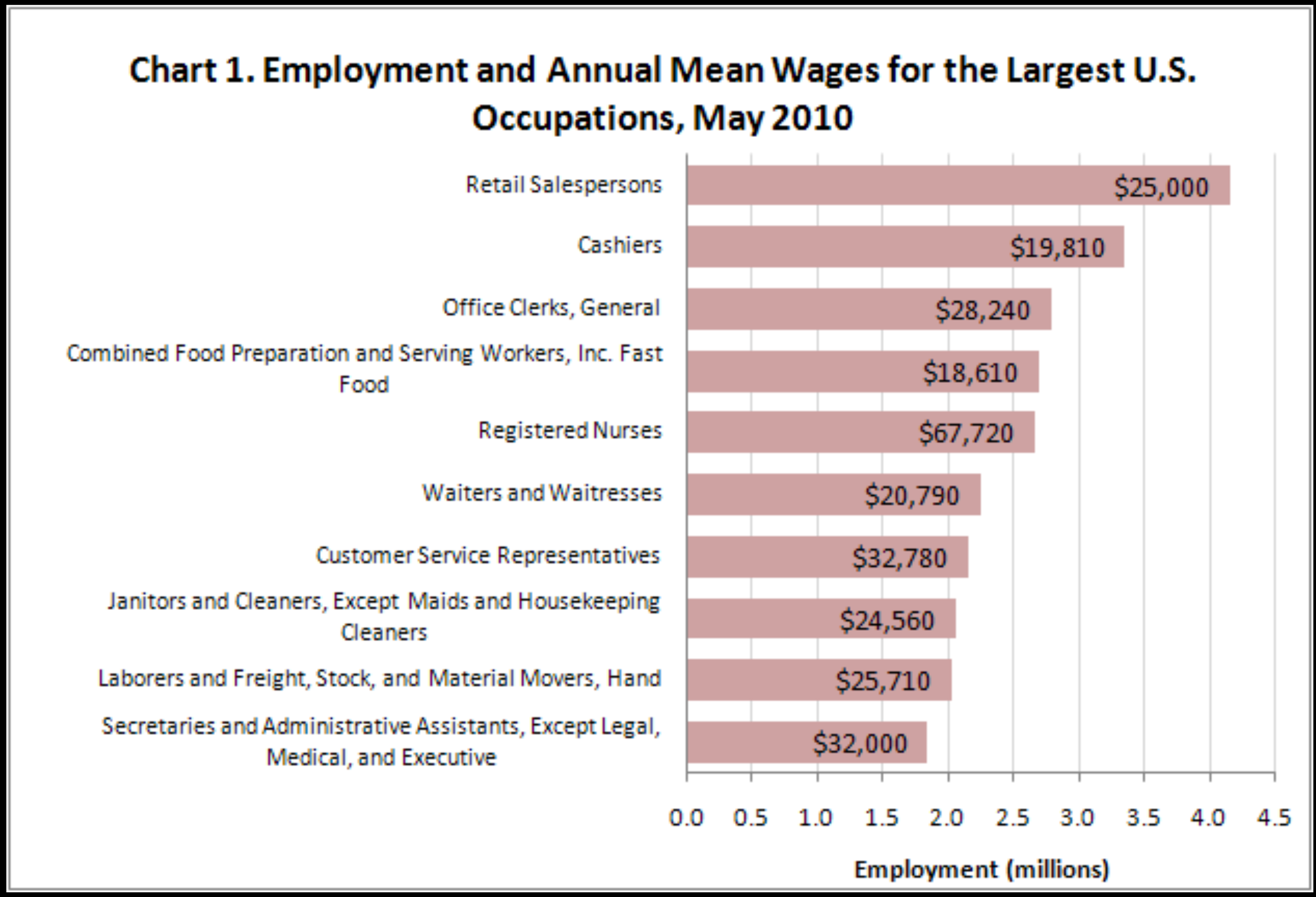
Observe the accommodation of the most day-labourer in a civilized and thriving country, and you will perceive that the number of people of whose industry a part, though but a small part, has been employed in procuring him this accommodation, exceeds all computation

if we examine, all these things, and consider what a variety of labour is employed about each of them, we shall be sensible that without the assistance and co-operation of many thousands, the very meanest person in a civilized country could not be provided

Adam Smith (wealth of nations, ch 2)



Professions in the USA



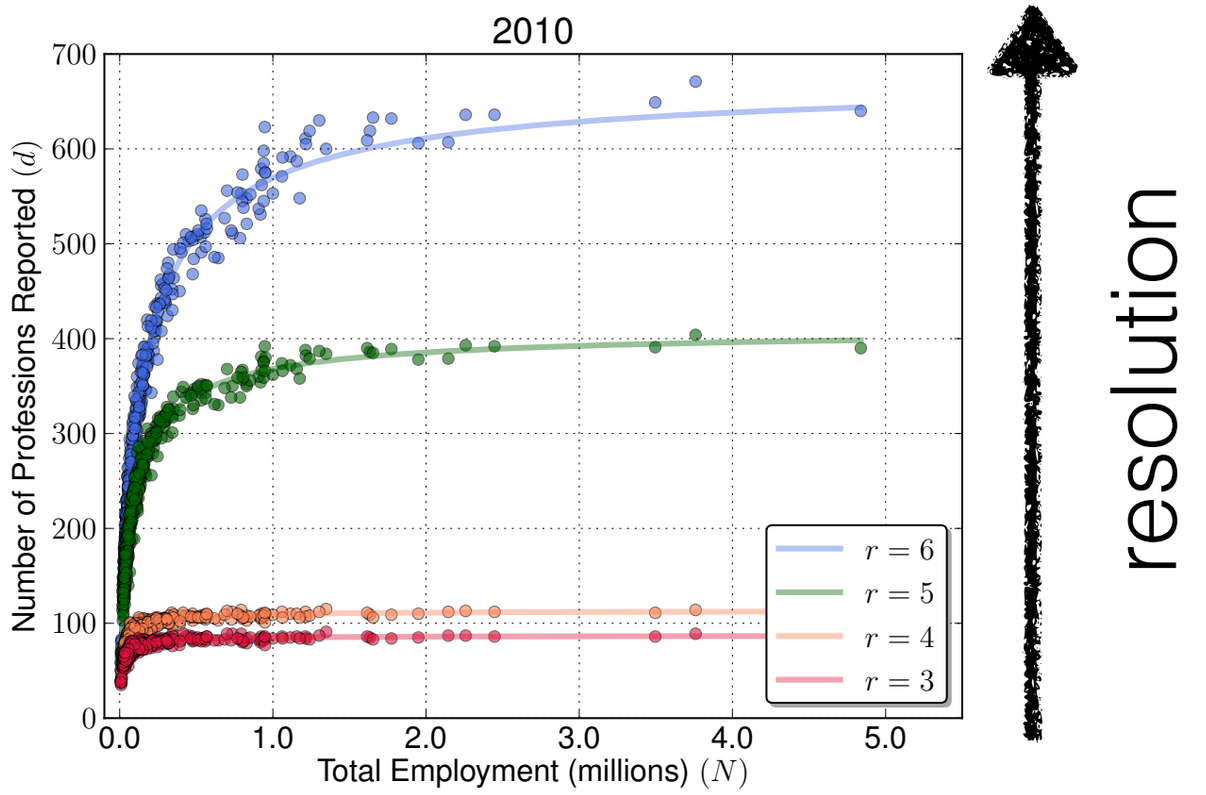
credit: bis.gov

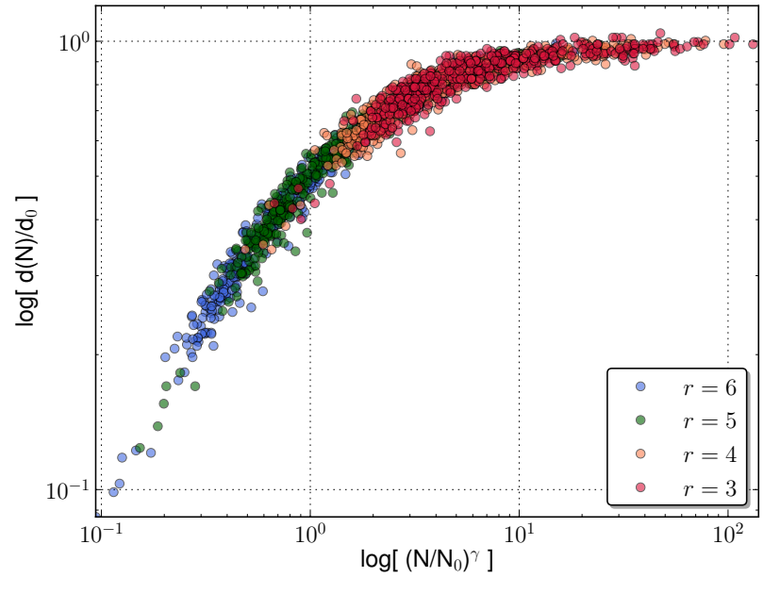
Professional Diversity and Classification Resolution

Occupations in US Metropolitan Statistical Areas

A good fit at all resolutions:

$$D(N_e) = d_0 \frac{\left(\frac{N_e}{N_0}\right)^{\gamma}}{1 + \left(\frac{N_e}{N_0}\right)^{\gamma}}.$$





Inferring actual diversity *D*(*N*):

$$D(N) = d_0 h \left(\frac{N}{N_0}\right) \left(\frac{N}{N_0}\right)^{\gamma} \rightarrow \begin{cases} D_0 N^{\gamma}, & N << N_0, \\ d_0(r), & N >> N_0, \end{cases}$$

In the limit:

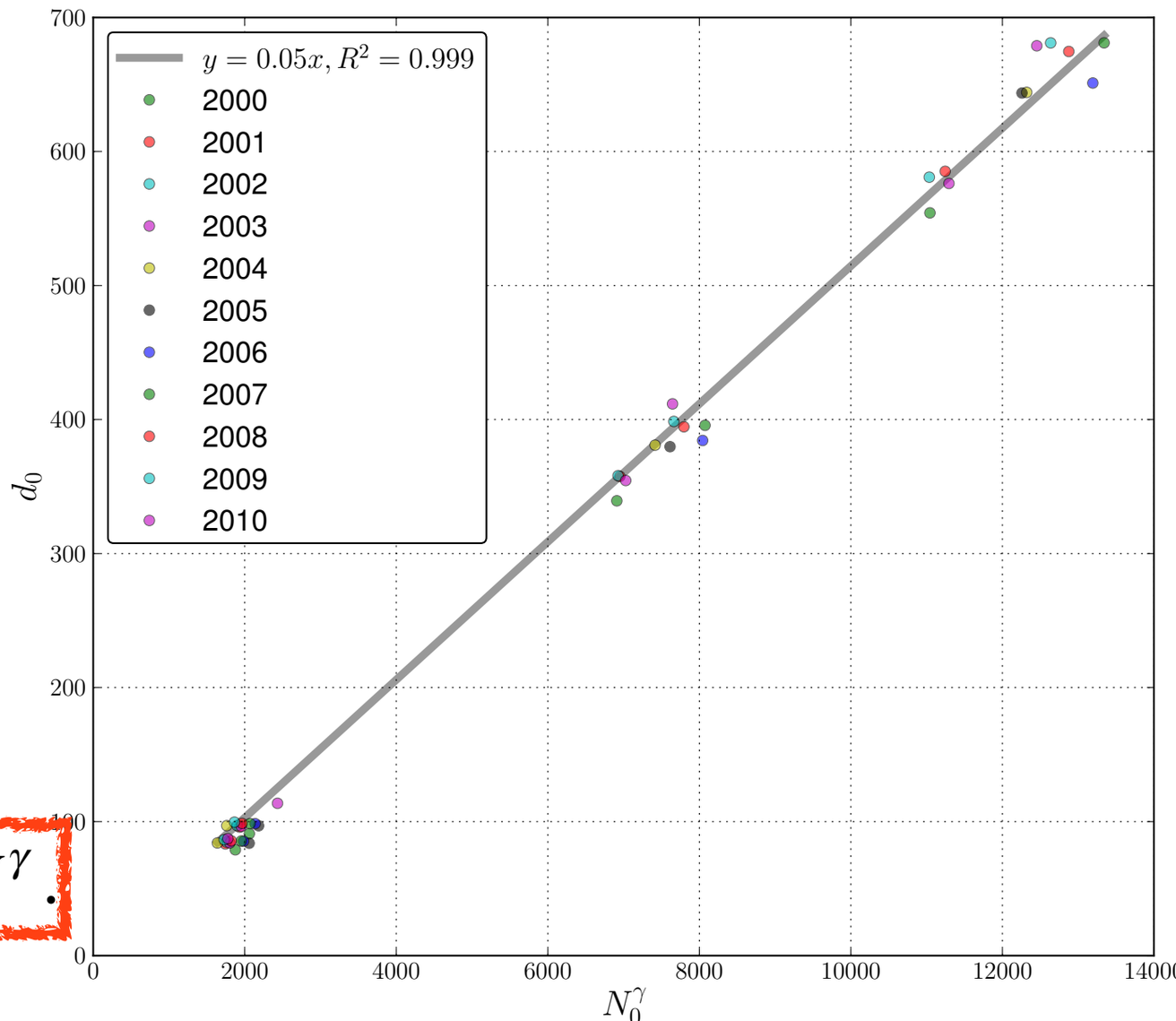
$$\frac{N}{N_0} \rightarrow 0; \qquad h \rightarrow 1, \qquad D_0 \rightarrow \frac{d_0}{N_0{}^{\gamma}}$$

In the limit:

$$\frac{N}{N_0} \rightarrow +\infty; \qquad h \rightarrow \left(\frac{N_0}{N}\right)^{\gamma},$$

A scaling limit exists iff:

$$D_0 \rightarrow \frac{d_0}{N_0{}^{\gamma}} = const. \quad \text{with} \quad \boxed{D(N) = D_0 N^{\gamma}}.$$



The rank size distribution of professions

From D(N), for all N, derive frequency distribution

$$f(i) = \frac{N_e}{N_0}\left(\frac{d_0 - i}{i}\right)^{1/\gamma}.$$

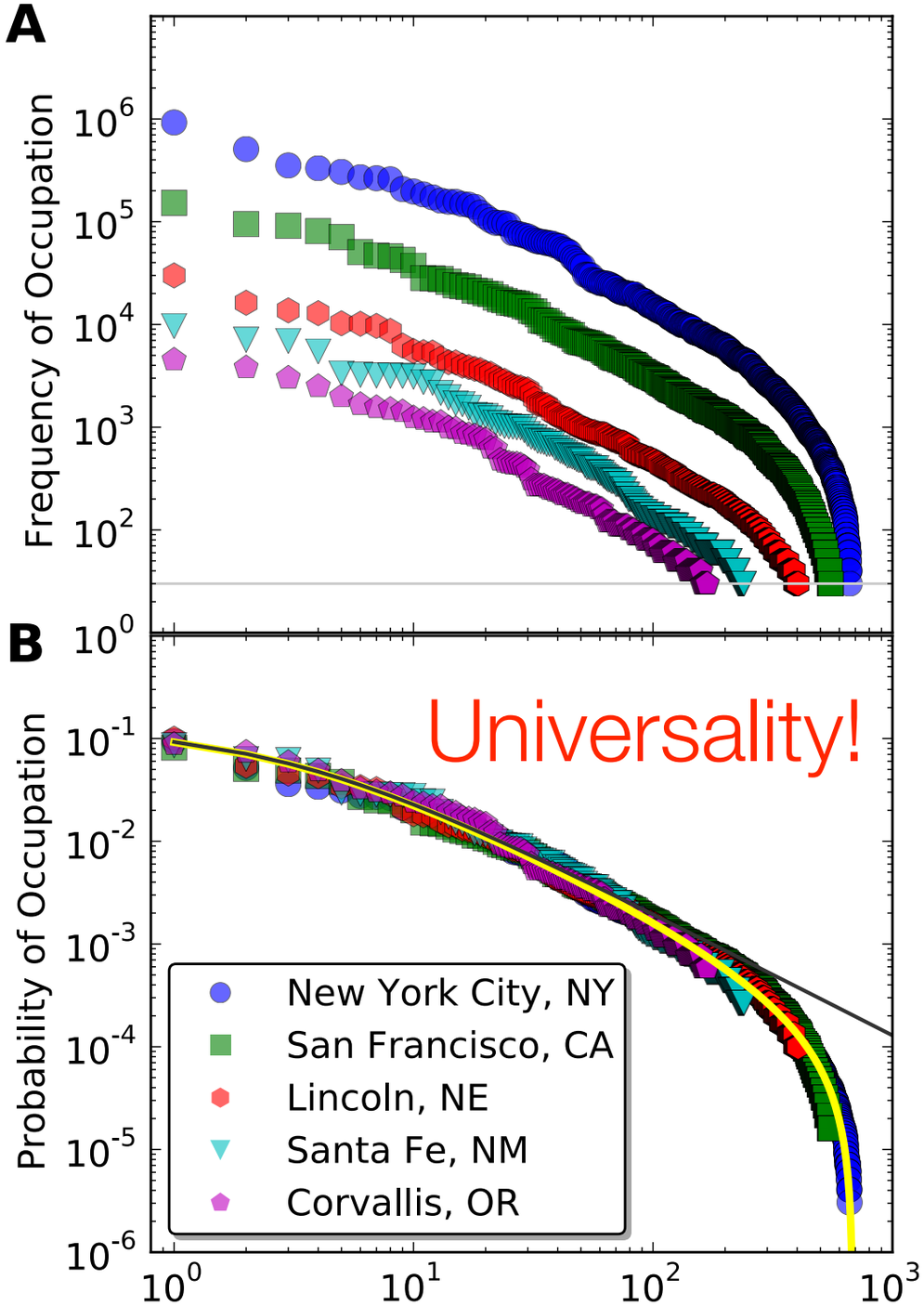
$$p(i) = \frac{f(i)}{\sum_{j=1}^{D(N)} f(j)} = \frac{1-\gamma}{\gamma}\frac{i^{-1/\gamma}}{1 - D(N)^{-\frac{1-\gamma}{\gamma}}};$$

Indices of Diversity:

$$HH(N) = \sum_{i=1}^{D(N)} p^2(i) = \frac{\delta^2}{1-\delta^2}\frac{1 - D_0^{-\frac{1+\delta}{1-\delta}} N^{-1-\delta}}{(1 - D_0^{\frac{\delta}{1-\delta}} N^{-\delta})^2}$$

$$\simeq \frac{\delta^2}{1-\delta^2}\left(1 + \frac{2}{D_0^{\frac{\delta}{1-\delta}} N^{\delta}}\right).$$

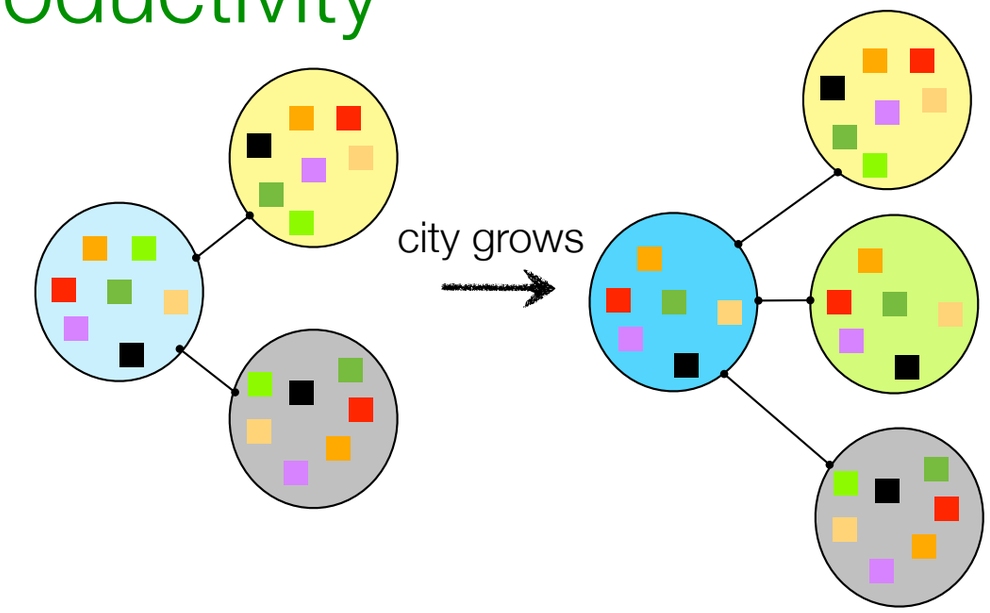
$$S = -\sum_{i=1}^{D(N)} p(i)\ln p(i) \simeq \frac{1}{\delta} - D_0^{-\delta/(1-\delta)} N^{-\delta} \ln(D_0^{1/\gamma} N)$$



Professional Diversity and Urban Productivity

Specialization and Division of Labor

as sources of increases in urban productivity



$$\mathcal{L}(d;\lambda) = \frac{g(kd)}{d} - \lambda\left(kd - A\right).$$

$$d = \frac{A}{k} = \frac{A}{k_0}\frac{1}{N^{\delta}}, \qquad w = \frac{g(A)}{A}k = \frac{g(A)}{A}k_0 N^{\delta},$$

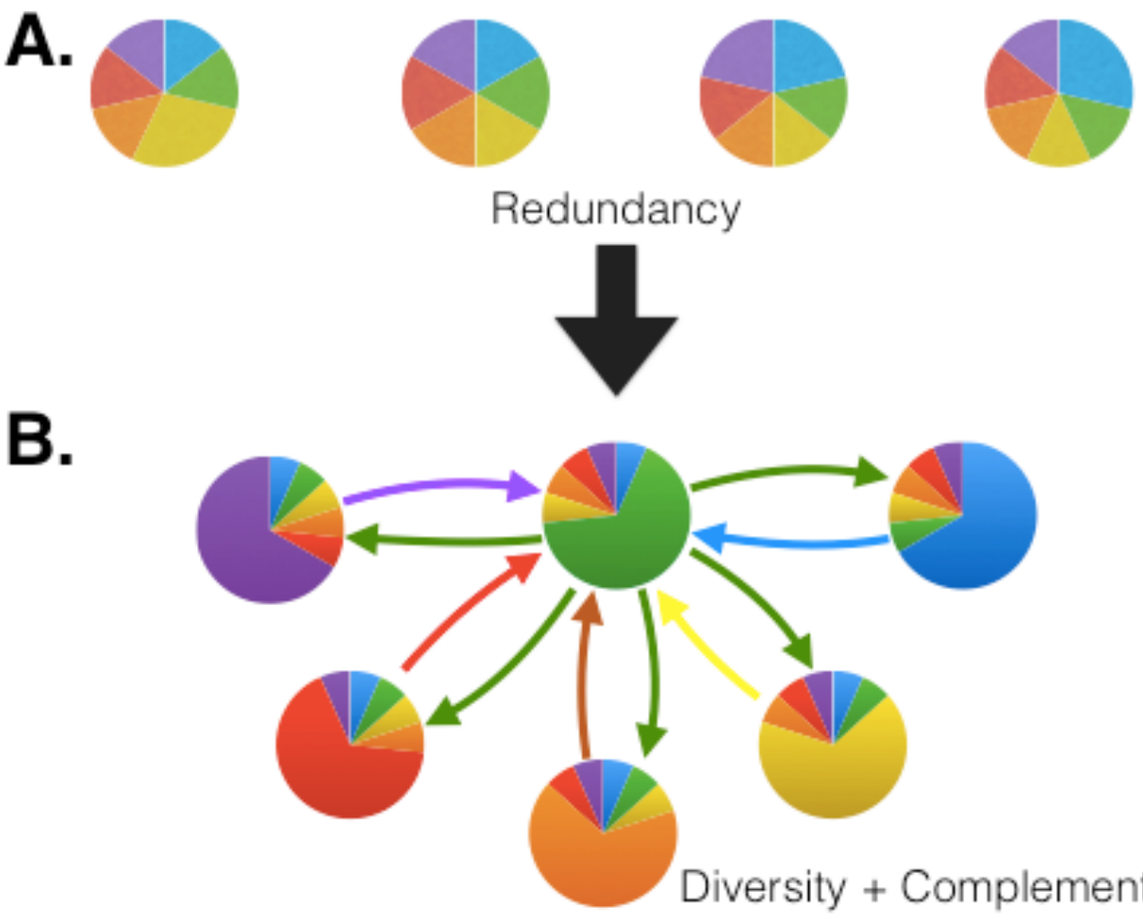
$$\frac{dg}{dA} - \frac{g}{A} - \lambda_1 A = 0 \rightarrow g(A) = \left[C + \int^{A} dA'\lambda_1(A')\right]A,$$

$$D_0 = \tfrac{A}{k_0} = 0.05$$

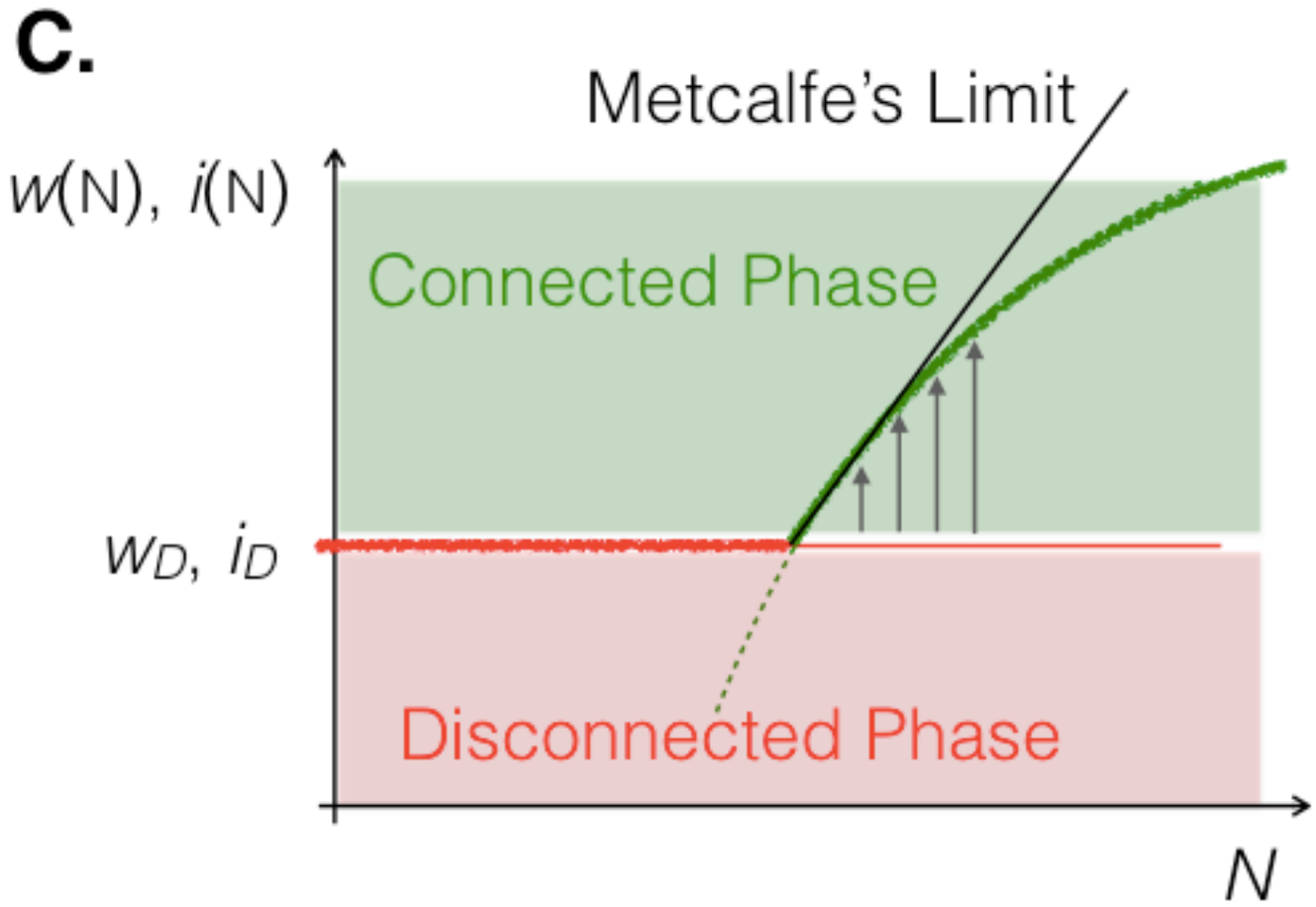
Bettencourt, Samaniego, Youn, 2013

Information, Connectivity & Productivity Growth

Poor



Rich



Bettencourt 2014, IEEE
The role of technology in complex networks

Interconnected human societies contain more information at higher connectivity costs

CHARACTERISTICS OF COMPLEX NETWORK PHASES

Symbol	Node Property	Disconnected Phase	Connected Phase
k	connectivity (degree)	k_D (small)	$k(N) = k_C(t)N^{\delta}$ (increasing)
d	number of functions	d_D (large)	$d(N) = d_C(t)N^{-\delta}$ (decreasing)
i	information	i_D (small)	$i(N) = i_C(t)N^{\delta}$ (increasing)
w	productivity	w_D (low)	$w(N) = w_C(t)N^{\delta}$ (increasing)
t	time per function	t_D (small)	$t(N) = t_C(t)N^{\delta}$ (increasing)
c	cost per connection	c_D (large)	$c(N) = c_C(t)N^{\delta}$ (increasing)

Metcalfe's limit of the connected phase is obtained as $\delta \longrightarrow 1$, see Figure 1.

Bettencourt 2014, IEEE
The role of technology in complex networks

development
is the ability to solve
human problems*

*socially

New and old ways of **being connected**

In a real sense all life is inter-related.

All people are caught in an inescapable network of mutuality, tied in a single garment of destiny.

Whatever affects one directly, affects all indirectly.

I can never be what I ought to be until you are what you ought to be, and you can never be what you ought to be until I am what I ought to be...

This is the inter-related structure of reality.

- Martin Luther King Jr, Letter from Birmingham Jail.

Twitter Founder Reveals Secret Formula for Getting Rich Online

BY RYAN TATE 09.30.13 | 9:30 AM | PERMALINK

Share 18 Tweet 22 +1 1.4k Share 1 Pin it

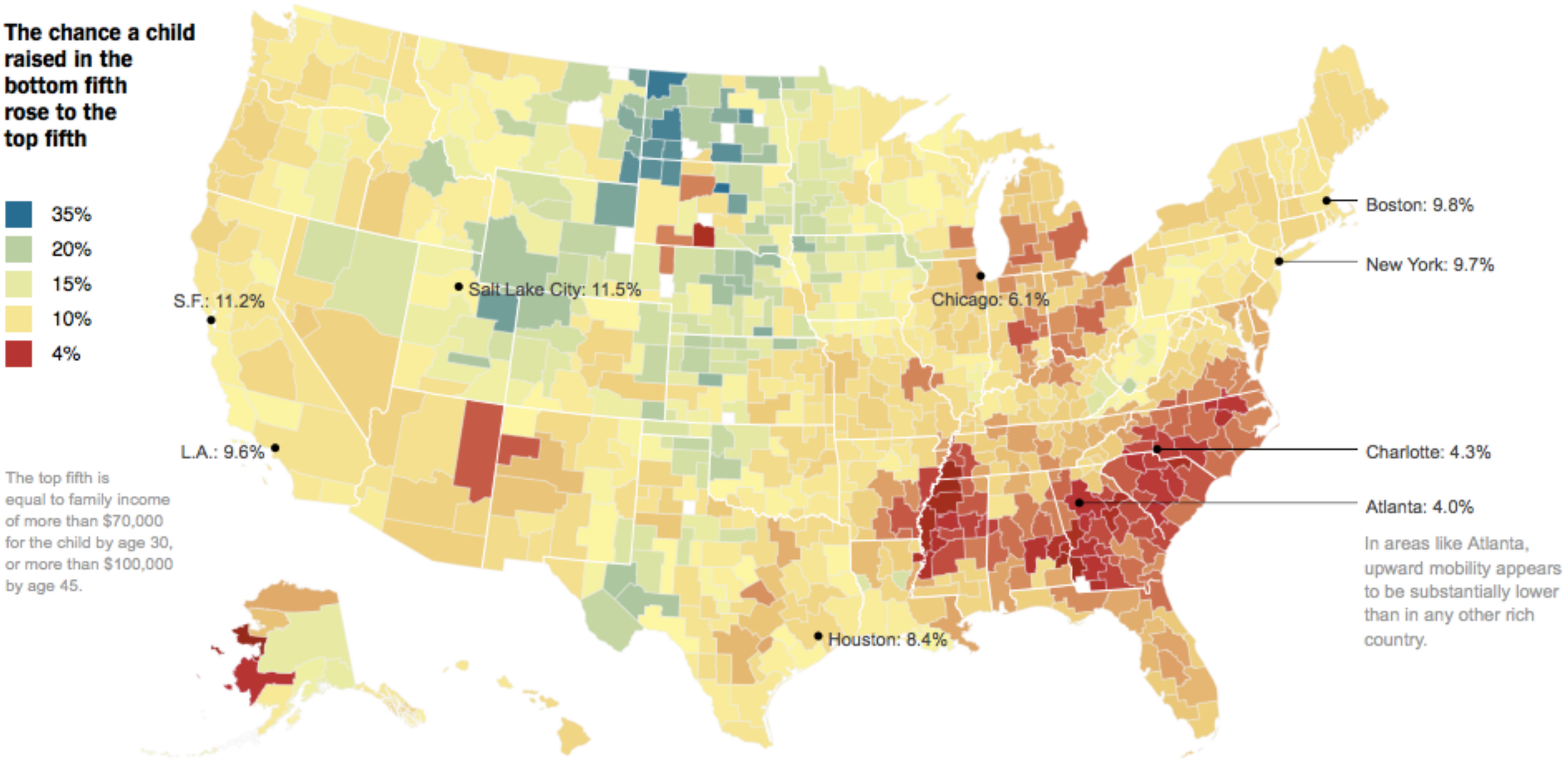
Ev Williams. *Photo: Andrew White/WIRED*

Ev Williams has figured out the internet.

"How Airbnb and Lyft finally got americans to trust each other"

In Climbing Income Ladder, Location Matters

A study finds the odds of rising to another income level are notably low in certain cities, like Atlanta and Charlotte, and much higher in New York and Boston.



E-MAIL

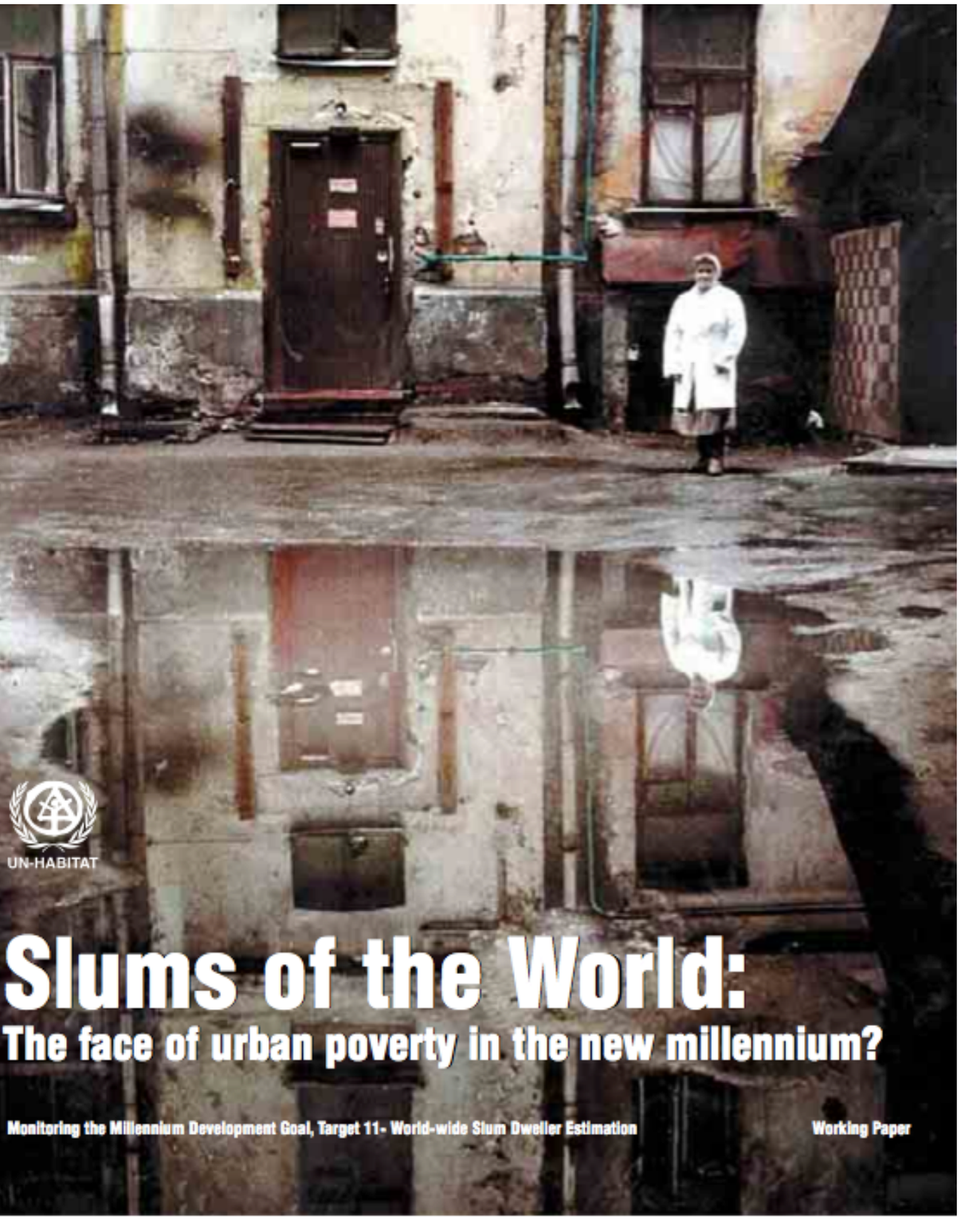
By DAVID LEONHARDT PUBLISHED: JULY 22, 2013 536 COMMENTS

But the researchers identified four broad factors that appeared to affect income mobility, including the size and dispersion of the local middle class. All else being equal, upward mobility tended to be higher in metropolitan areas where poor families were more dispersed among mixed-income neighborhoods.

Income mobility was also higher in areas with more two-parent households, better elementary schools and high schools, and more civic engagement, including membership in religious and community groups.

Rio de Janeiro
credit: guardian

An “Information Crisis”



The depiction of the city,
its problems and its potential
still remain sorely distorted.

Most cities in the developing world
are suffering from
an information crisis
which is seriously undermining
their capacity to
develop and analyze
effective urban policy.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Shack/Slum Dwellers International (SDI)
Santa Fe Institute

An interactive experience of more than 6,000 informal settlements and slums worldwide

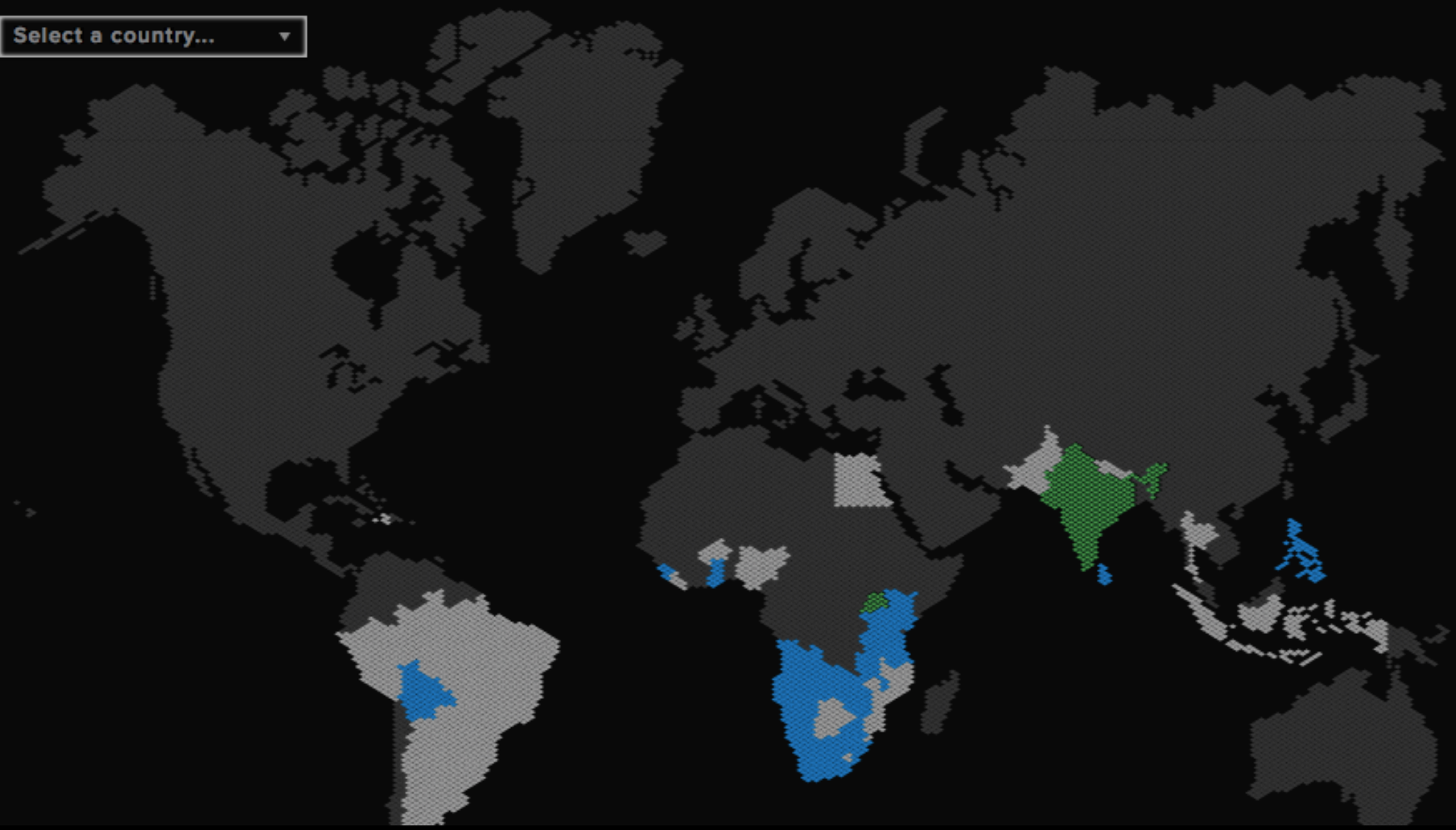
Data Available Data Forthcoming SDI Affiliate

LEARN MORE ABOUT THE DATA

KNOW YOUR CITIES
KNOW YOUR SLUM

http://civitas.santafe.edu/viz/
7,000+ slums

Select a country...



Shack/Slum Dwellers International (SDI)
Santa Fe Institute

GLOBE > INDIA > RANGA REDDY

Population | Water | Health Access | Infrastructure | Community | Toilets

LEARN MORE ABOUT THE DATA

RANGA REDDY

X

LOCATION

BASIC INFORMATION

Slum Population

792,772

Total Settlements

314

Total Households

180,695

Median Family Size

4

WATER

Residents per Tap

11.4

Residents per Well

2,781.7

Residents per Water Source

10.8

HEALTH ACCESS

% Settlements with Hospital Access

36.3%

INFRASTRUCTURE

% Households with Electricity

Bus Stops

24

COMMUNITY

Libraries

12

Average Residents per Library

66,064.3

Markets

16

TOILETS

% Settlements with Sewer

49.0%

Individual Toilets

111,403

http://civitas.santafe.edu/viz/

OpenStreetMap

Edit | History | Export

Monrovia, Liberia

GPS Traces User Diaries

Search Where am I? Go

Samie Town (1)
Nyanfore Town
Tomo
Dwahn Town
Dwahn Town
Dry Rice Market Community
Lower Johnson
Engels
Johnsonville Old Field Community
Patience Shop
Day Break Mouth Open
Barekling
MKK Community
New Georgia Junction
Gardnersville
J.J.Y. Community
Somalia Drive
Liberia Refining Company
Barekling
Iron Factory
Chocalate City
Supermarket


PROBLEM STATEMENT
PEOPLE LIVING IN SLUMS
NEED
ACCESS NETWORKS FOR BASIC & EMERGENCY SERVICES, BECAUSE
RESIDENTS OF INFORMAL SETTLEMENTS OFTEN LACK SECURITY, A SENSE OF PLACE AND THE BASIC SERVICES THEY NEED.

AMPLIFY

OPENREBLOCK: **CONNECTING RESEARCHERS, PLANNERS AND COMMUNITIES** TO UPGRADE URBAN SLUMS IN INDIA AND SOUTH AFRICA.

- Slum Dwellers International & Santa Fe Institute

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The Cities of the Future

Population projections of the 101 largest cities in the 21st century [edit]

Large urban areas are hubs of economic development and innovation, with larger cities underpinning regional economies and local and global sustainability initiatives. Currently, 757 million people reside in the 101 largest cities;[22] these cities are home to 11% of the world's population.[22] By the end of the century, the world population is projected to grow, with estimates ranging from 6.9 billion to 13.1 billion;[22] the percentage of people residing in the 101 larger cities is estimated to be 15% to 23%.[22]

The 101 cities with the largest population projections for the years 2025, 2050, 2075, and 2100 are listed below.[22]

Rank	City	Projected Population (millions) 2025	City	Projected Population (millions) 2050	City	Projected Population (millions) 2075	City	Projected Population (millions) 2100
1	Tokyo	36.40	Mumbai	42.40	Mumbai	57.86	Lagos	76.60
2	Mumbai	26.39	Delhi	36.16	Lagos	55.26	Dar es Salaam	73.68
3	Delhi	22.50	Dhaka	35.19	Kinshasa	54.51	Mumbai	67.24
4	Dhaka	22.02	Kinshasa	35.00	Delhi	49.34	Kinshasa	63.05
5	Sao Paulo	21.43	Kolkata	33.04	Kolkata	45.09	Lilongwe	57.43
6	Mexico City	21.01	Lagos	32.63	Karachi	43.37	Delhi	57.33
7	New York	20.63	Tokyo	32.62	Dhaka	42.45	Blantyre City	56.78
8	Kolkata	20.56	Karachi	31.70	Dar es Salaam	37.49	Khartoum	56.59
9	Shanghai	19.41	New York	24.77	Cairo	33.00	Niamey	55.24
10	Karachi	19.10	Mexico City	24.33	Manila	32.75	Kolkata	52.40
11	Kinshasa	16.76	Cairo	24.04	Kabul	32.67	Kabul	59.27
12	Lagos	15.80	Manila	23.55	Khartoum	30.68	Karachi	49.06
13	Cairo	15.56	Sao Paulo	22.83	Nairobi	28.42	Nairobi	46.66
14	Manila	14.81	Shanghai	21.32	New York	27.19	N'Djamena	41.15
15	Beijing	14.55	Lahore	17.45	Tokyo	24.64	Cairo	40.54

Wikipedia

Hoornweg & Pope (2014).
Population predictions of the 101 largest cities in the 21st century

1 NO POVERTY

2 ZERO HUNGER

3 GOOD HEALTH AND WELL-BEING

4 QUALITY EDUCATION

5 GENDER EQUALITY

6 CLEAN WATER AND SANITATION

7 AFFORDABLE AND CLEAN ENERGY

8 DECENT WORK AND ECONOMIC GROWTH

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

10 REDUCED INEQUALITIES

11 SUSTAINABLE CITIES AND COMMUNITIES

THE GLOBAL GOALS

For Sustainable Development

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

14 LIFE BELOW WATER

15 LIFE ON LAND

16 PEACE AND JUSTICE STRONG INSTITUTIONS

17 PARTNERSHIPS FOR THE GOALS

The New Urban Agenda

9. We anchor our vision in the concept of cities for all, referring to the equal use and enjoyment of cities, towns, and villages, seeking to promote inclusivity and ensure that all inhabitants, of present and future generations, without discrimination of any kind, are able to inhabit and produce just, safe, healthy, accessible, resilient, and sustainable cities and human settlements, as a common good that essentially contributes to prosperity and quality of life. Cities for all is also recognized as the Right to the City in some countries, based on a people-centered vision of cities as places that strive to guarantee a decent and full life for all inhabitants.

Provided that some groups on earth continue either muddling or revolutionizing themselves into periods of economic development, we can be absolutely sure of a few things about **future cities**:

The cities will not be smaller, simpler or more specialized as cities of today.

Rather, they will be more intricate, comprehensive, diversified and larger than today's and will have even more complicated jumbles of old and new things than ours do.

Jane Jacobs
The Economy of Cities, 1980

Challenge Questions:

1. Do **cities in 3D** show larger or smaller agglomeration effects?

Recall that : $$\delta = \frac{H}{D(D+H)}$$

What's H so that δ stays unchanged? What does it mean?

2. We discussed **connectivity and the division of labor** as a mechanism for mutual advantage, learning and economic growth.

When does the division of labor fail?

Think of the most common professions. What's the solution?