WHAT CAN THE SCIENCE OF CITIES TEACH US ABOUT THE NONPROFIT SECTOR:

AN EXPLORATION OF PHILANTHROPIC RESOURCE ENVIRONMENTS AND NONPROFIT DENSITY

Jesse Lecy

Arizona State University

THE NEW SCIENCE OF CITIES: SCALING AND COMPLEXITY

Bettencourt, L. M. A. (2013). The origins of scaling in cities. *Science, 340*(6139), 1438–1441. https://doi.org/10.1126/science.1235823

Bettencourt, L. M. A., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the National Academy of Sciences, 104*(17), 7301–7306. https://doi.org/10.1073/pnas.0610172104

Bettencourt, L. M. A., Lobo, J., Strumsky, D., & West, G. B. (2010). Urban scaling and its deviations: Revealing the structure of wealth, innovation, and crime across cities. *PLoS ONE, 5*(11), e13541. https://doi.org/10.1371/journal.pone.0013541

Batty, M. (2008). The size, scale, and shape of cities. *Science, 319*(5864), 769–771. https://doi.org/10.1126/science.1151419

Batty, M. (2013). *The new science of cities.* MIT Press.

West, G. (2017). *Scale: The universal laws of life, growth, and death in organisms, cities, and companies.* Penguin Press.

Youn, H., Bettencourt, L. M. A., Lobo, J., Strumsky, D., Samaniego, H., & West, G. B. (2016). Scaling and universality in urban economic diversification. *Journal of the Royal Society Interface, 13*(114), 20150937. https://doi.org/10.1098/rsif.2015.0937

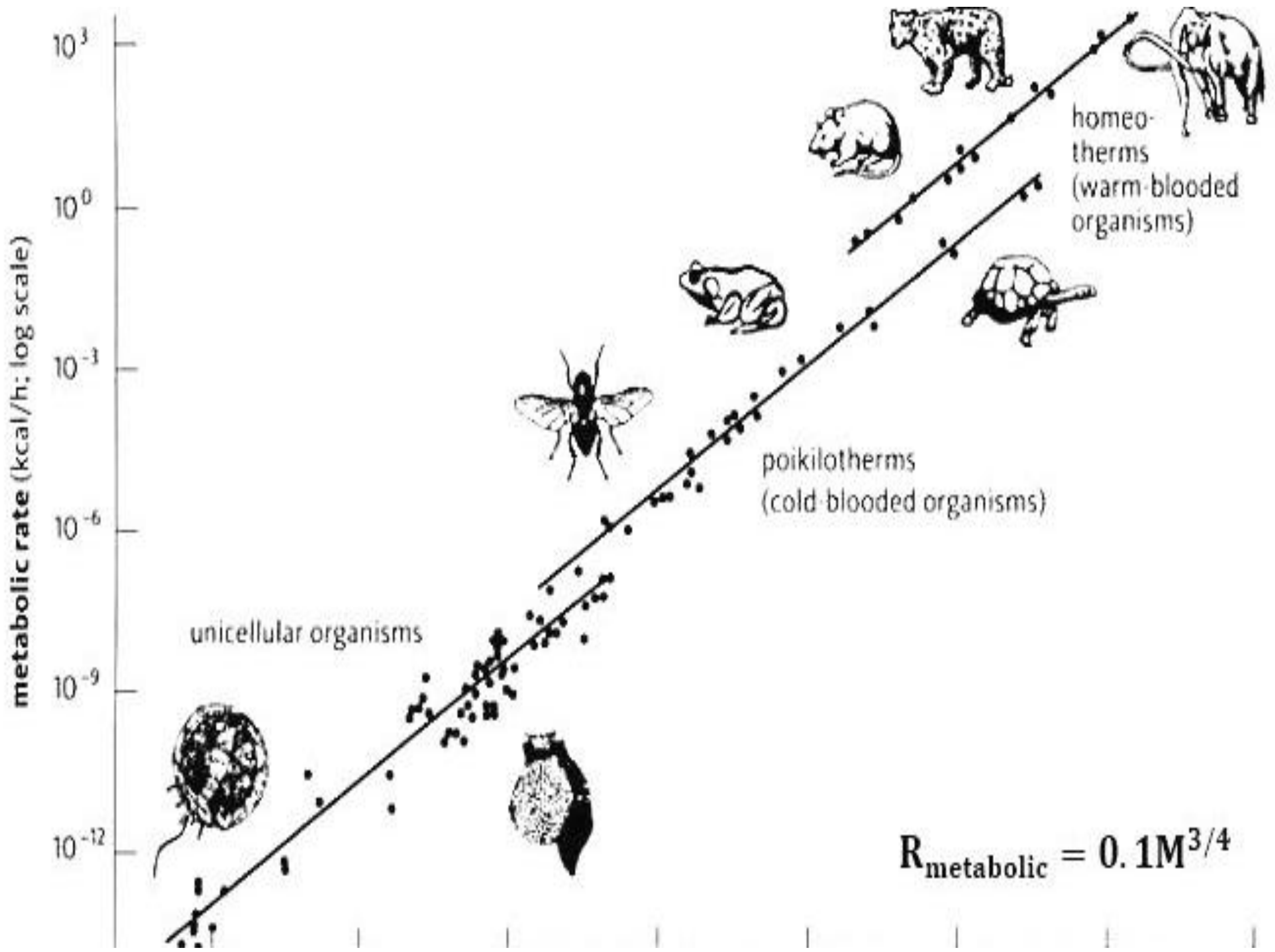
Lobo, J., Bettencourt, L. M. A., & Strumsky, D. (2020). Energy, information, and the environment: The nexus of urban and global sustainability. *Current Opinion in Environmental Sustainability, 44*, 1–8. https://doi.org/10.1016/j.cosust.2019.09.005

Pan, W., Ghoshal, G., Krumme, C., Cebrian, M., & Pentland, A. (2013). Urban characteristics attributable to density-driven tie formation. *Nature Communications, 4*, 1961. https://doi.org/10.1038/ncomms2961

Schläpfer, M., Bettencourt, L. M. A., Grauwin, S., et al. (2014). The scaling of human interactions with city size. *Journal of the Royal Society Interface, 11*(98), 20130789.

THE STATISTICAL LAWS OF CITIES

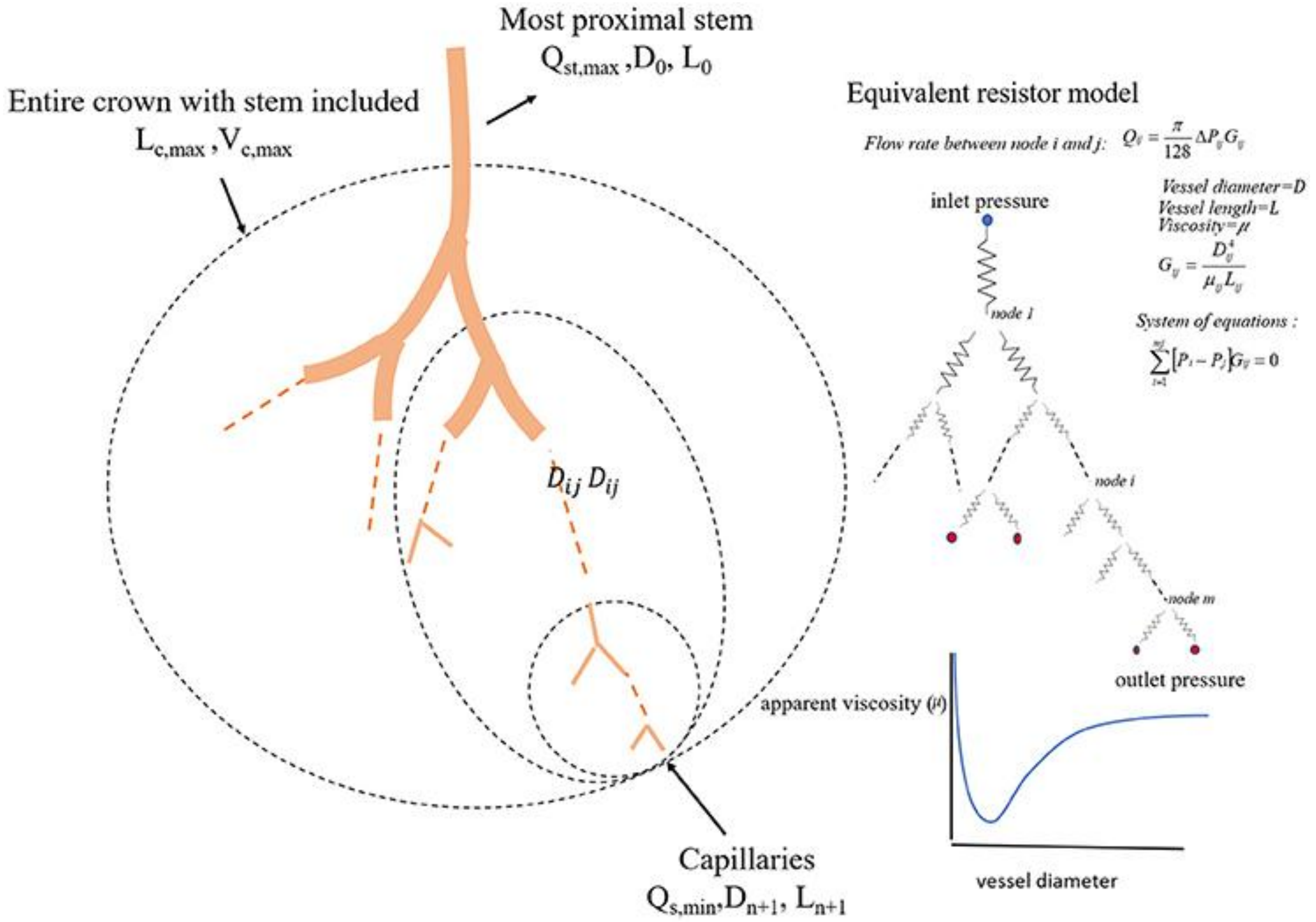
1. Cities follow universal scaling laws — innovation and problems grow superlinearly, infrastructure grows sublinearly.



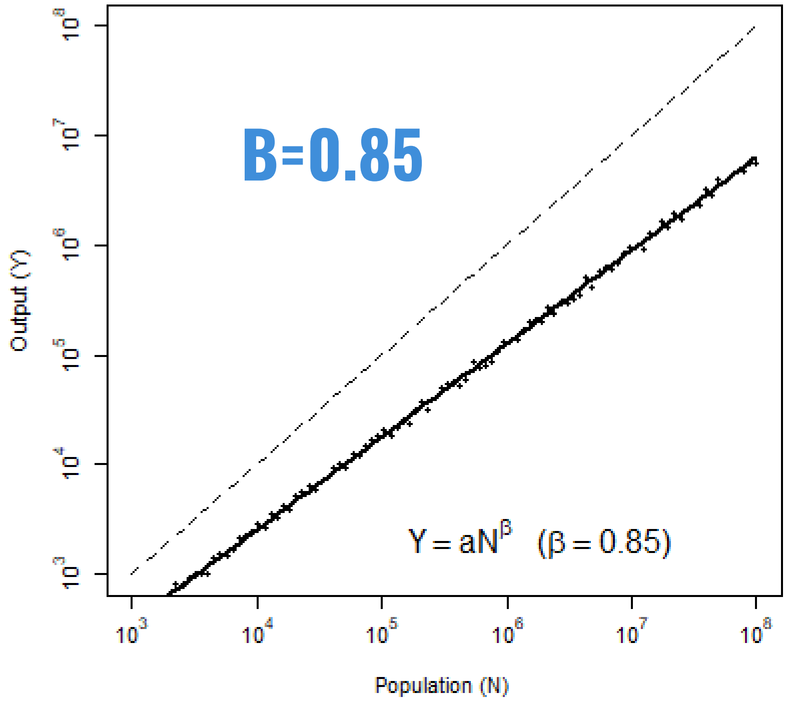
INFRASTRUCTURE

The total length of infrastructure networks (roads, pipes, cables) grows roughly **POP $^{\mathbf{0.75}}$**

(**population raised to the 3/4 power**)

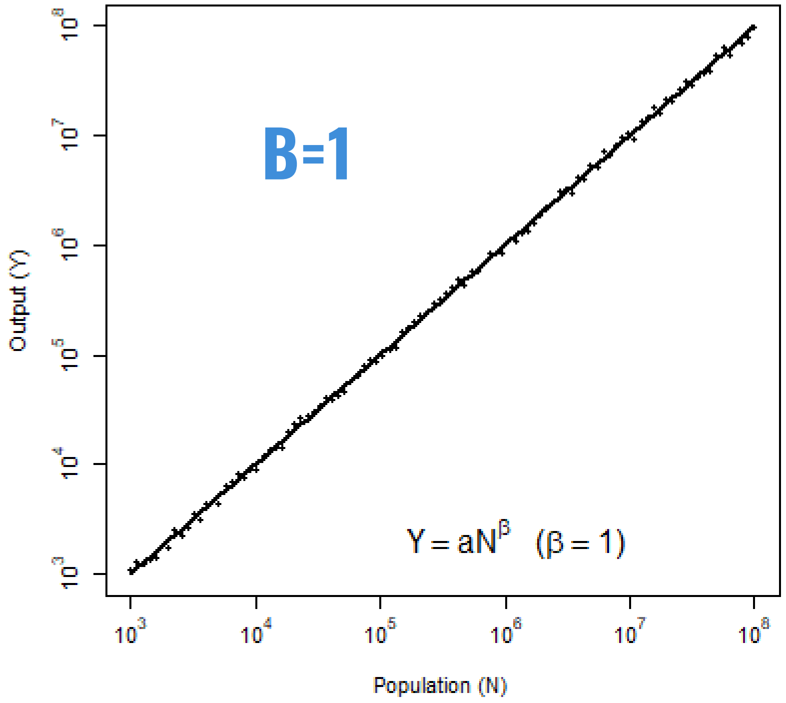

Most proximal stem
$Q_{st,max}, D_0, L_0$
Entire crown with stem included
$L_{c,max}, V_{c,max}$
D_{ij} D_{ij}
Capillaries
$Q_{s,min}, D_{n+1}, L_{n+1}$
Equivalent resistor model
Flow rate between node i and j: $Q_{ij} = \frac{\pi}{128} \Delta P_{ij} G_{ij}$
inlet pressure
node 1
node i
node m
outlet pressure
Vessel diameter=D
Vessel length=L
Viscosity=μ
$G_{ij} = \frac{D_{ij}^4}{\mu_{ij} L_{ij}}$
System of equations :
$\sum_{i=1}^{mj} [P_i - P_j] G_{ij} = 0$
apparent viscosity (μ)
vessel diameter

Infrastructure (Sublinear Scaling)



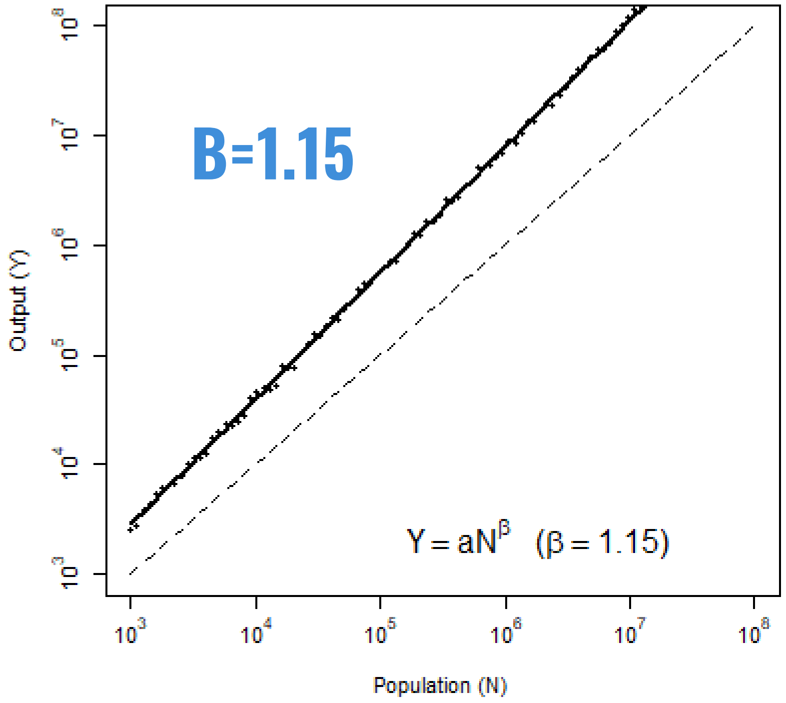
- Warehouses
- Logistics hubs
- Manufacturing plants
- Construction supply firms
- Gas stations
- Utilities (water, waste, power)
- Mining, extraction

Human Needs (Linear Scaling)



- Restaurants
- Cafes, bars
- Grocery stores
- Pharmacies
- Big-box retail
- Salons, laundromats

Innovation (Superlinear Scaling)



- R&D firms
- Software, biotechnology
- Semiconductors
- Scientific services
- Engineering consulting
- Architecture & design firms
- Creative (film, music, arts)
- Legal, finance, advertising

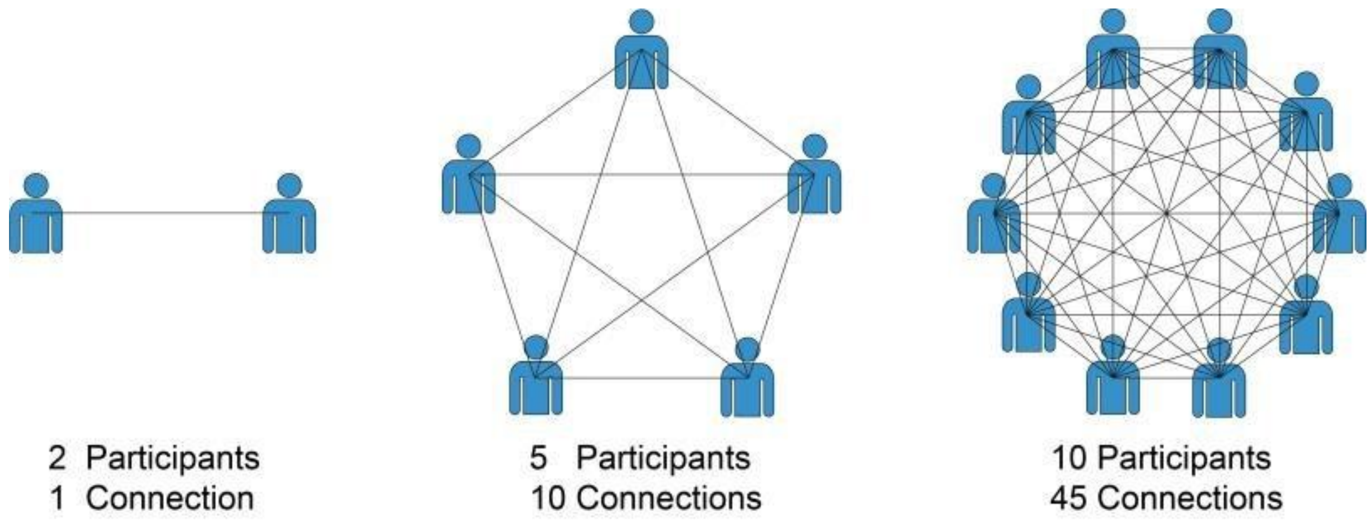
OCCP2 categories	β-estimate (OLS) aggregate workers	Adj R^2	β-estimate (OLS) aggregate income	Adj R^2	income cluster
chief executives, general managers and legislators	1.17	0.95	1.19	0.94	high
specialist managers	1.14	0.97	1.16	0.96	high
business, human resource and marketing professionals	1.23	0.97	1.25	0.96	high
design, engineering, science and transport professionals	1.16	0.93	1.15	0.90	high
education professionals	1.04	0.98	1.04	0.97	high
health professionals	1.09	0.97	1.11	0.96	high
ICT professionals	1.47	0.93	1.43	0.93	high
legal, social and welfare professionals	1.11	0.96	1.14	0.95	high
engineering, ICT and science technicians	1.07	0.94	1.05	0.88	high
electrotechnology and telecommunications trades workers	1.00	0.94	0.99	0.88	high
protective service workers	1.04	0.89	1.02	0.88	high
office managers and programme administrators	1.10	0.98	1.14	0.96	high
sales representatives and agents	1.14	0.97	1.16	0.96	high
machine and stationary plant operators	0.85	0.70	0.81	0.59	high
farmers and farm managers	0.70	0.46	0.65	0.57	medium
hospitality, retail and service managers	1.02	0.99	1.04	0.98	medium
arts and media professionals	1.21	0.96	1.16	0.95	medium

Evidence for localization and urbanization economies in urban scaling (2020)

THE STATISTICAL LAWS OF CITIES

1. Cities follow universal scaling laws — innovation and problems grow superlinearly, infrastructure grows sublinearly.

2. Social networks drive city performance — cities are engines of interaction.



THE STATISTICAL LAWS OF CITIES

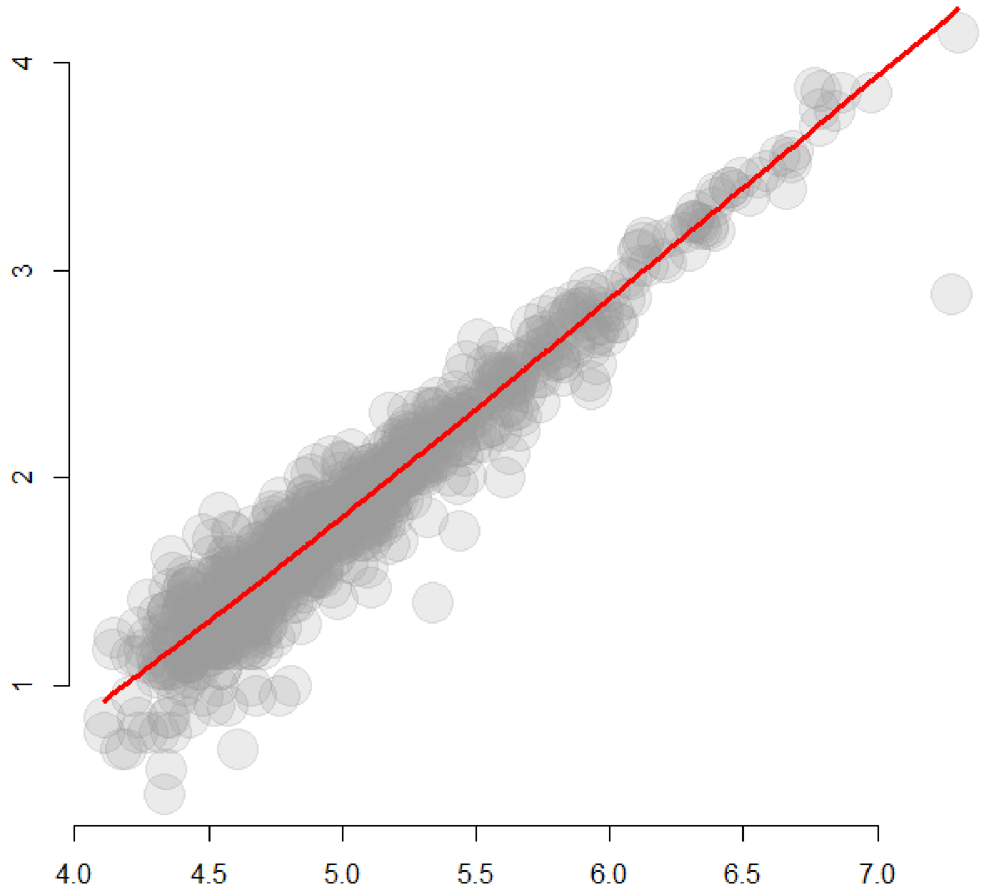
1. Cities follow universal scaling laws — innovation and problems grow superlinearly, infrastructure grows sublinearly.

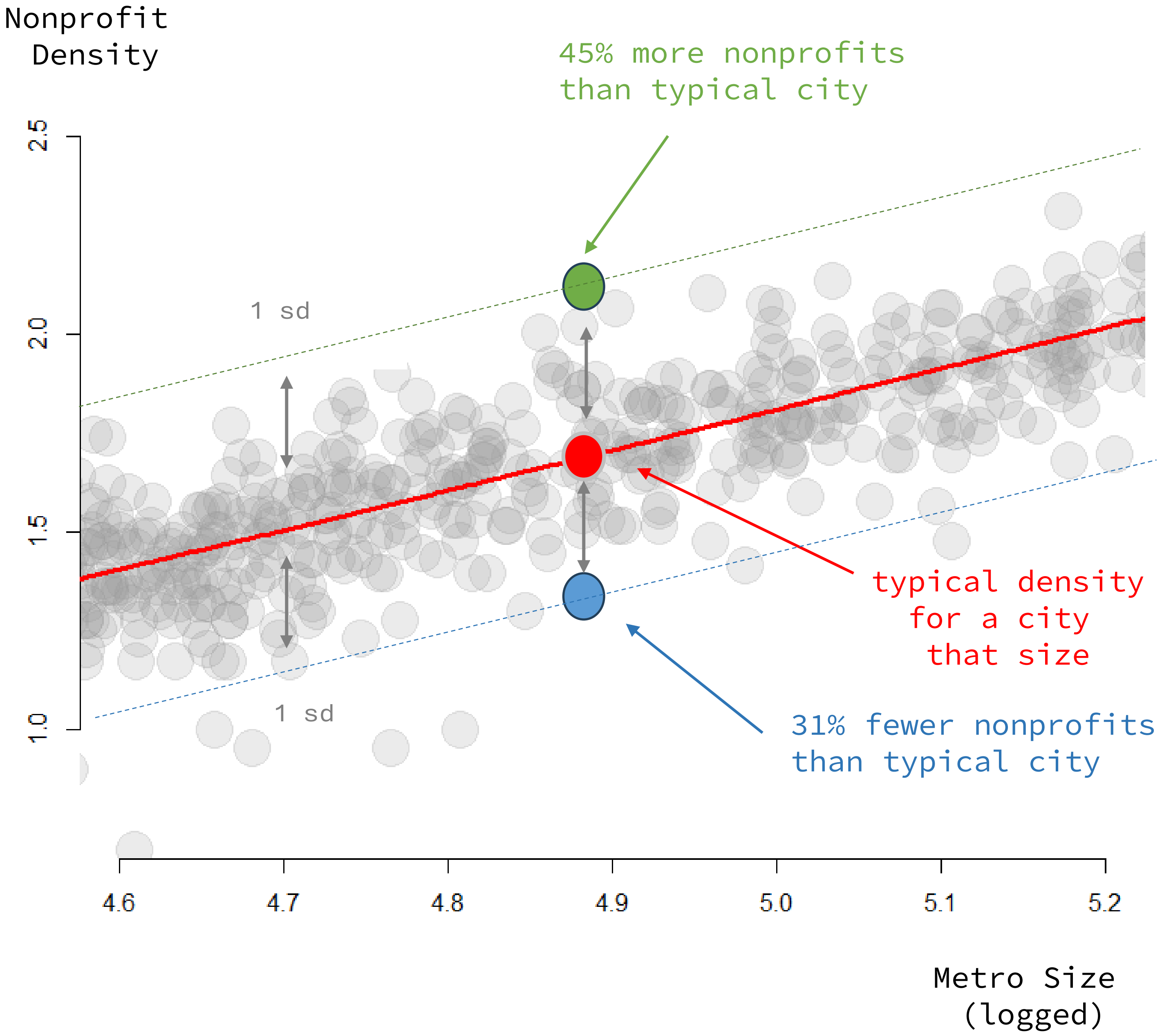
2. Social networks drive city performance — cities are engines of interaction.

3. Large cities are more efficient yet more challenging — both productivity and crime rise faster than population.

4. Cities must innovate faster as they grow — to avoid collapse or stagnation.

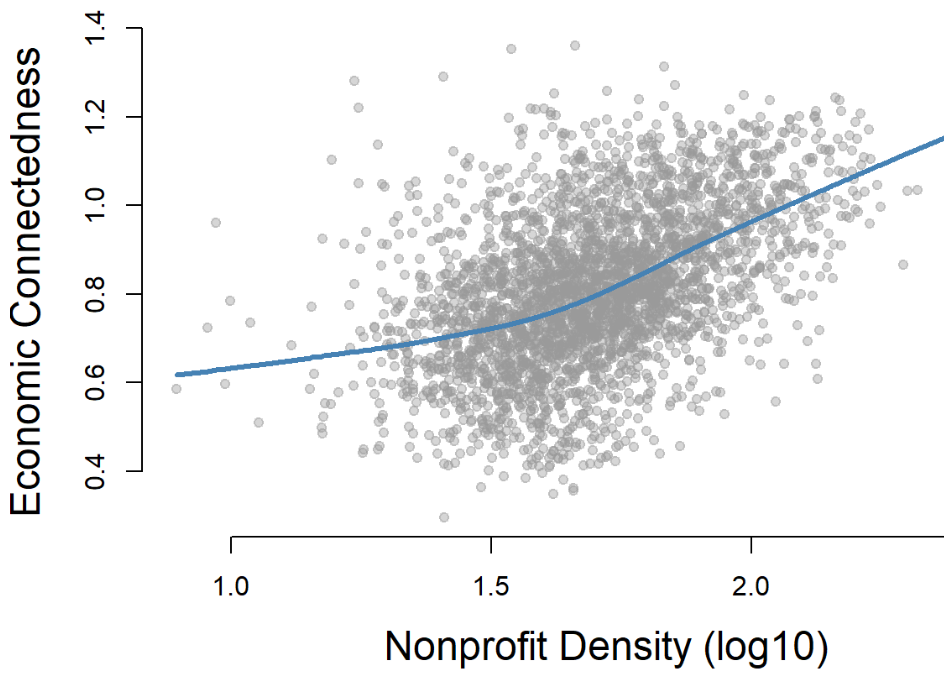
	Dependent variable:
	logN
logP	1.025***
	(0.010)
Constant	-3.318***
	(0.050)
Observations	868
R2	0.926
Adjusted R2	0.926
Residual Std. Error	0.160 (df = 866)
F Statistic	10,783.110*** (df = 1; 866)
Note:	*p<0.1; **p<0.05; ***p<0.01

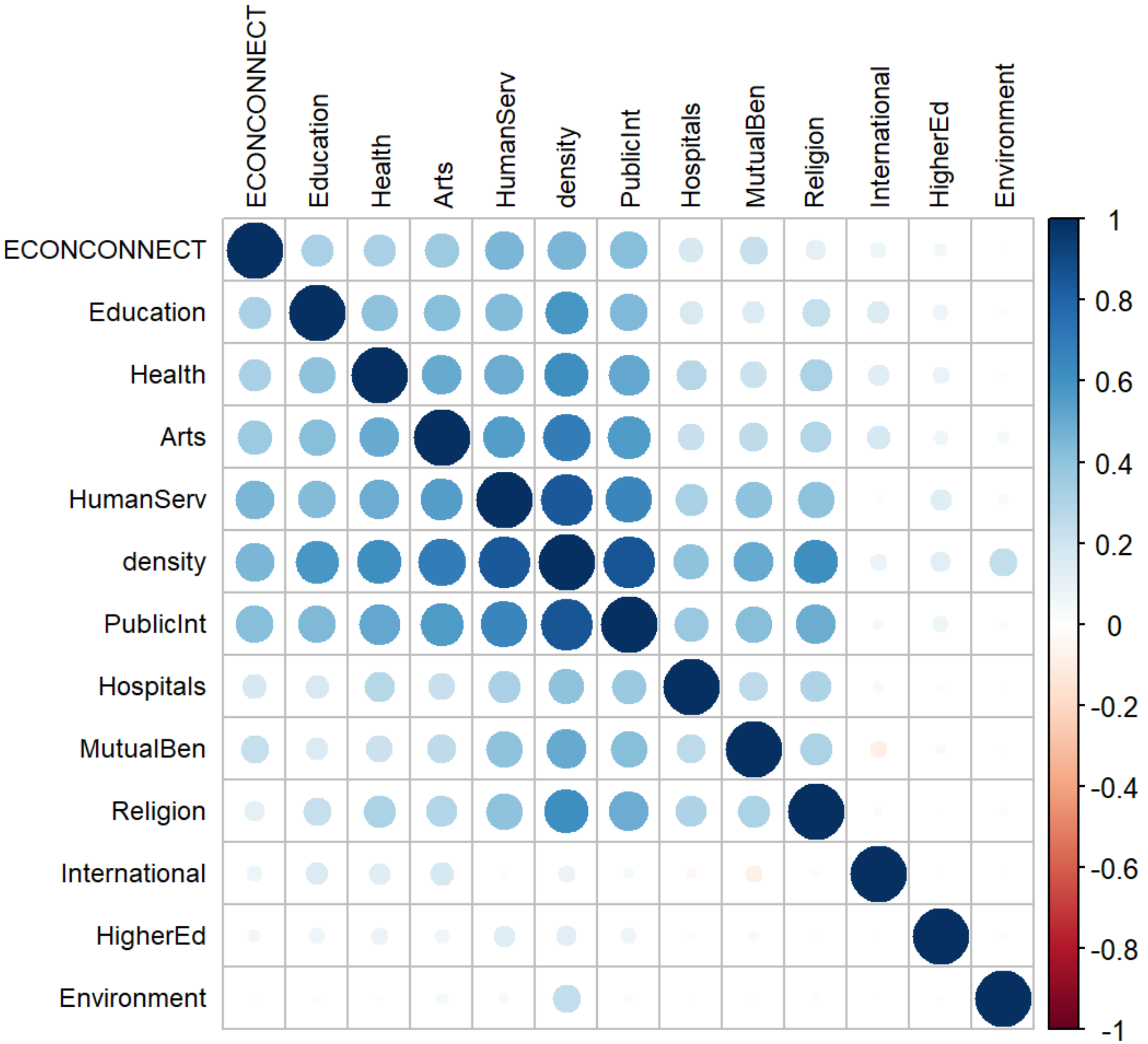




It is a consistent measure (the low and high ratios are parallel lines) but challenging to interpret because the score is relative to metro size

	popM	low.ratio	high.ratio
1	0.01	0.67	1.50
2	0.03	0.70	1.40
3	0.10	0.69	1.45
4	0.32	0.69	1.44
5	1.00	0.69	1.45
6	3.16	0.69	1.45
7	10.00	0.69	1.45

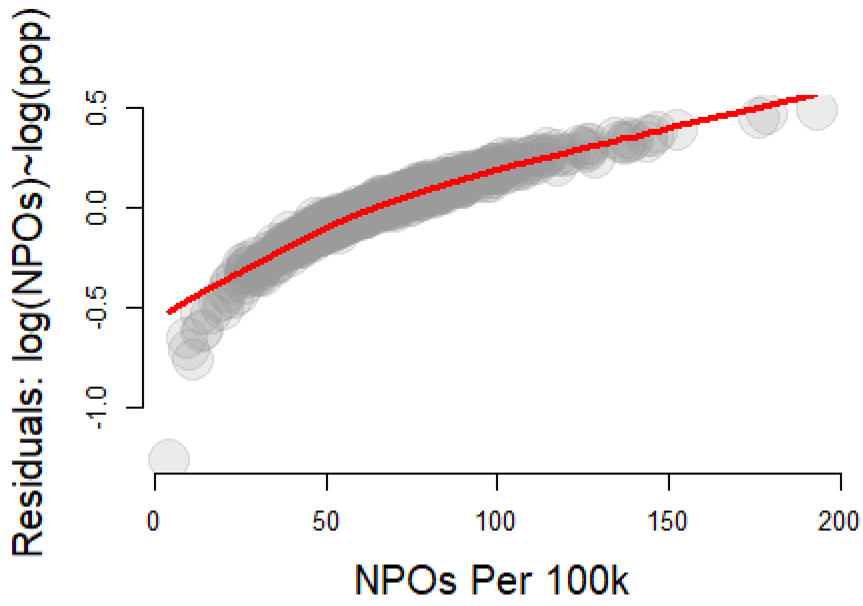

Economic Connectedness
0.4
0.6
0.8
1.0
1.2
1.4
1.0
1.5
2.0
Nonprofit Density (log10)

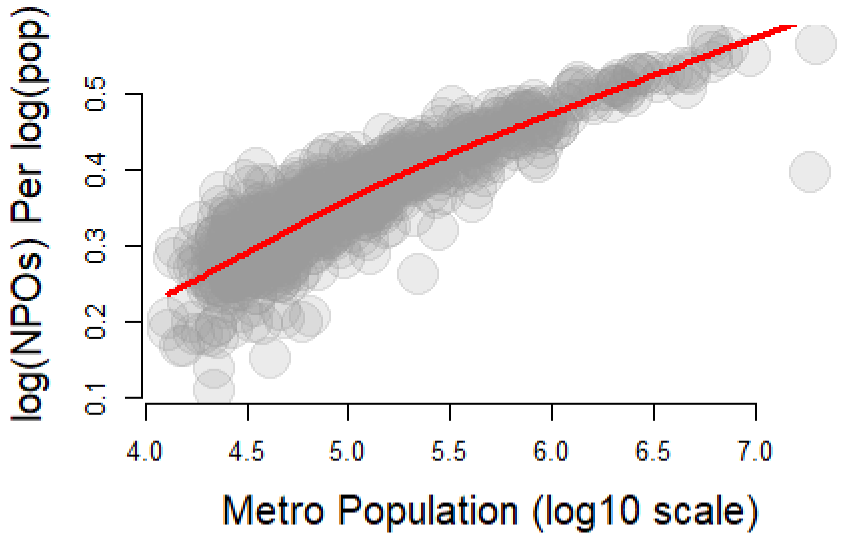

ECONCONNECT
Education
Health
Arts
HumanServ
density
PublicInt
Hospitals
MutualBen
Religion
International
HigherEd
Environment
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

INTERNALLY CONSISTENT BENCHMARKING: SCALE-ADJUSTED METROPOLITAN INDICATORS (SAMIs)

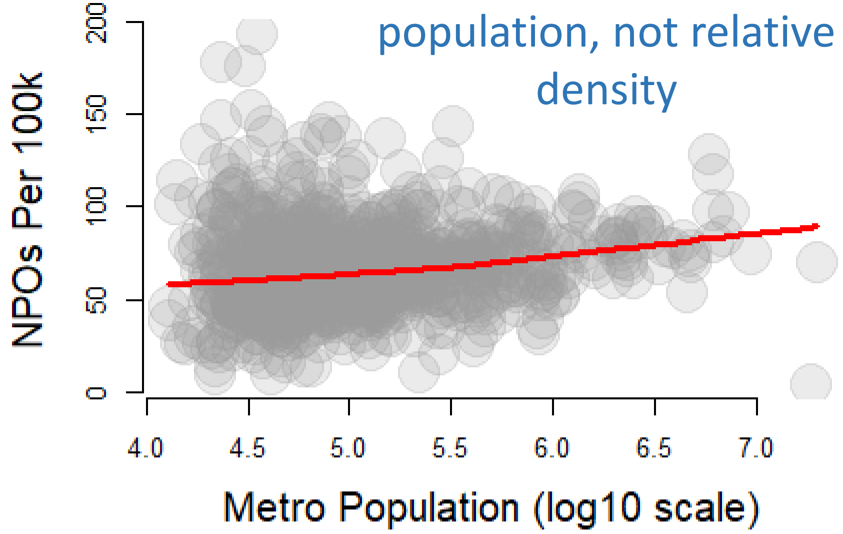
PER CAPITA MEASURES of urban performance are ubiquitous in official statistics, policy documents and in the scientific literature. For example, official statistics on **wages**, income or **gross domestic product** (GDP) compiled by governmental agencies and international bodies worldwide report on both total amounts and per capita quantities as a means to compare the economic performance of various places. Similarly, official **crime statistics** (see e.g. the FBI Uniform Crime Reports) are expressed in terms of crime rates (number of crimes per 100,000 inhabitants per year). Many other important indicators that measure local economic and social well-being, such as **unemployment rates**, **innovation rates**, **cost of living index**, morbidity and **mortality rates**, **poverty rates**, etc, all are reported on a per capita basis.

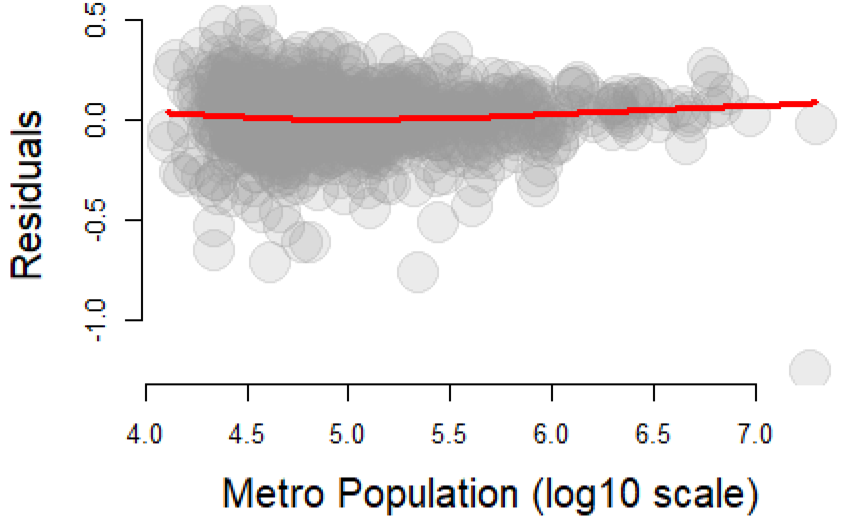
The use of per capita indicators assumes implicitly that, on average, specific urban characteristics increase linearly with population size. However, this approach is unsuitable for characterizing and comparing cities because it ignores the fundamental emergent **phenomenon of agglomeration** resulting from non-linear interactions in social dynamics and organization as cities grow. Such non-linearities are fundamental to the very existence of cities...



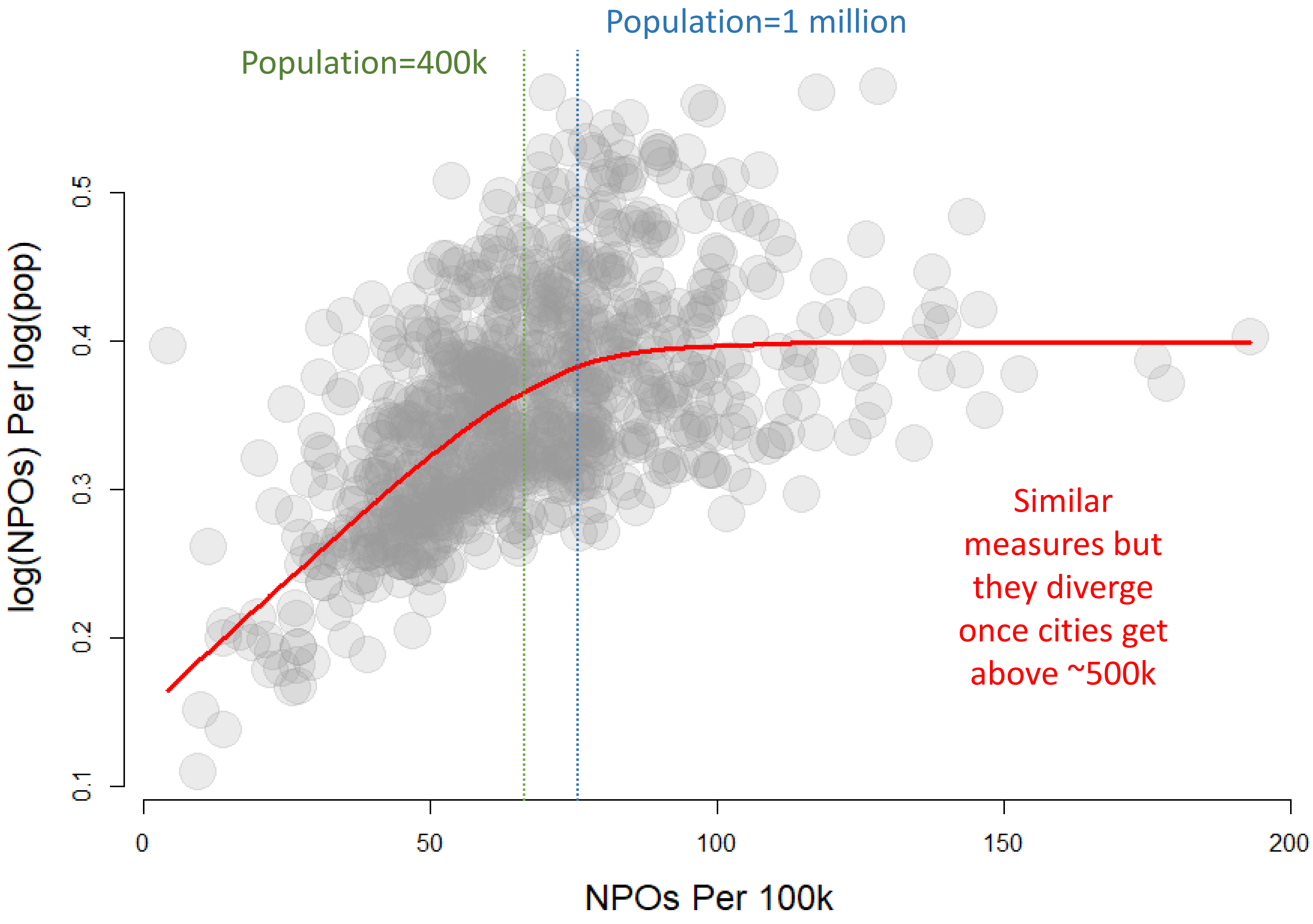


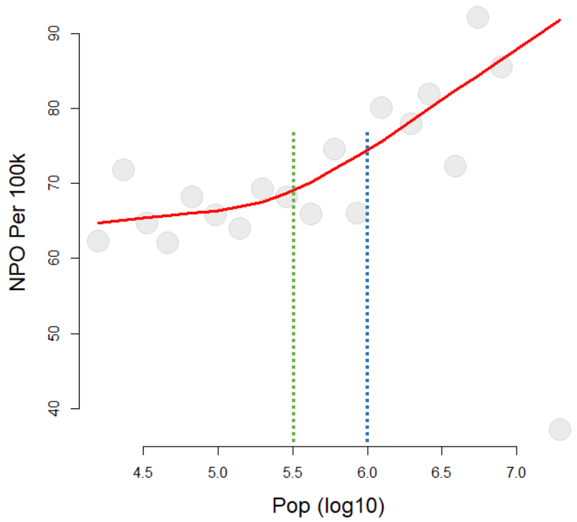
still modeling population, not relative density





population size and the density metric are uncorrelated: cleaner measure of relative density independent of population

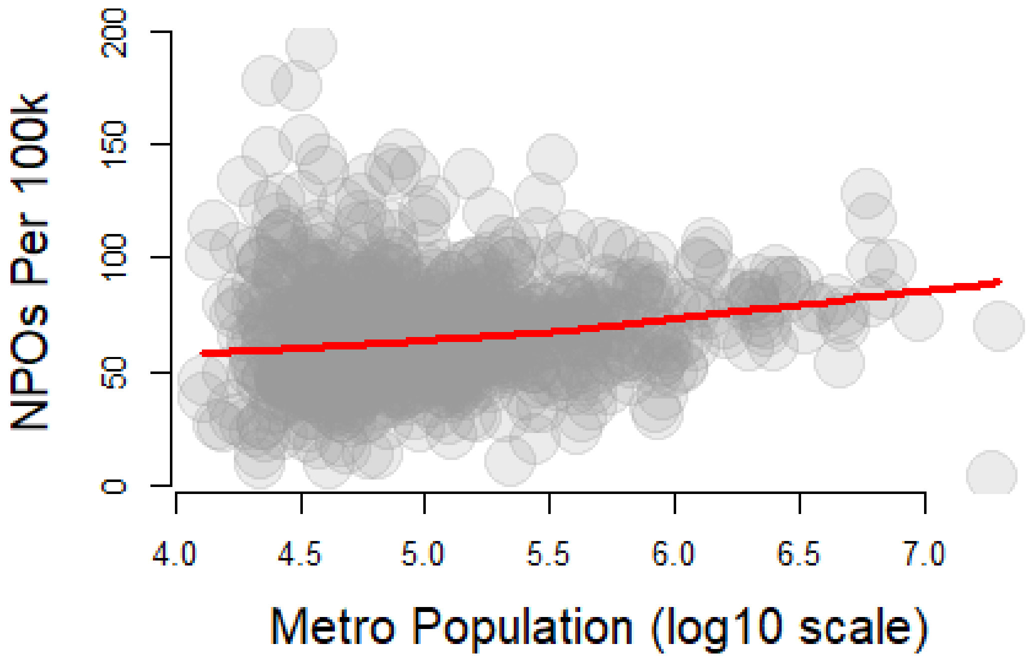




Similar measures but they diverge once cities get above ~500k

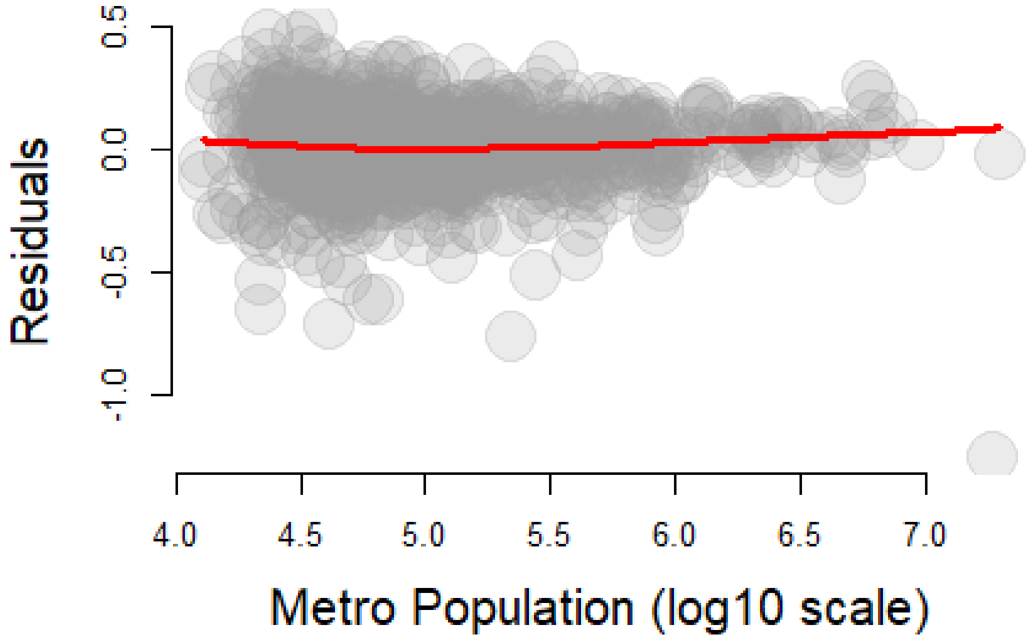
Per Capita Metric

since the metric is not independent from population we cannot compare rates across cities of different sizes



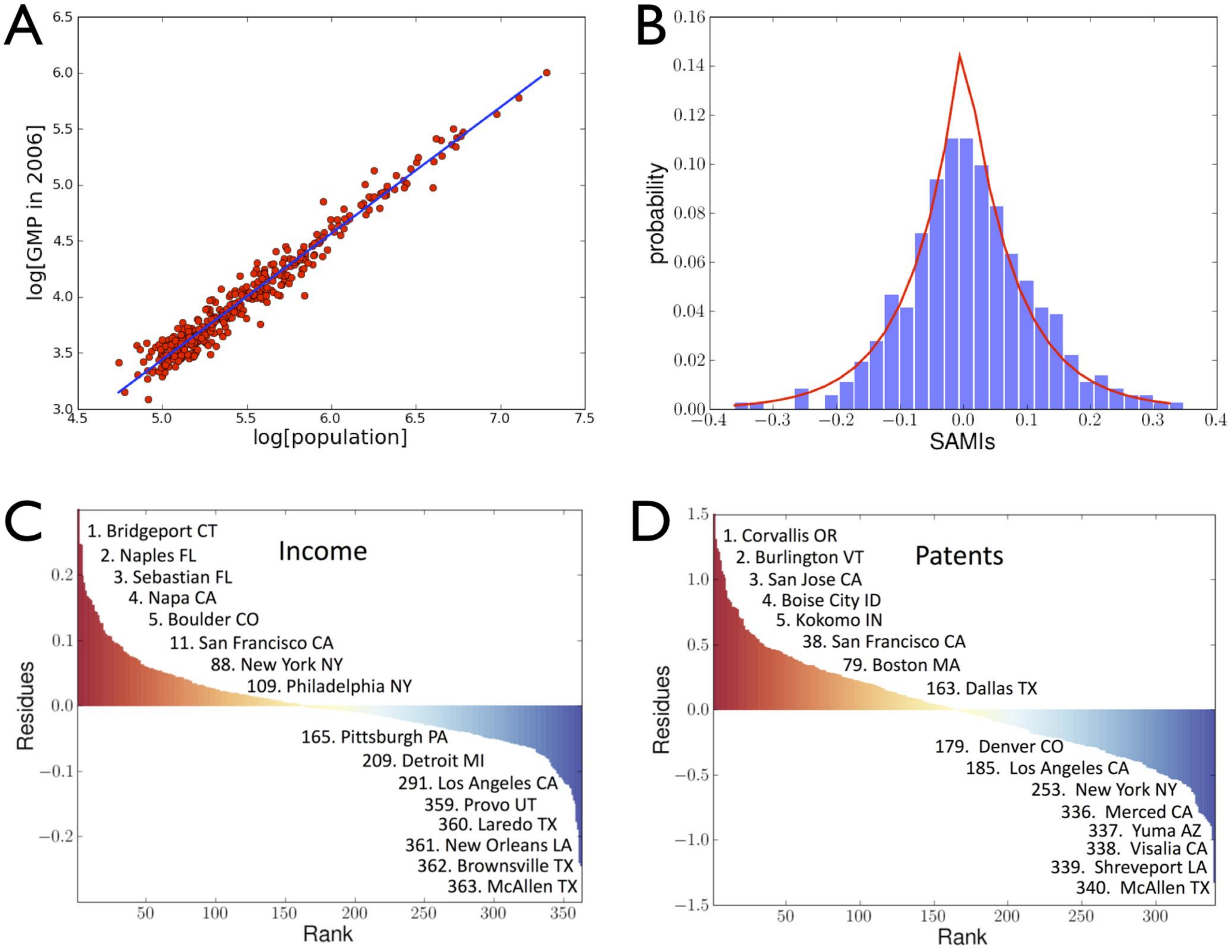
Residualized log-log Metric

population size and the density metric are uncorrelated: cleaner measure of relative density independent of population



Scale-Adjusted Metropolitan Indicators (SAMIs)

Urban Scaling and Its Deviations: Revealing the Structure of Wealth, Innovation and Crime across Cities (2010)



Scale-Adjusted Metropolitan Indicators (SAMIs) are not strongly correlated (cities don't consistently perform high or low on many categories).

Cities tend to **overperform** in some domains and **underperform** in others, and these patterns are surprisingly **independent** across categories.

CLUSTERS ONLY APPEAR WITHIN FUNCTIONAL CATEGORIES

They are modest correlations

Across clusters the SAMIs are nearly independent

INNOVATION

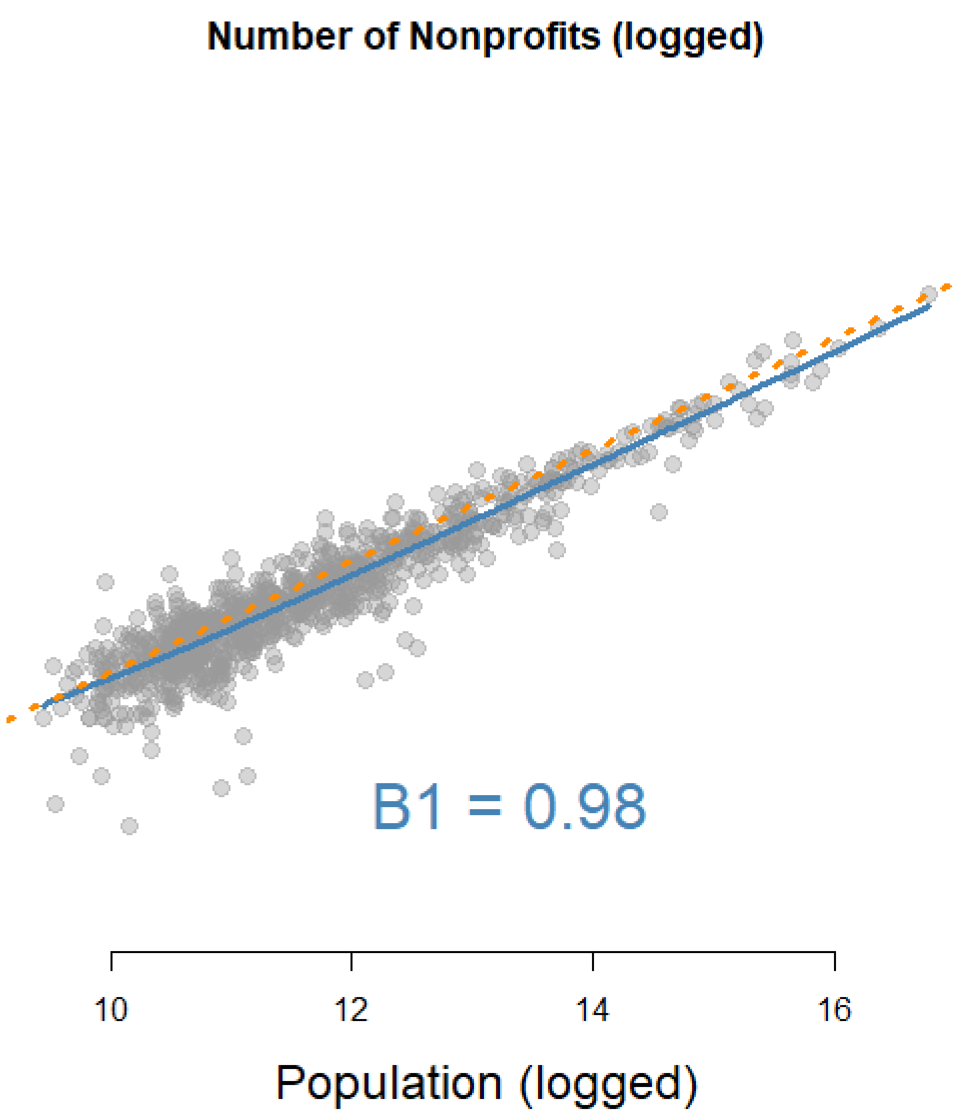
- patents
- creative occupations
- R&D jobs
- STEM industries

CRIME & SOCIAL STRESS

- violent crime
- certain property crimes
- policing intensity
- public health emergencies

CONSUMPTION & AMENITY

- restaurants
- bars
- creative arts venues
- tourism
- nightlife intensity



Counts of Nonprofits

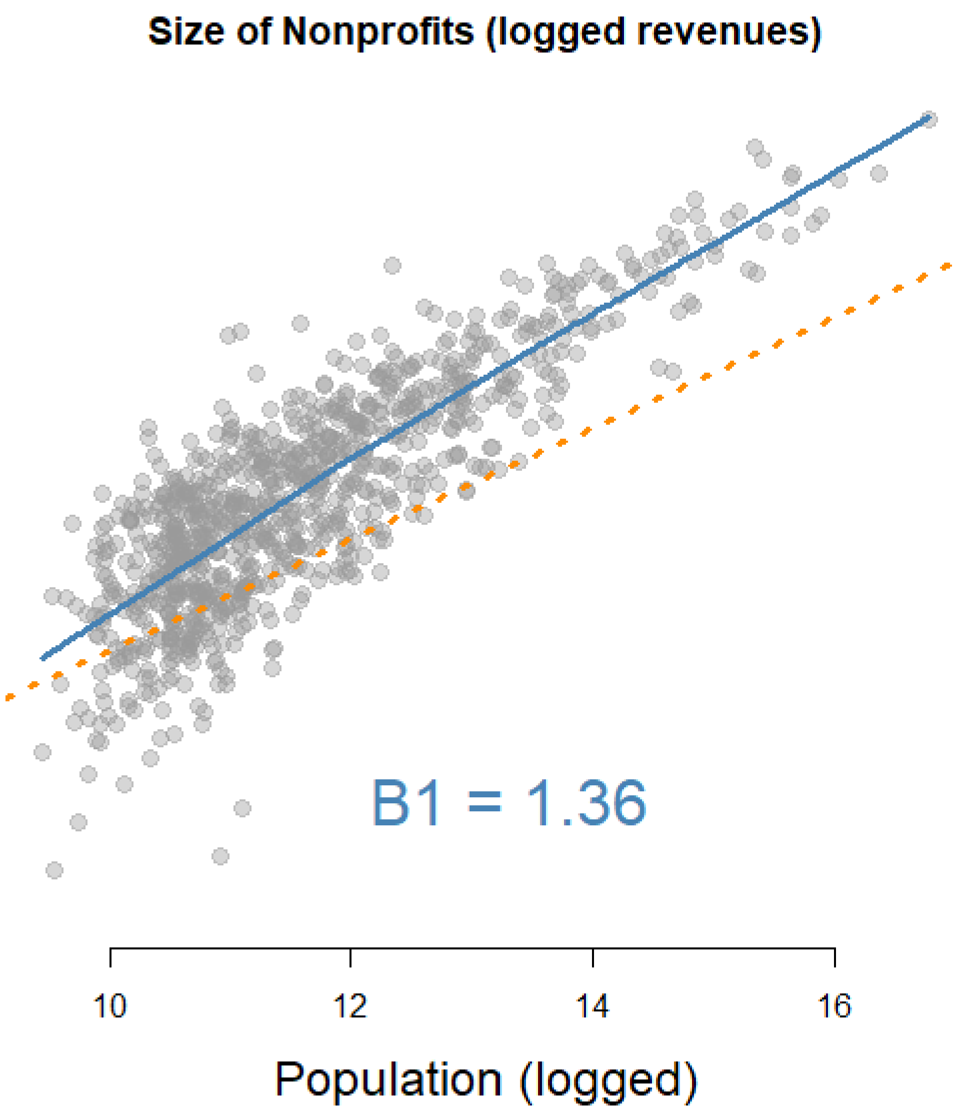
log(NP) ~ B0 + B1 x log(pop)

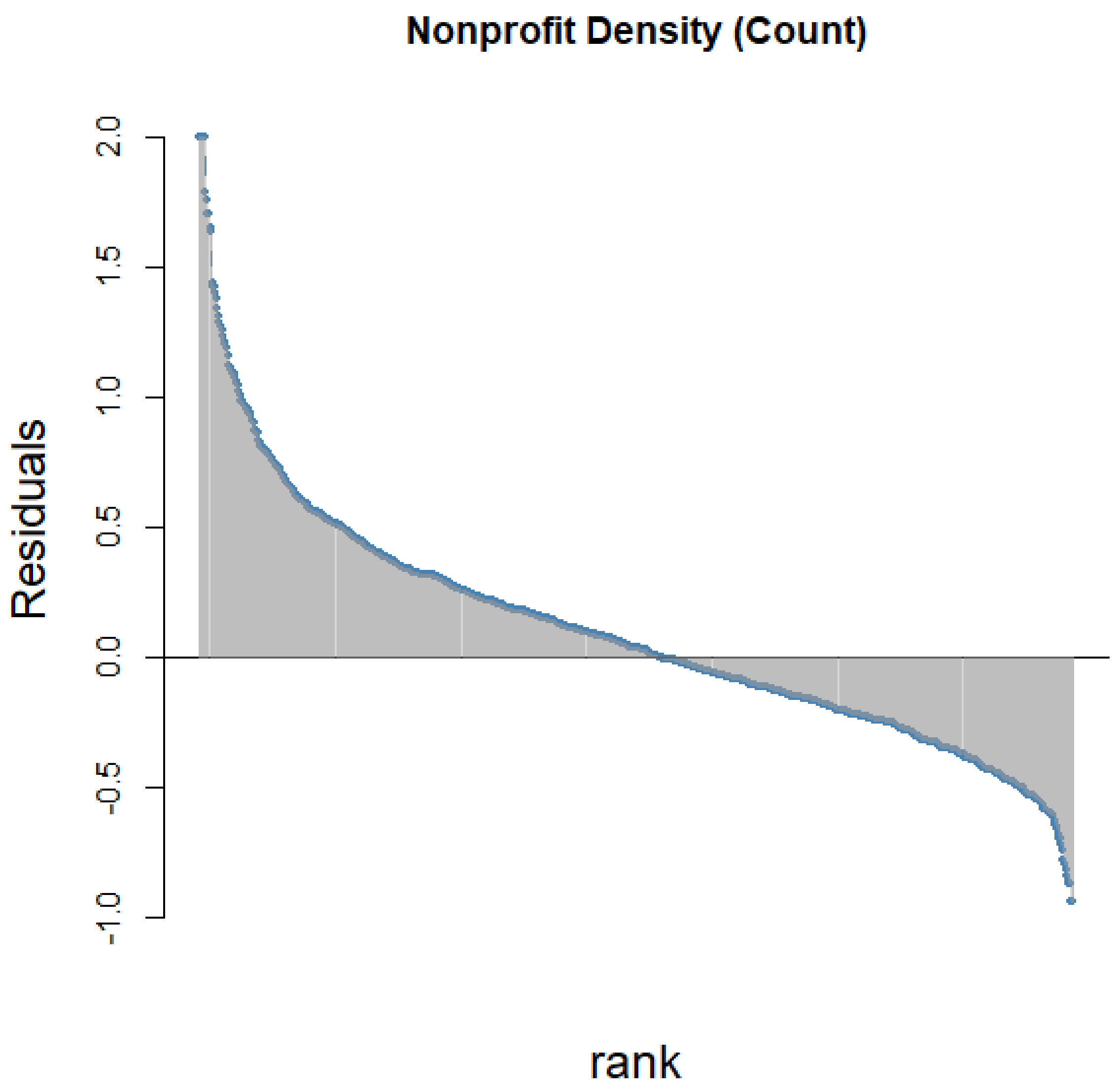
SUBSECTOR	B1
ARTS	0.92
EDUCATION	1.02
ENVIRONMENT	0.86
HEALTH	0.94
HUMAN SERV	0.94
HOSPITALS	0.50
AVERAGE	**0.96**

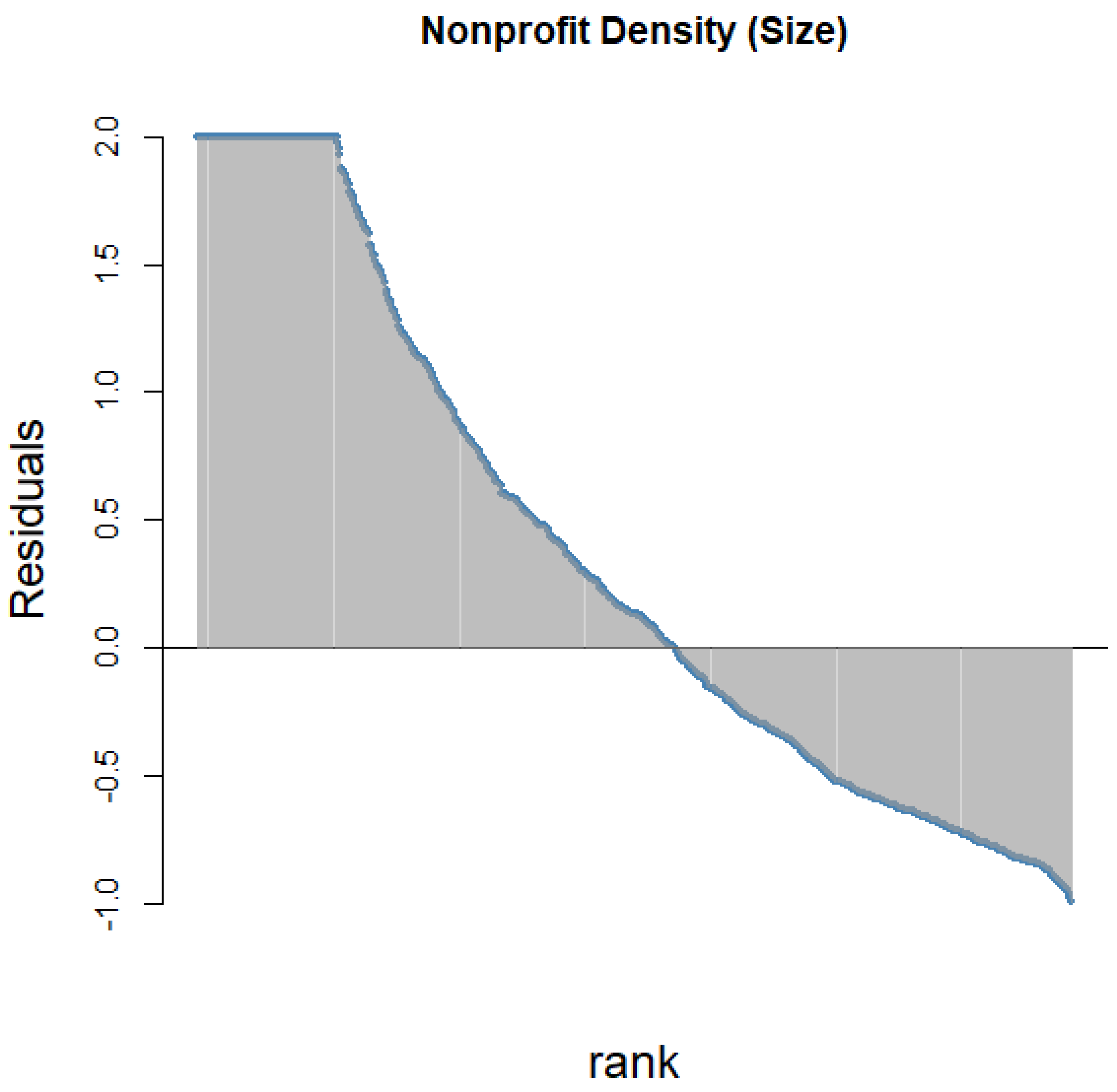
TOTAL EXPENDITURES

```
log( totexp ) = b0 + b1 log(pop)
```

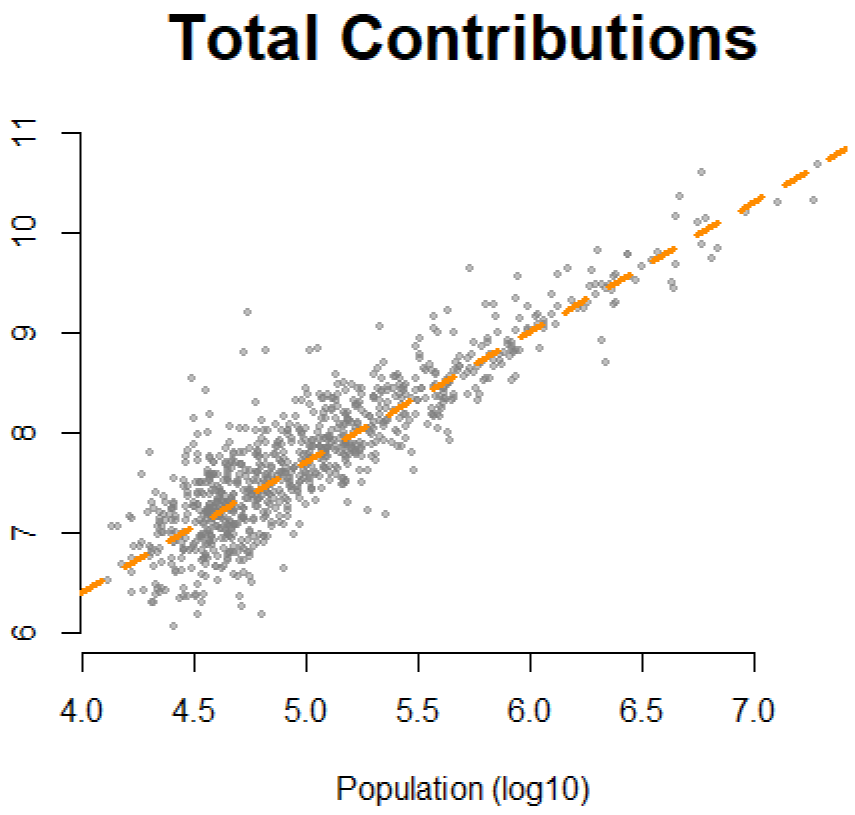
SUBSECTOR	B1
ARTS	1.44
EDUCATION	1.48
ENVIRONMENT	1.51
HEALTH	1.57
HUMAN SERVICES	1.27
HOSPITALS	1.50
AVERAGE	**1.35**

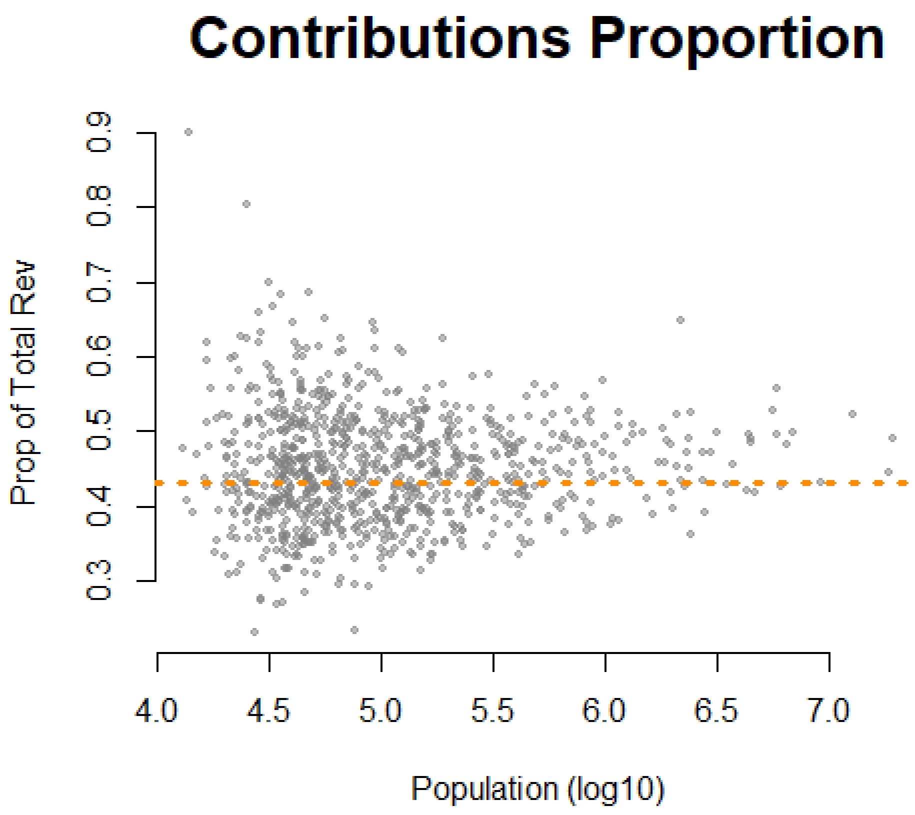



Nonprofit Density (Count)
Residuals
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
rank


Nonprofit Density (Size)
Residuals
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
rank

RESOURCE ENVIRONMENTS


Total Contributions
6
7
8
9
10
11
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Population (log10)


Contributions Proportion
Prop of Total Rev
0.3
0.4
0.5
0.6
0.7
0.8
0.9
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Population (log10)

Three Broad Classes of Scaling

1.Superlinear Scaling ($\beta > 1$)

1. Features tied to social interaction increase *more than proportionally* with population.
2. Examples: GDP, innovation (patents), R&D employment, wages, crime.
3. Interpretation: larger cities are disproportionately more productive and more innovative—but also more crime-prone.

2.Sublinear Scaling ($\beta < 1$)

1. Physical infrastructure grows *less than proportionally* with population.
2. Examples: length of roads, gas stations, electrical cables, gasoline consumption.
3. Interpretation: larger cities achieve **increasing returns to scale** in infrastructure → they are more efficient.

3.Linear Scaling ($\beta \approx 1$)

1. Individual human needs scale proportionally.
2. Examples: household water use, total employment.
3. Interpretation: some quantities simply follow population.

Infrastructure Efficiency Is a Network Phenomenon

Sublinear scaling for infrastructure is not “nice to have” but structurally required:

- Larger cities wire and connect more efficiently.
- The total length of infrastructure networks (roads, pipes, cables) grows roughly with population to the **3/4 power**.
- This parallels biological organisms, where metabolic networks scale sublinearly.

Insight:

Cities demonstrate **economies of scale** in their physical networks, enabling high densities of population to exist at lower per-capita infrastructure cost.

Innovation and Growth Accelerate as Cities Grow — But So Do Their Problems
Core paradox:
“The very same factors that produce increased productivity and creativity also produce increased crime, disease, and inequality.”
Cities turbocharge:
•Innovation
•Wage growth
•Scientific output
•Entrepreneurship
•Cultural production
But the same scaling processes also yield:
•Crime increases superlinearly
•Infectious disease spreads more rapidly
•Housing costs rise disproportionately
•Social inequality grows
Insight:
Cities produce **good and bad** at increasing rates, driven by the same underlying mathematics.

to equilibrium; they must grow or they stagnate.

Implications:

•Cities require continuous **innovation** to avoid collapse (“Red Queen effect”).

•They behave like **open systems** with constant energy, material, and information throughput.

•Economic growth is tied to sustaining socially-driven superlinear returns.

Insight:

Urban systems survive by maintaining a pace of innovation that matches the accelerating growth of their social networks.

6. Failures and Crises Are Predictable Features of Scaling

Bettencourt West argue that scaling predicts **increasingly frequent crises** unless innovation offsets them.

Examples:

•Housing affordability crises

•Infrastructure congestion

•Epidemics

•Crime spikes

•Energy demands

Cities must innovate **faster** the larger they get to stay ahead of systemic pressures.

Insight:

7. Urban Growth, Pace of Life, and Tempo Accelerate with Size

Empirical data show larger cities:

- Move faster
- Innovate faster
- See higher pace of daily rhythms
- Exhibit faster turnover in cultural trends

Quantitative finding:

Choreographed aspects of life (walking speed, tempo of interactions) scale superlinearly.

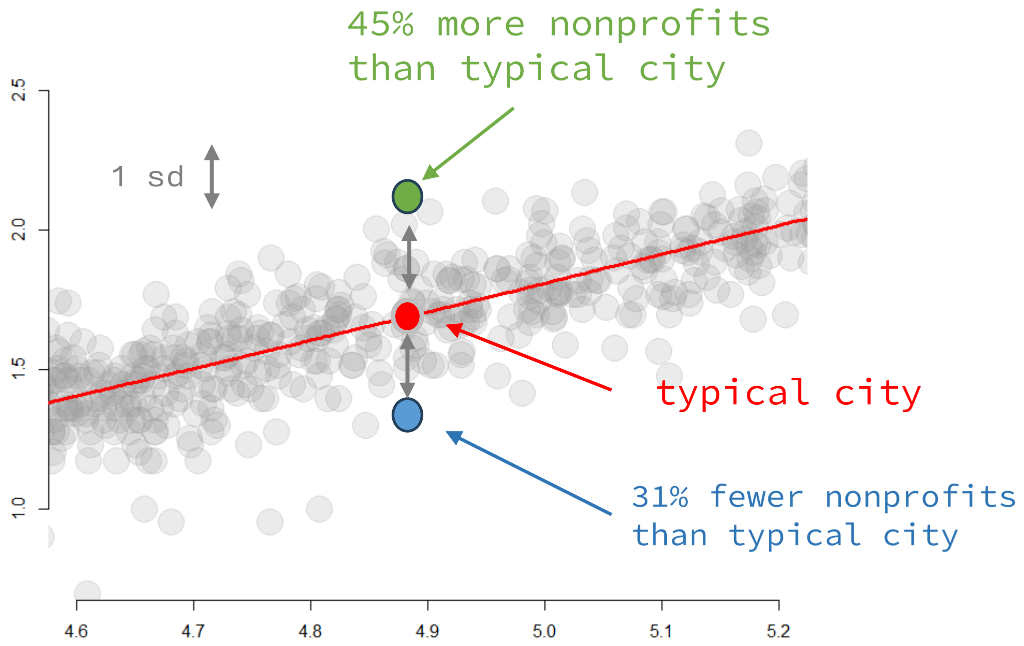
Insight:

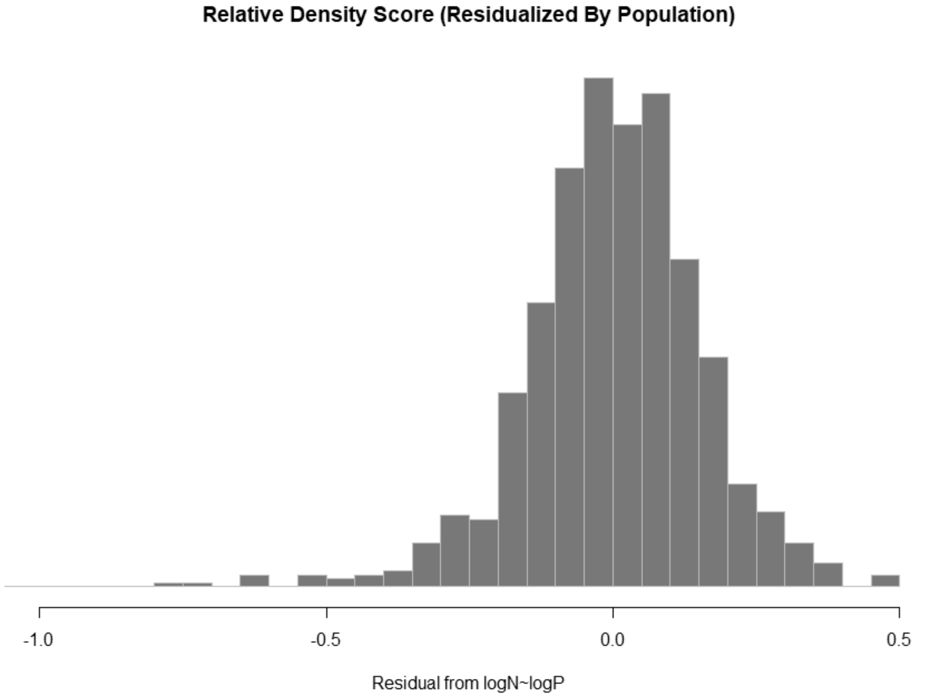
The “pace of life” empirically increases with city size — a measurable acceleration of human activity.

	popM	low	ave	high	low.ratio	high.ratio
1	0.01	4	6	9	0.67	1.50
2	0.03	14	20	28	0.70	1.40
3	0.10	44	64	93	0.69	1.45
4	0.32	144	209	302	0.69	1.44
5	1.00	470	679	982	0.69	1.45
6	3.16	1529	2211	3195	0.69	1.45
7	10.00	4977	7194	10399	0.69	1.45

log10(Num NPO) = -3.318 + 1.025•log10(pop)

sd(residual) = 0.15

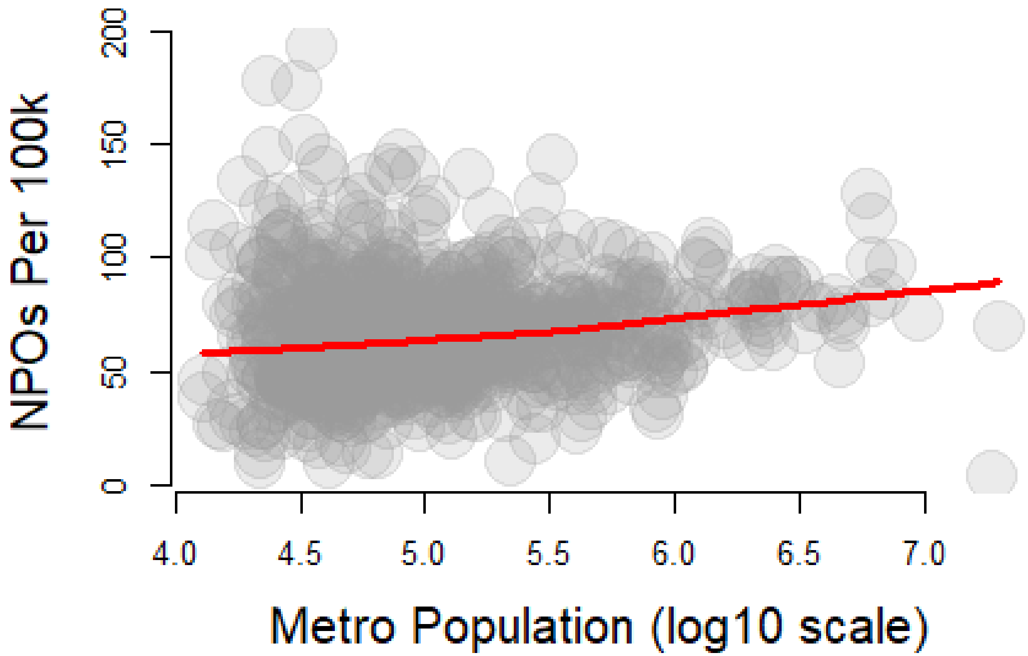





```
> summary( dd2$residuals )
     Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
-1.252324 -0.086992  0.008122  0.000000  0.095839  0.495278
```

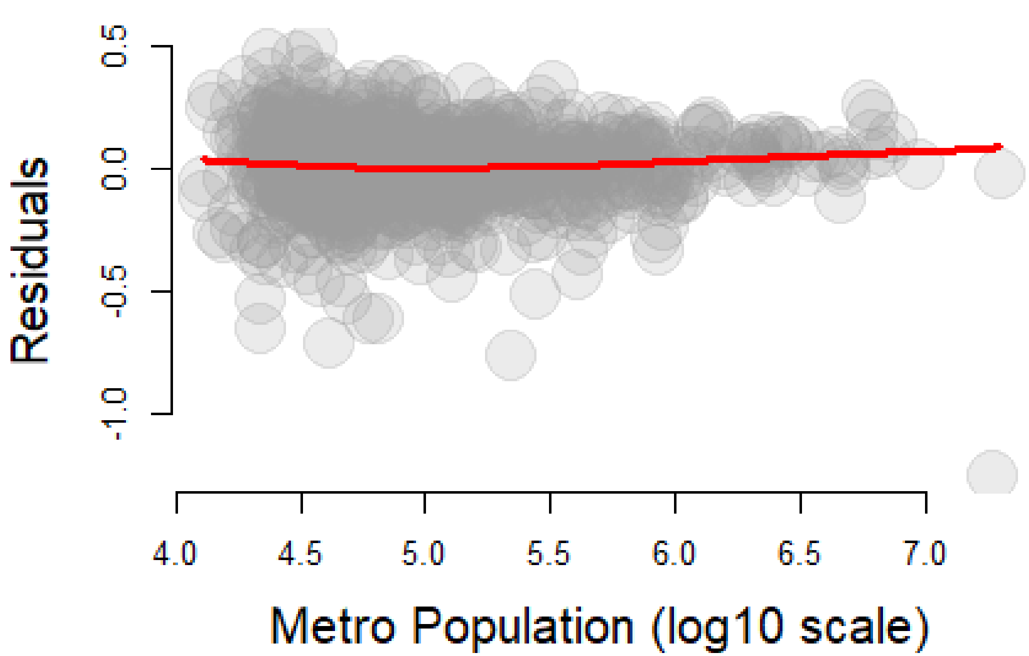
Per Capita Metric

since the metric is not independent from population we cannot compare rates across cities of different sizes



Residualized log-log Metric

population size and the density metric are uncorrelated: cleaner measure of relative density independent of population



Per Capita Metric

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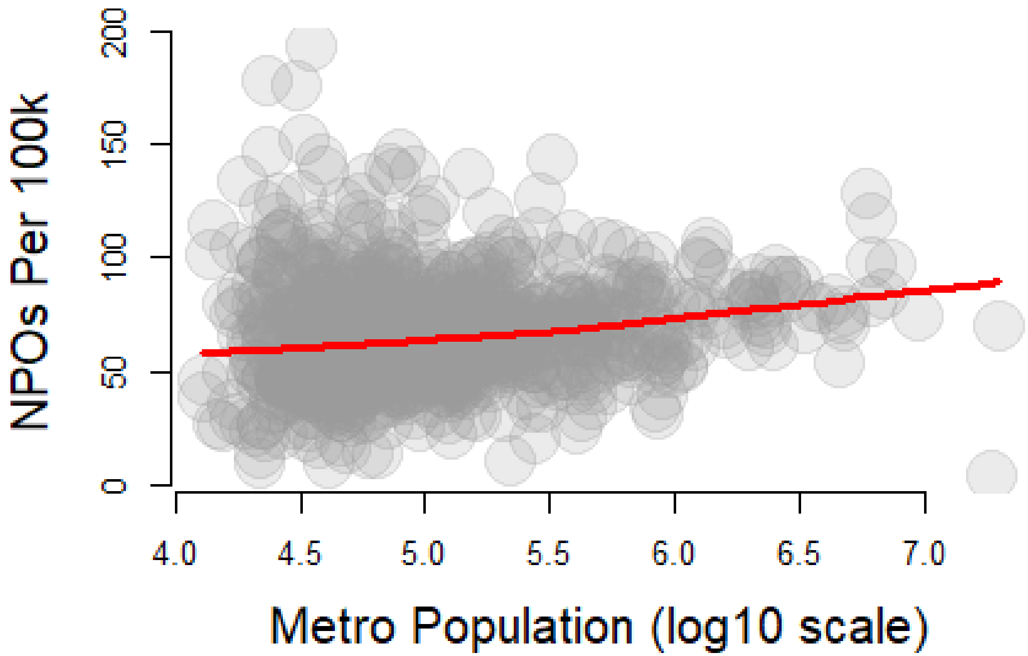
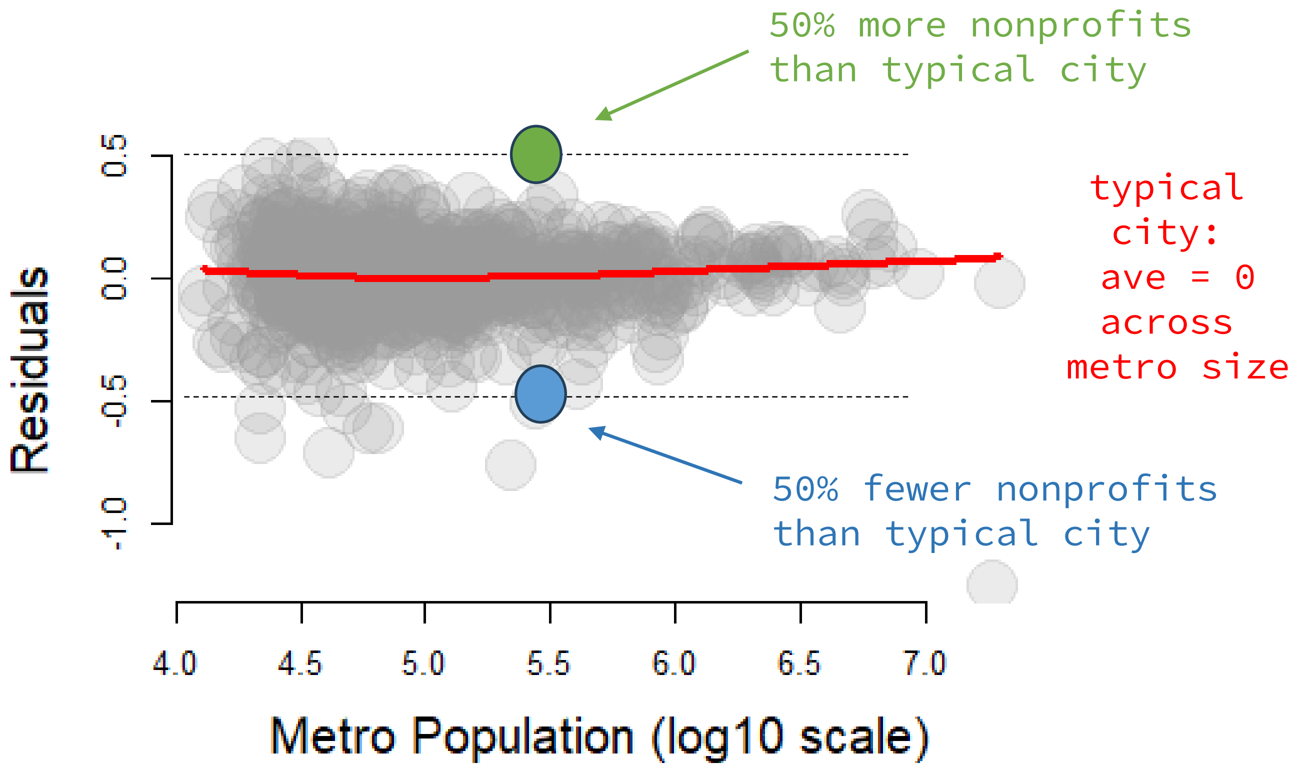


Residualized log-log Metric

population size and the density metric are uncorrelated: cleaner measure of relative density independent of population



HOW DO FIRMS SCALE?

Type of Industry	Scaling Exponent (β)	Why?
Knowledge, innovation, professional services	Superlinear (1.1–1.3)	Productivity from social interactions
Consumption-based retail & restaurants	Linear (~1.0)	Proportional to population
Infrastructure & spatial industries	Sublinear (0.8–0.95)	Economies of scale, shared networks

Sectors That Scale *Superlinearly* (β > 1)
These are sectors that benefit from dense social interaction, knowledge spillovers, agglomeration economies, and diverse networks.

Innovation & Knowledge Industries (β ≈ 1.1–1.3)
- R&D firms
- Software companies
- Biotechnology
- Semiconductors
- Scientific services
- Engineering consulting
- Architecture & design firms
- Creative industries (film, music, arts)
- Professional services (legal, finance, advertising)

Why superlinear?
These sectors depend on **idea recombination**, talent pooling, and frequent face-to-face interactions—all of which accelerate with population.

Examples (empirical β values):
- R&D establishments: **β ≈ 1.25**
- High-tech firms: **β ≈ 1.20**
- Creative industries: **β ≈ 1.15–1.20**
- Finance/insurance: **β ≈ 1.10–1.15**

Sectors That Scale *Sublinearly* (β < 1)
These industries rely heavily on **land**, **transport networks**, or **energy**, where large cities share infrastructure efficiently or reduce relative demand.

Infrastructure & Utility-Intensive Sectors (β ≈ 0.8–0.95)
- Warehouses
- Logistics hubs
- Manufacturing plants
- Construction supply firms
- Gas stations
- Utilities (water, waste, power)
- Mining, extraction, primary industries

Why sublinear?
Bigger cities use infrastructure more efficiently and centralize activity, so you need **fewer establishments per capita**.

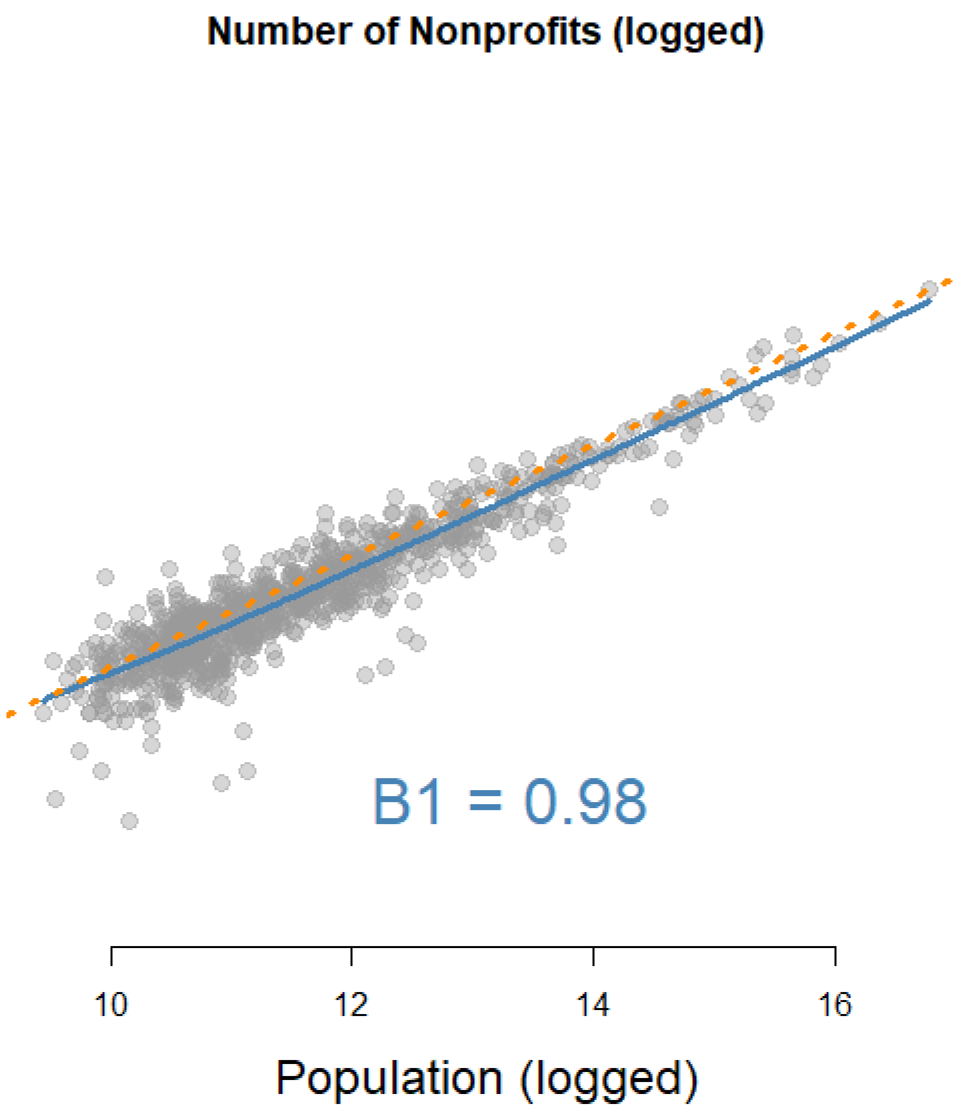
Examples (empirical β values):
- Gas stations: **β ≈ 0.85**
- Manufacturing establishments: **β ≈ 0.92**
- Warehouses: **β ≈ 0.90**
- Electric/water utilities: **β ≈ 0.85**

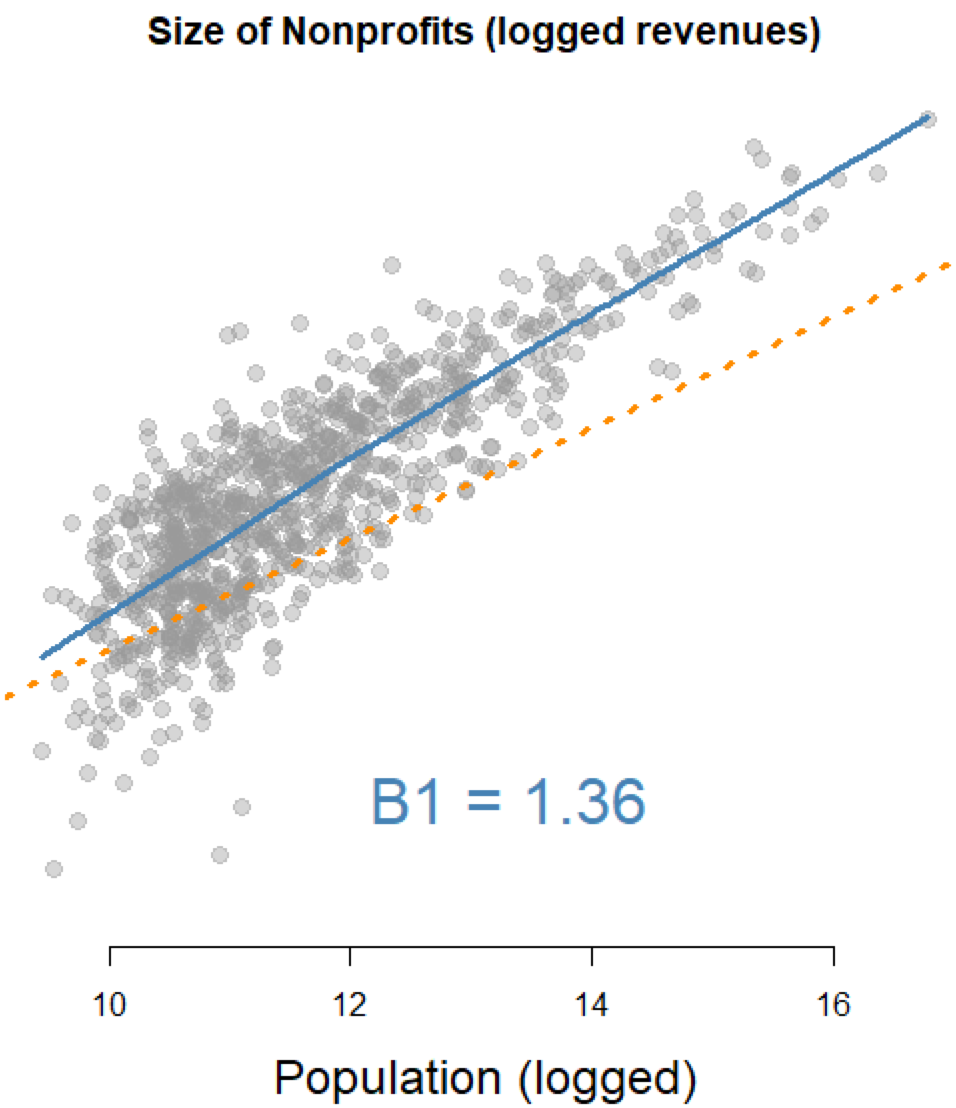
Sectors That Scale *Linearly* (β ≈ 1.0)
These depend on **per-capita consumption** and basic household demand rather than network effects.

Consumption Services (β ≈ 1.0)
•Restaurants
•Cafes, bars (sometimes slightly > 1 due to nightlife)
•Grocery stores
•Pharmacies
•Big-box retail
•Personal services (salons, laundromats)

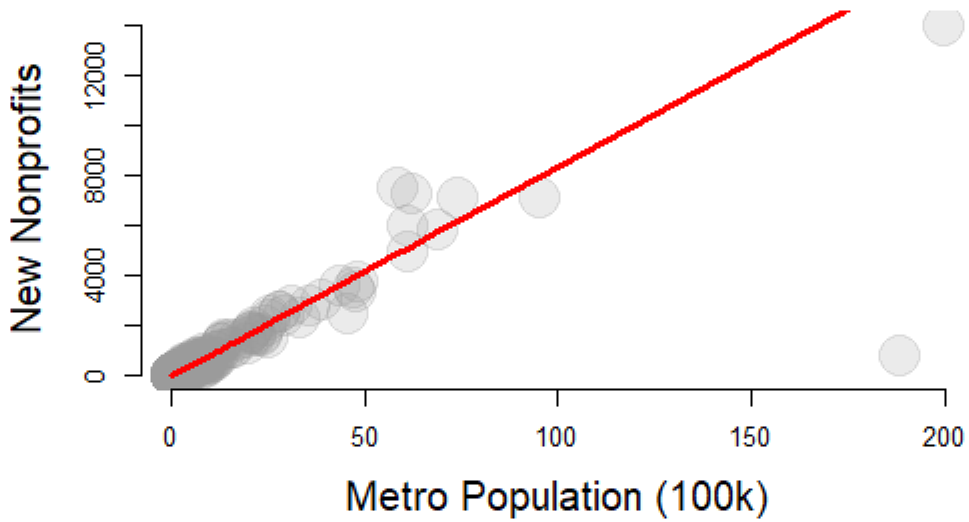
Restaurants scale **almost exactly linearly** because each person eats roughly the same amount regardless of city size.

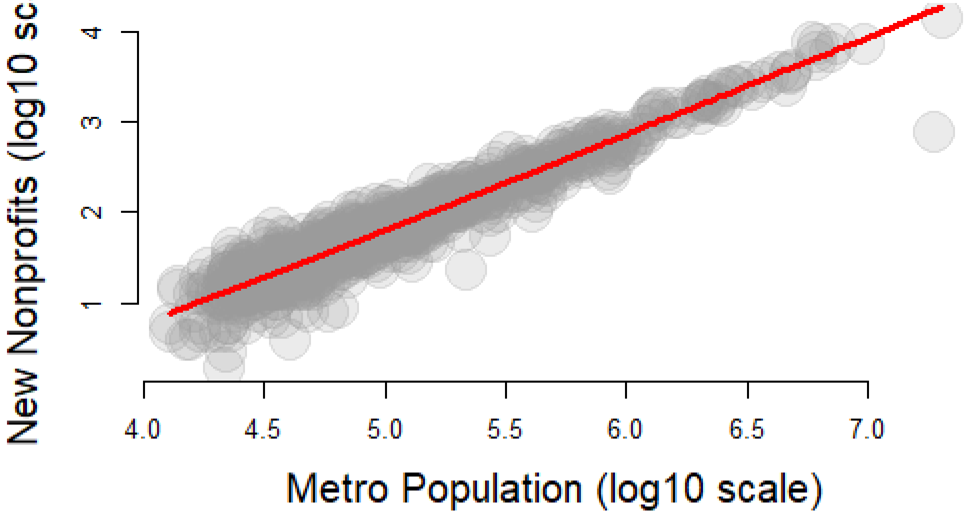
Why linear?
These businesses serve **individual needs**, not social interaction networks.

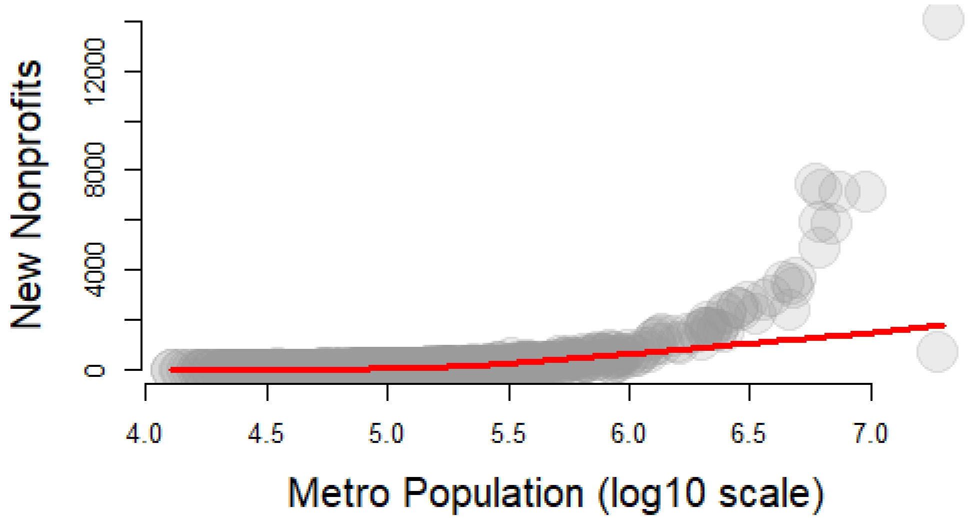

Number of Nonprofits (logged)
B1 = 0.98
10
12
14
16
Population (logged)

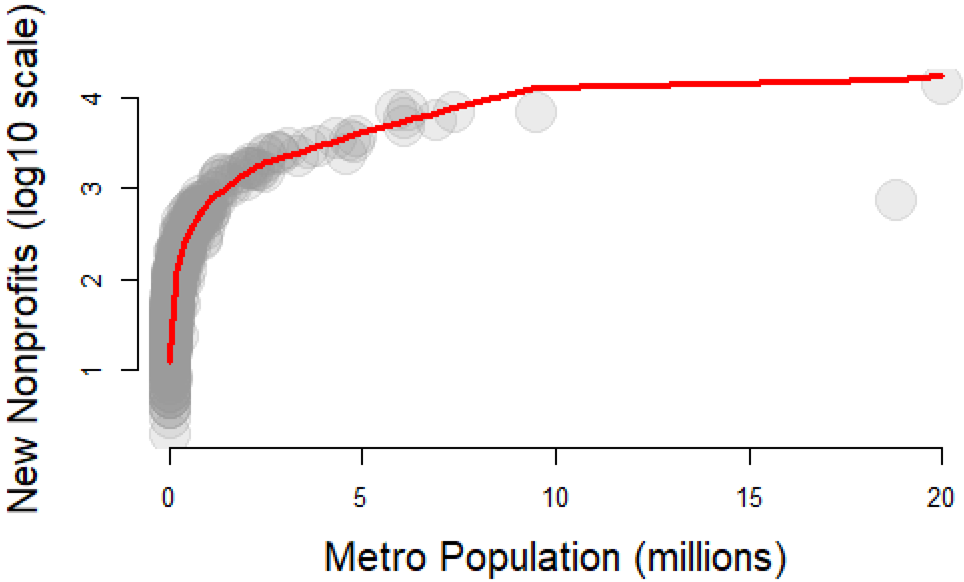

Size of Nonprofits (logged revenues)
B1 = 1.36
10
12
14
16
Population (logged)

BEST WAY TO NORMALIZE?









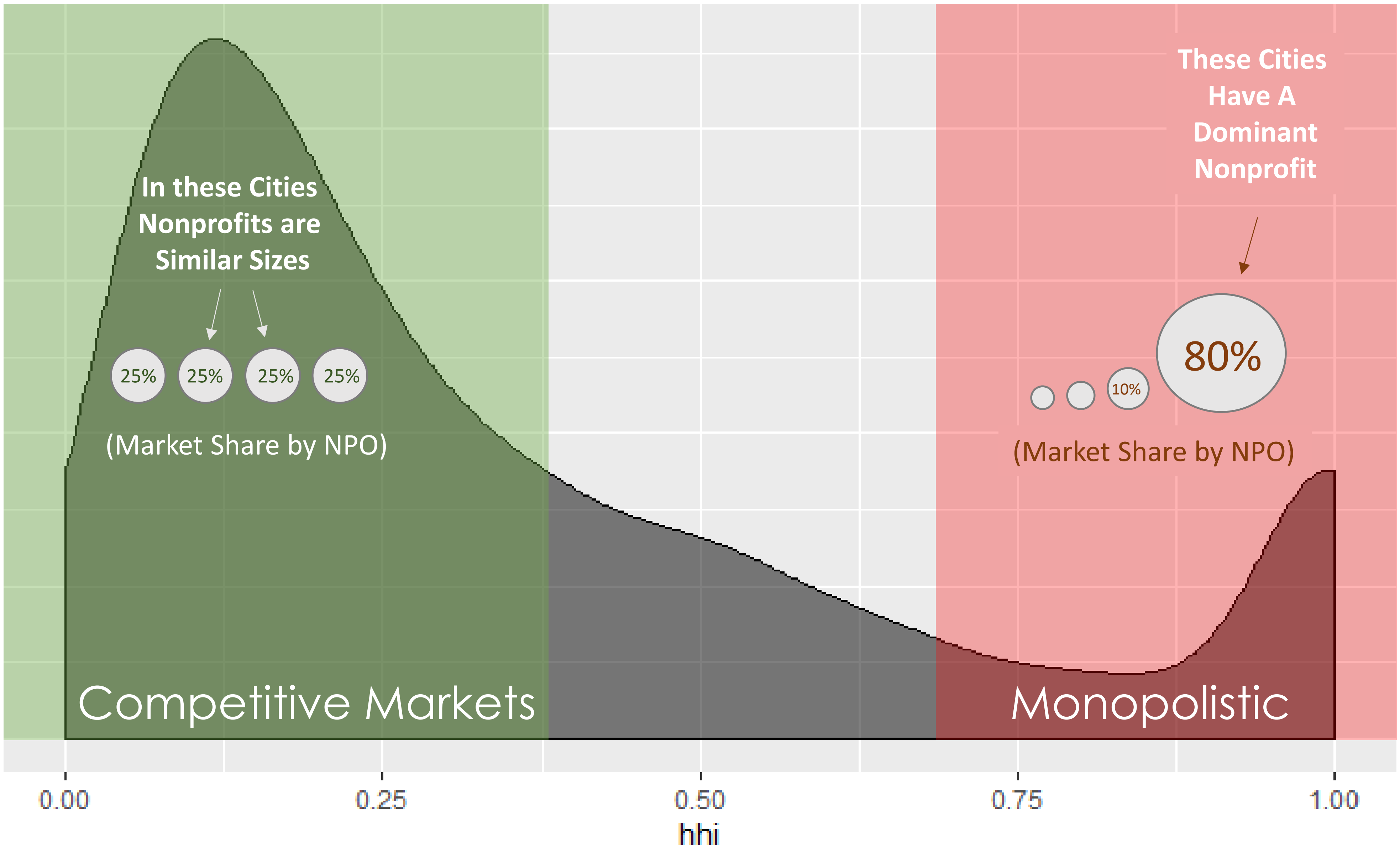
Market Competition Metrics
Market = MSA + NTEE

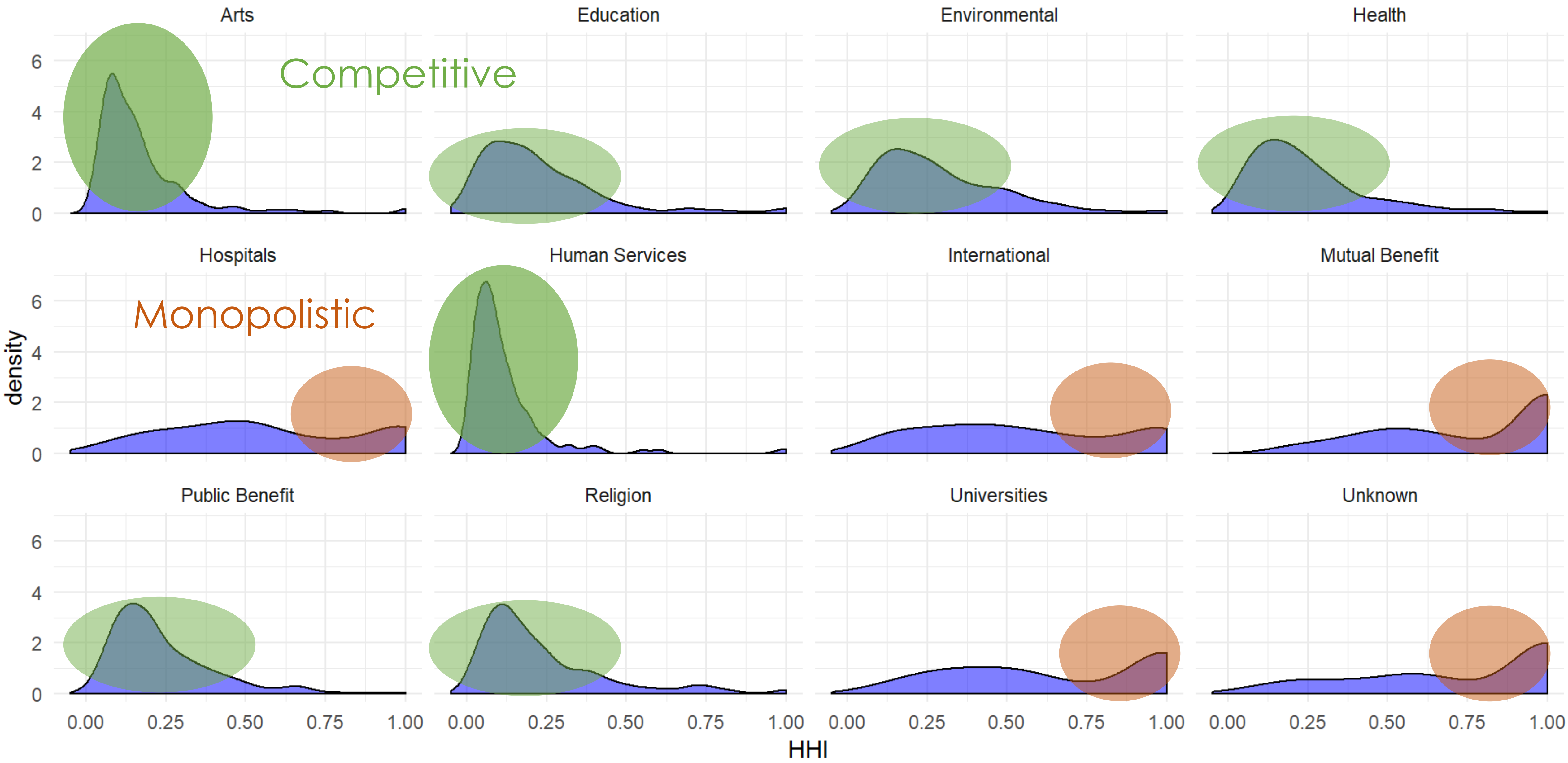
MARKET COMPETITION METRICS

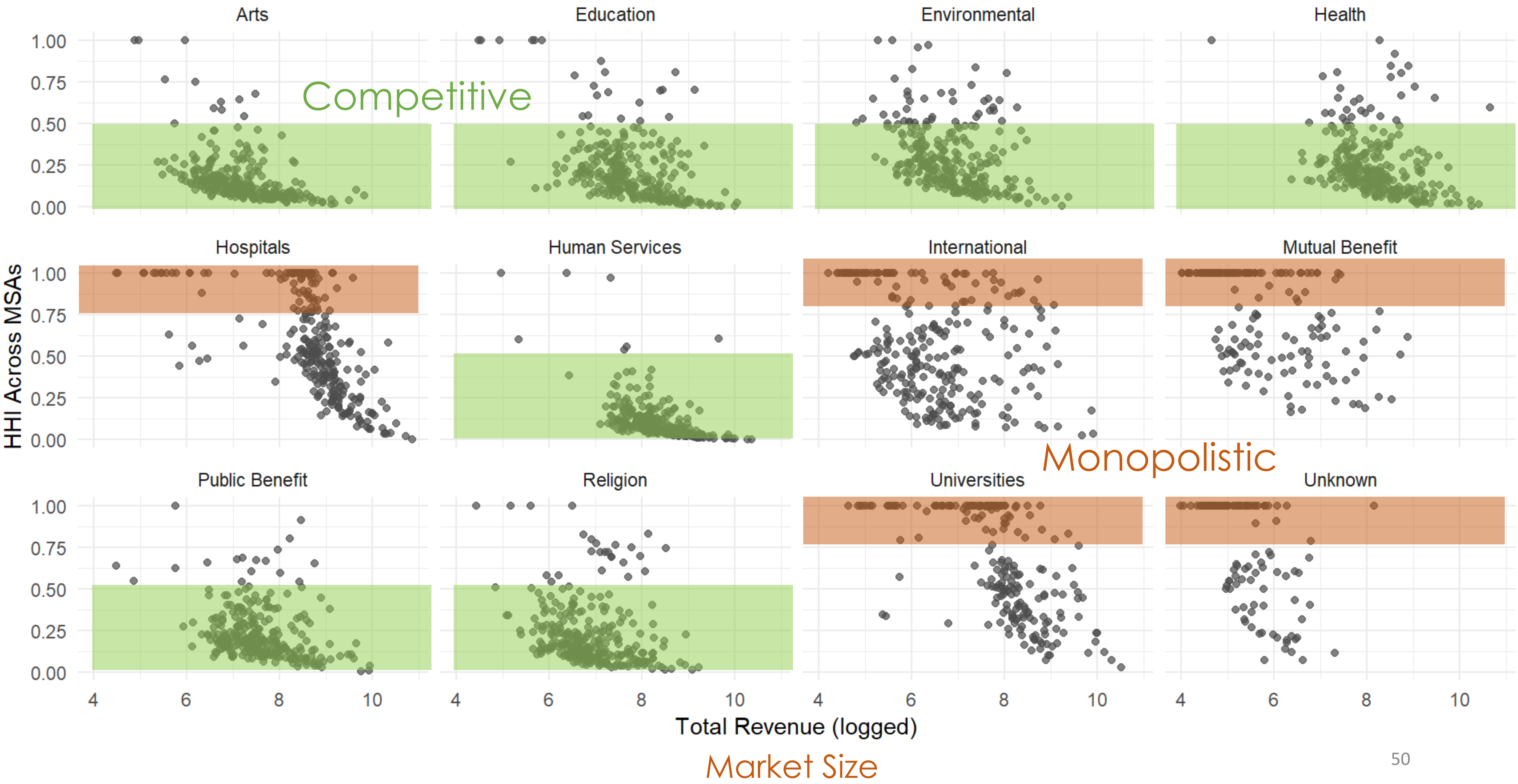
285 MSAs + 12 NTEE Categories = 2,979 “markets” examined

1. HHI
2. CR4 – four-firm competition ratio
3. Kwoke index – HHI of three largest firms in market
4. Gini coefficient
5. Density – number of nonprofits
6. Demand density – number of nonprofits / 10,000 people
7. Big Dog Ratio (# orgs rev > $1m / # orgs)
8. Little Pup Ratio (# orgs rev < $100k / # orgs)
9. Density of commercial nonprofits
10. Resource availability index (total rev / # orgs – ave size of org in market)
11. Fundraising efficiency for NPs with > $1m in revenue
12. Ave fiscal health in market
13. Ave growth rate in market
14. Growth equity: ave growth rate top quintile / ave growth rate smallest quintile
15. Birth rates (rate of new org formation) [should this be new orgs / current, or new orgs per 10k people?
16. Five-year “smallness” index
17. Death rate (rate of closure) [closures per 10k people? What is expected rate?]
18. Five-year closure rate
19. Philanthropic capital
20. Generosity index

Distribution of HHI Metrics Across 285 Metro Areas

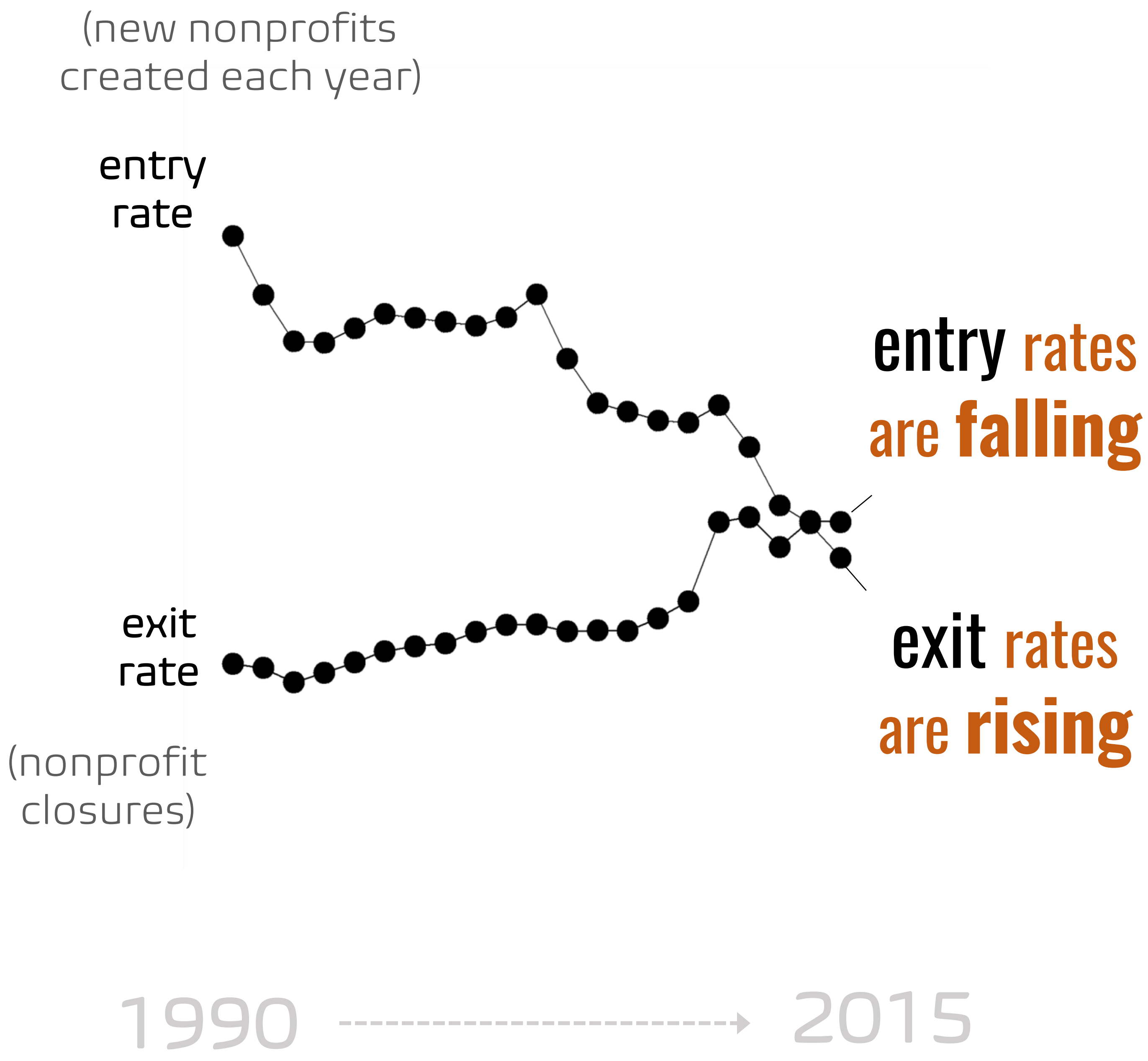



Arts
Education
Environmental
Health
Competitive
Hospitals
Human Services
International
Mutual Benefit
Monopolistic
Public Benefit
Religion
Universities
Unknown
density
HHI
0
2
4
6
0.00
0.25
0.50
0.75
1.00

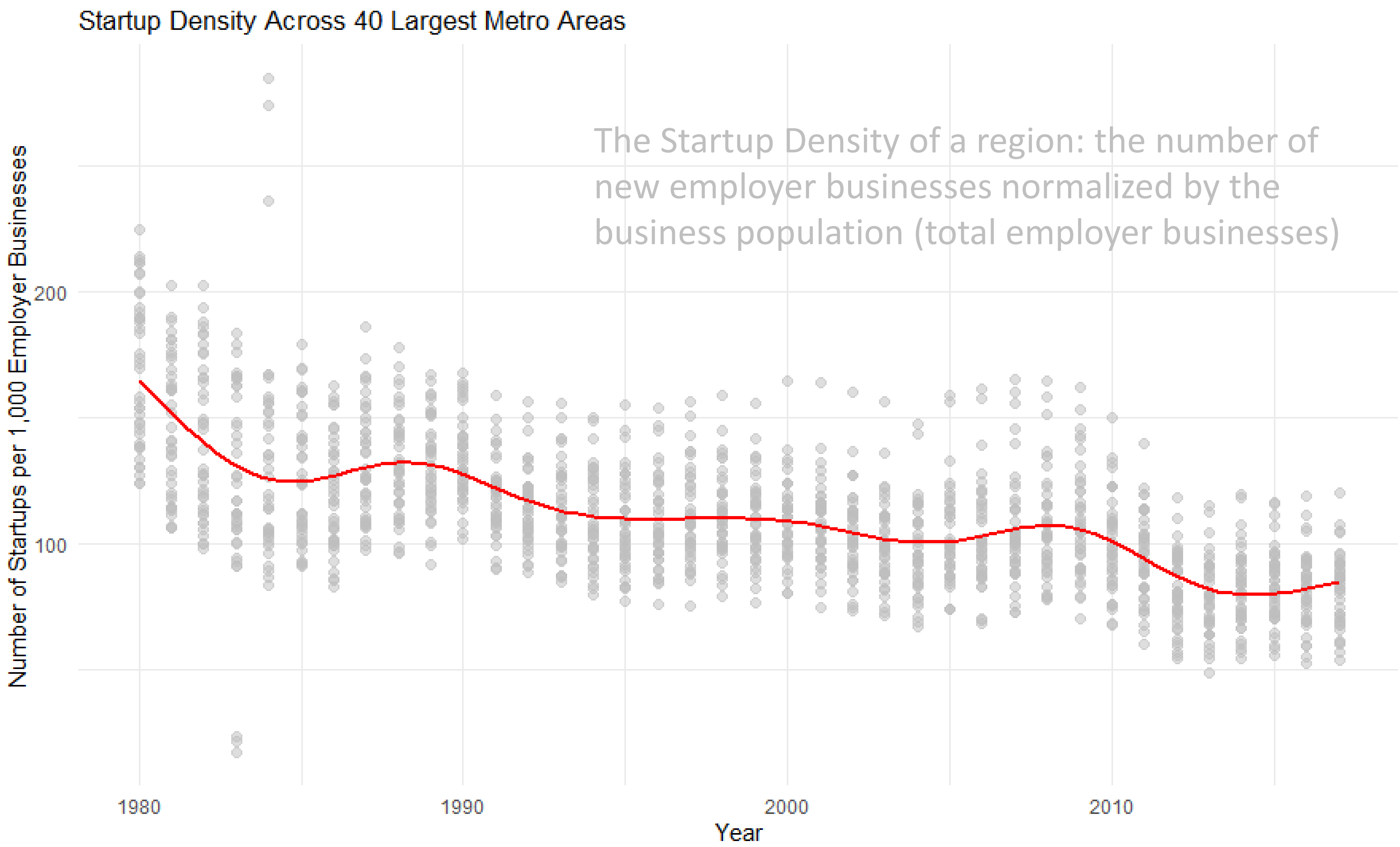

Arts
Education
Environmental
Health
Hospitals
Human Services
International
Mutual Benefit
Public Benefit
Religion
Universities
Unknown
Competitive
Monopolistic
HHI Across MSAs
Total Revenue (logged)
Market Size

MOTIVATION:

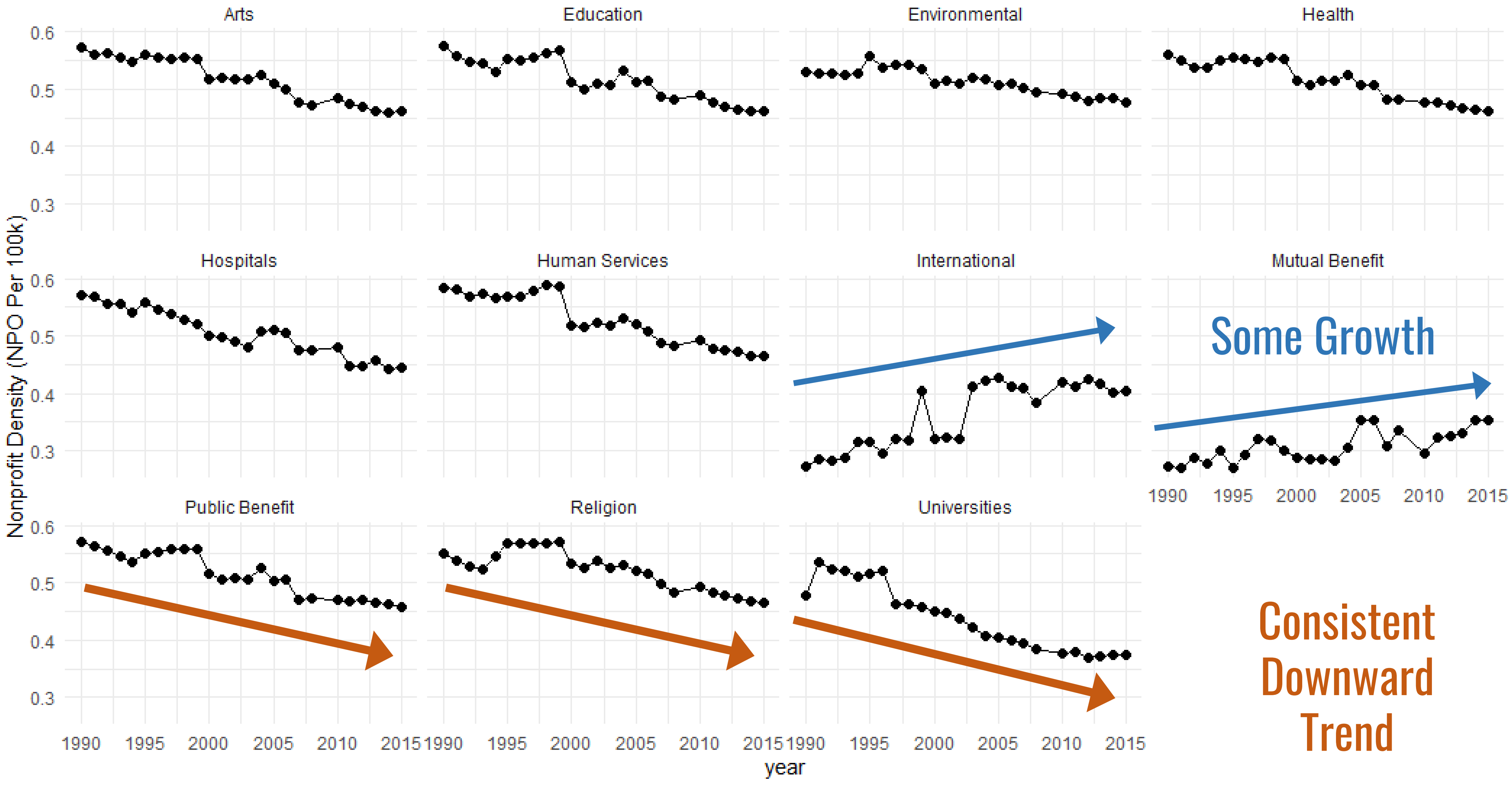
Are we at a tipping point in the growth of the US Nonprofit Sector?



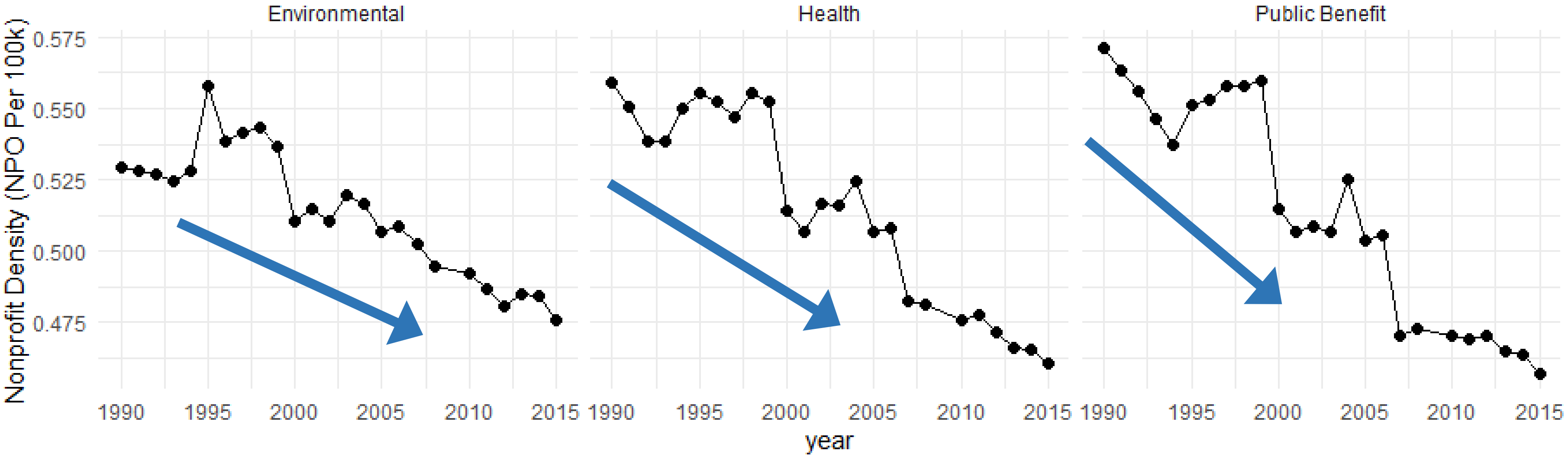
CHANGE IN FOR-PROFIT STARTUP DENSITY



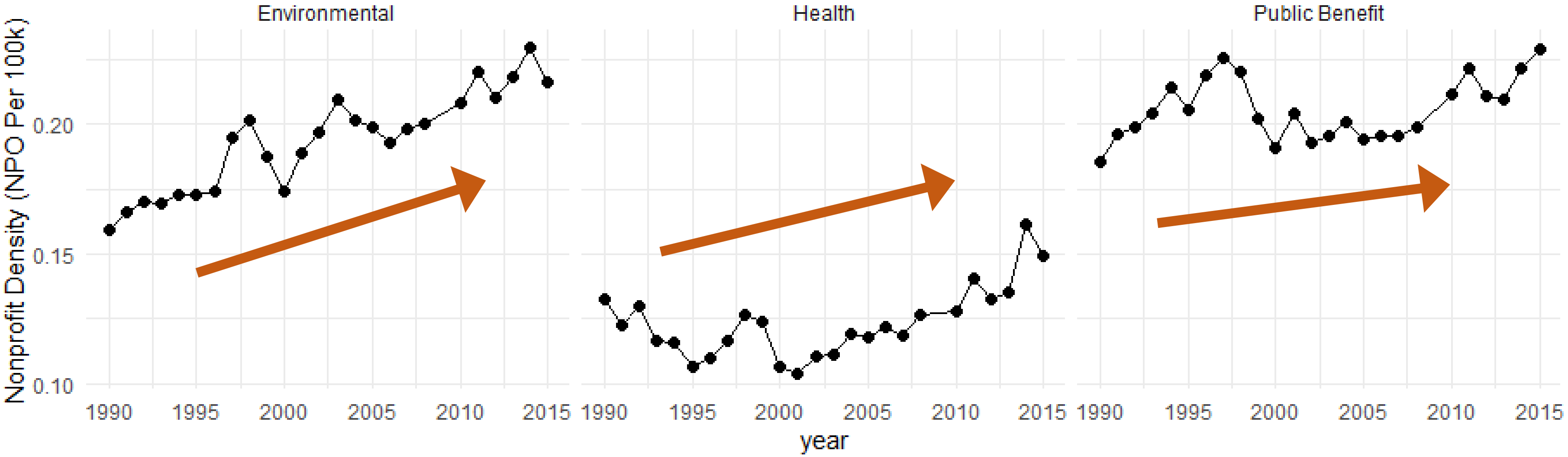
CHANGE IN NONPROFIT DENSITY: NPOs PER 100K



TOTAL DENSITY VS SMALL NONPROFIT DENSITY

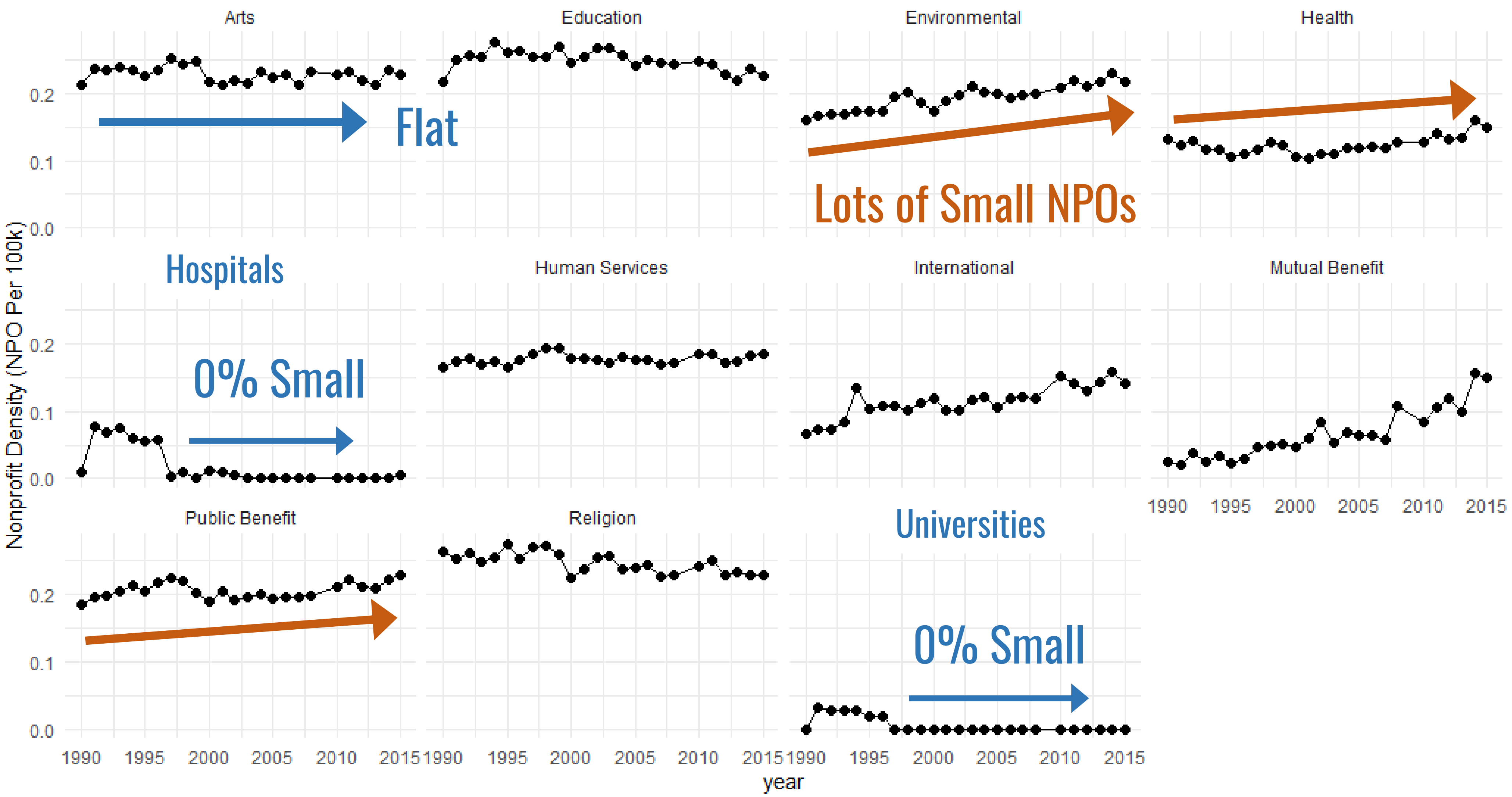


Fall in OVERALL Density

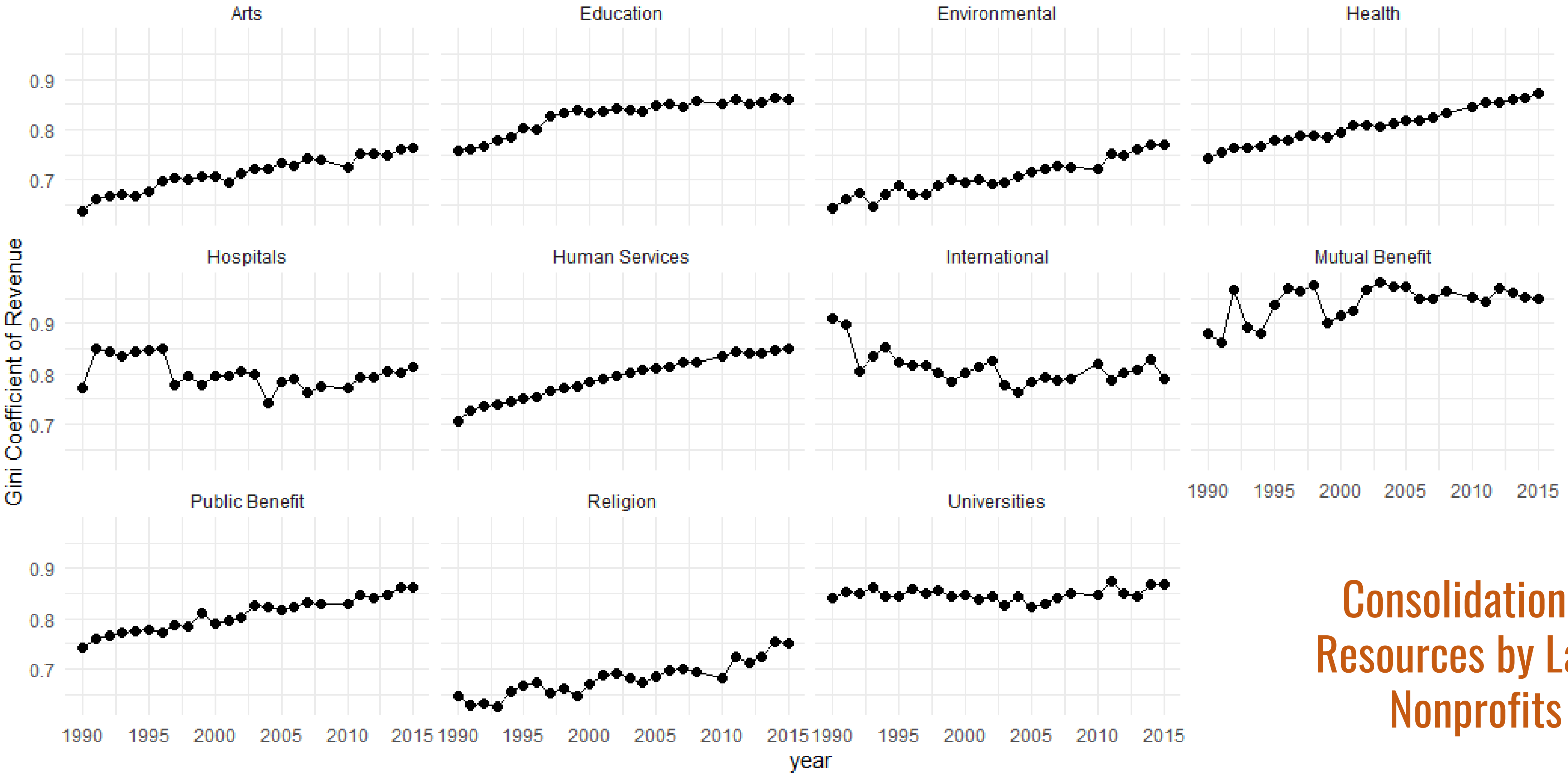


Growth of SMALL NONPROFIT Density

DENSITY OF SMALL NONPROFITS 1990-2015



MARKET CONCENTRATION: REVENUE GINI COEFFICIENT



Consolidation of Resources by Large Nonprofits