Scaling of mortality in 742 metropolitan areas of the Americas

Roberto F. S. Andrade

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Outline

- Introduction
- Data
    - Sources
    - Variables
- Methodology
- Results
    - Urban scaling of all-cause mortality
    - Urban scaling of detailed causes of death and regions
- Conclusions

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- Introduq_tion
  - Tsallis inspired work and fun

Tsallis inspired work and fun

- R.F.S. Andrade - Ising Chain In The Generalized Boltzmann-Gibbs Statistics. Physica A 175, 285-292, 1991
- R.F.S. Andrade - Remarks On The Behavior of The Ising Chain In The Generalized Statistics. Physica A 203, 486-494, 1994
- E.P. Borges, C. Tsallis, J.G.V. Miranda, R.F.S. Andrade - Mother wavelet functions generalized through q-exponentials - Journal of Physics A Mathematical and General 37, 9125-9137, 2004.
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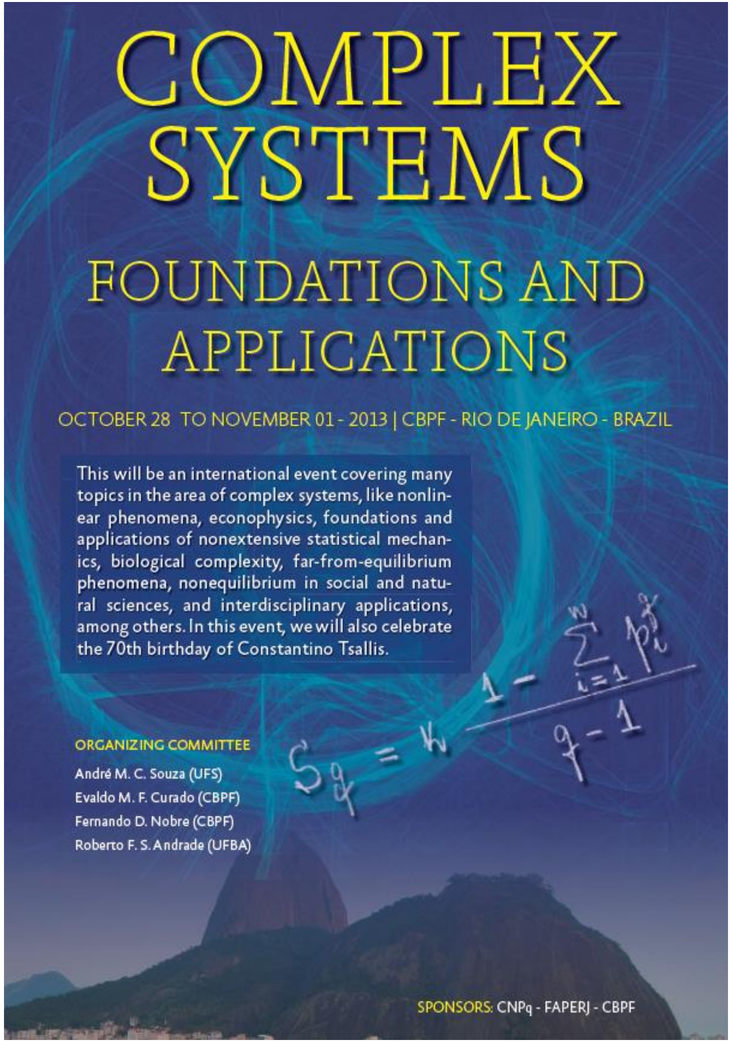
Tsallis inspired work and fun

ELSEVIER Physica A: Statistical Mechanics and its Applications

Volume 175, Issue 2, 1 July 1991, Pages 285-292

Ising chain in the generalized Boltzmann-Gibbs statistics

R.F.S. Andrade



Tsallis inspired work and fun

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Carnot cycle for interacting particles in the absence of thermal noise

Tsallis inspired work and fun

Carnot cycle for interacting particles in the absence of thermal noise

- Lisa, in this house, we obey the laws of thermodynamics!!!

(After her claim to have constructed a perpetual motion machine)

Tsallis inspired work and fun

Carnot cycle for interacting particles in the absence of thermal noise

- Lisa, in this house, we obey the laws of thermodynamics!!!

As all of us in this room do!!

Happy birthday q_onstantino!

Happy birthday q_onstantino!

(oops, sorry for the misprints!)

Happy birthday Constantino!

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UFBA Universidade Federal da Bahia

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Scaling of mortality in 742 metropolitan areas of the Americas

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SCIENCE ADVANCES | RESEARCH ARTICLE

EPIDEMIOLOGY

Scaling of mortality in 742 metropolitan areas of the Americas

Usama Bilal[1,2]*, Caio P. de Castro[3,4], Tania Alfaro[5], Tonatiuh Barrientos-Gutierrez[6], Mauricio L. Barreto[3,7], Carlos M. Leveau[8,9], Kevin Martinez-Folgar[1,2], J. Jaime Miranda[10,11], Felipe Montes[12], Pricila Mullachery[1], Maria Fatima Pina[13,14], Daniel A. Rodriguez[15], Gervasio F. dos Santos[3,16], Roberto F. S. Andrade[3,4], Ana V. Diez Roux[1,2]

We explored how mortality scales with city population size using vital registration and population data from 742 cities in 10 Latin American countries and the United States. We found that more populated cities had lower mortality (sublinear scaling), driven by a sublinear pattern in U.S. cities, while Latin American cities had similar mortality across city sizes. Sexually transmitted infections and homicides showed higher rates in larger cities (superlinear scaling). Tuberculosis mortality behaved sublinearly in U.S. and Mexican cities and superlinearly in other Latin American cities. Other communicable, maternal, neonatal, and nutritional deaths, and deaths due to noncommunicable diseases were generally sublinear in the United States and linear or superlinear in Latin America. Our findings reveal distinct patterns across the Americas, suggesting no universal relation between city size and mortality, pointing to the importance of understanding the processes that explain heterogeneity in scaling behavior or mortality to further advance urban health policies.

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  - Variables
- Methodology
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  - Urban scaling of detailed causes of death and regions
- Conclusions

Introduction

- Like living organisms, complexity of city processes grows with size.
- Population (size) + socioenvironmental interactions ⇔ complexity ⇒ (dis/)advantages depending on specific feature.
- Fingerprints of complex behavior revealed by scaling analysis.
- Infrastructure: road network and water supply scale sub-linearly ⇒ economy of scale.
- Socially generated products: wealth, knowledge and crime scale super-linearly ⇒ network effects and increased social interactions

Introduction

- Knowledge of specific features of cities affecting population health, and underlining processes is still limited.
- This work: Comprehensive of mortality scaling behavior in 742 cities / metropolitan areas with > 100,000 residents in United States and 10 Latin American countries.
  - Cities at 11 very different countries $\Rightarrow$ draw more clear inferences regarding urban scaling of mortality
  - Coarse and fine-grained scaling analyses of causes of death (CoD).
  - Analyses consider key epidemiologic / demographic aspects that may impact mortality $\times$ city size: age differentials and coding differences

Data

- 366 Latin America (LA) and 376 United States (US) cities.
- 10 countries: Argentina, Brazil, Chile, Colombia, Costa Rica, El Salvador, Mexico, Peru, and Panama.
- LA cities: urban agglomerations of administrative units (*municipios, comunas, distritos*, *partidos, etc.*) that overlapped with the urban extent of the city
- US cities: core-based statistical areas, agglomeration of adjacent counties, or part of a core area with at least 10,000 people.
- Analysis restricted to LA and US cities with more than 100,000 people in 2010

Data

- CoD divided in six large groups: 3 disease and 3 injury (external causes) groups
- (1) CMNN - Communicable diseases, Maternal, Neonatal and Nutritional conditions; (2) Cancer; (3) CVD/NCD - Cardiovascular and other Non-Communicable Diseases
- (4) non-violent injuries (road traffic accidents and other unintentional injuries); (5) suicides; and (6) homicides.
- Finer division of disease groups to obtain 41 fine-grained groups
- Adjusted compositional effect of different age structures across cities
- May influence scaling, causing strong effect on mortality patterns
- Proportion of residents aged 0 to 14, 15 to 39, 40 to 64, 65 and above,

Methodology

- Scaling hypothesis $\Rightarrow$ power law relationship between Y and N

$$Y = Y_0 * N^{\beta}$$

- Ordinary least squares regression for set of cities i in country j

$$ln\left(Y_{ij}\right) = \alpha + \beta * ln\left(N_{ij}\right) + \epsilon_{ij} \quad \text{(minimize residuals } \epsilon_{ij}\text{)}$$

- Heterogeneous data (different countries, ages, etc.) may scale with same pattern (exponent β) but different magnitude (different α)
- Necessary account for intrinsic differences in used data during exponent evaluation

Methodology

- Current work: account for different levels of mortality rates and coding of causes of death by country, and role of age distribution

$$log\left(Y_{ij}\right) = \alpha + \beta \cdot log\left(N_{ij}\right) \ + \ \boldsymbol{\alpha_2} \cdot \boldsymbol{Country_j} + \alpha_3 \cdot Prop(15\_39)_{ij} + \alpha_4 \cdot Prop(40\_64)_{ij} + \alpha_5 \cdot Prop(65p)_{ij} + \epsilon_{ij}$$

- Additional variables
  - $Country_j$: country where the city Y_{ij} is located (arbitrary choice)
  - $Prop(15\_39)_{ij}$, $Prop(40\_64)_{ij}$, and $Prop(65p)_{ij}$: *%* of the population in city Y_{ij} aged *15-39, 40-64,* and *65+*

M. Keuschnigg, S. Mutgan, P. Hedström, Urban scaling and the regional divide. Sci. Adv. 5, eaav0042 (2019).

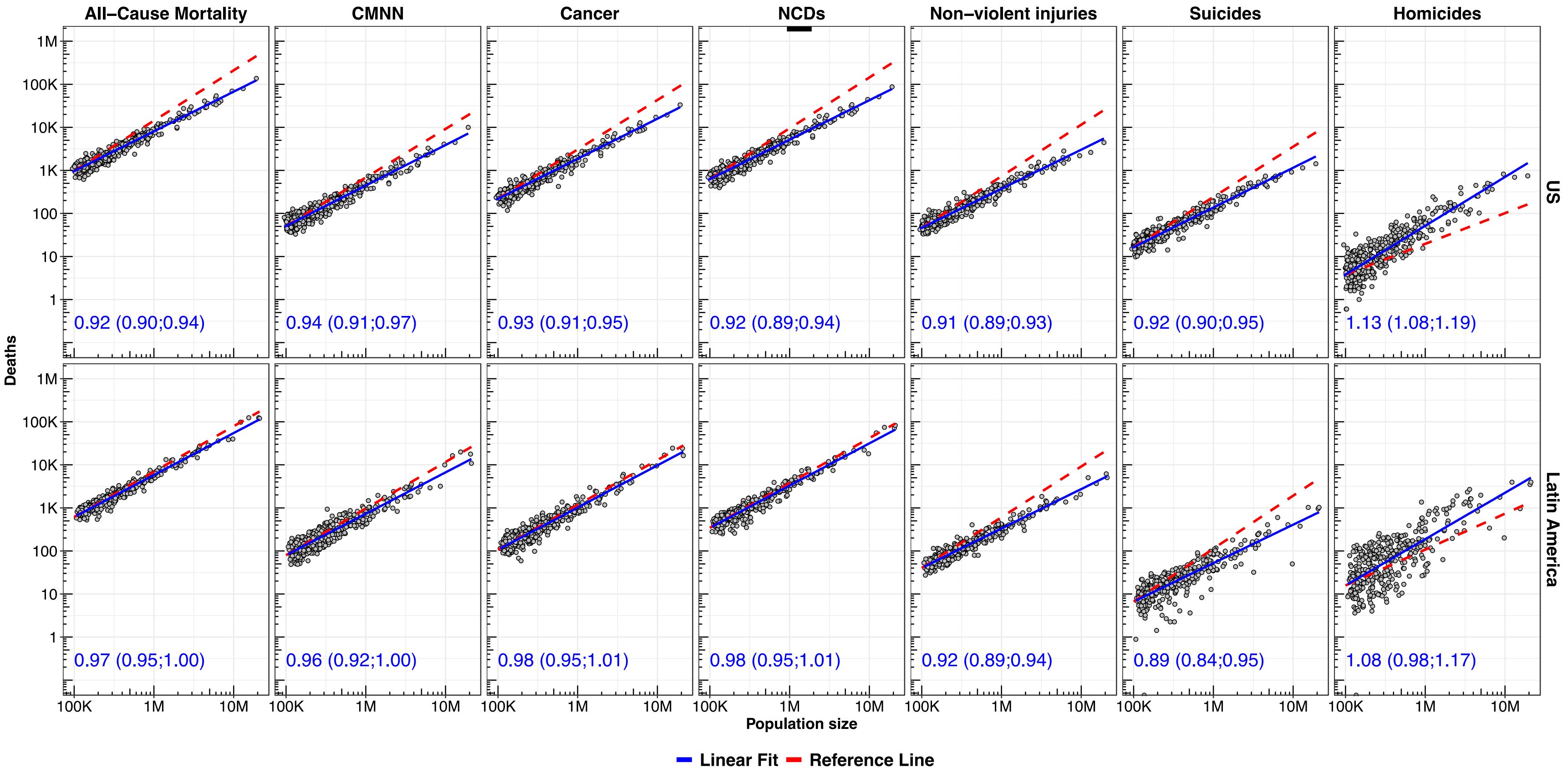
Methodology

- Above equations used to evaluate β and α for all cities combined and also stratified by region (LA and US cities separately)
- Country-specific coefficients for Brazil (152), Mexico (92), and all other LA cities (122).
- Multiple country adjustment included in analyzes for all LA countries and for all LA countries minus Brazil and Mexico, but not in single country analyzes (US, Brazil, and Mexico)

Methodology

- Explore association between scaling behavior and variance and general prevalence.
- For each cause of death compare β with corresponding intercepts (α is a metric of the general prevalence), and standard deviation of log(number of deaths) (a metric of the variability of the phenomenon)

Results – All-cause and large groups of causes of death



Results – All-cause and large groups of causes of death

Table 1. Scaling coefficients (β, 95% CI) by cause of death for all U.S. and Latin American cities. CMNN, communicable, maternal, neonatal, and nutritional diseases; CVD/NCDs, cardiovascular disease and other noncommunicable diseases.

Cause/group	Unadjusted	Adjusted*	United States†	Latin America†	BR†	MX†	Latin America (no MX/BR)†
All-cause mortality	0.94 (0.92–0.96)	0.97 (0.96–0.97)	0.94 (0.93–0.95)	1.00 (0.99–1.01)	1.00 (0.99–1.01)	1.01 (0.98–1.03)	0.99 (0.97–1.01)
CMNN	0.96 (0.93–0.99)	0.97 (0.95–0.99)	0.95 (0.92–0.97)	1.01 (0.98–1.03)	1.01 (0.98–1.04)	0.99 (0.95–1.03)	1.02 (0.98–1.07)
Cancer	0.94 (0.91–0.97)	0.98 (0.97–0.99)	0.95 (0.94–0.97)	1.01 (1.00–1.03)	1.01 (1.00–1.03)	1.01 (0.98–1.04)	1.00 (0.97–1.03)
CVD/NCDs	0.93 (0.91–0.96)	0.96 (0.95–0.97)	0.94 (0.92–0.95)	1.00 (0.99–1.01)	0.99 (0.98–1.01)	1.02 (0.99–1.04)	0.99 (0.96–1.01)
Nonviolent injuries	0.91 (0.89–0.93)	0.93 (0.91–0.94)	0.92 (0.90–0.94)	0.93 (0.90–0.95)	0.93 (0.90–0.97)	0.94 (0.90–0.99)	0.90 (0.85–0.95)
Suicides	0.88 (0.84–0.93)	0.92 (0.89–0.94)	0.94 (0.92–0.97)	0.88 (0.84–0.92)	0.88 (0.83–0.93)	0.91 (0.82–1.00)	0.87 (0.79–0.95)
Homicides	1.14 (1.07–1.22)	1.12 (1.07–1.16)	1.12 (1.07–1.18)	1.10 (1.04–1.17)	1.17 (1.09–1.25)	0.97 (0.80–1.13)	1.01 (0.91–1.12)

*Adjusted model is adjusted by age structure and country. †Stratified models are run only on the indicated sample (e.g., Latin America is ran with all Latin American cities), all adjusted by age structure and country (where relevant). For Latin American cities, the main analysis includes the 366 cities in 10 countries, while BR includes Brazilian cities (n = 152), MX includes Mexican cities only (n = 92), and "no BR/MX" includes all Latin American cities except for those in BR and MX (n = 122).

- Details of obtained results, adjusted by country and age

Results – All-cause and large groups of causes of death

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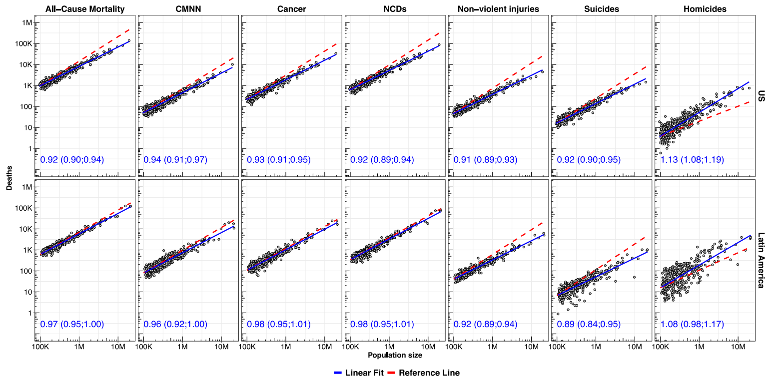
- Details of obtained results, adjusted by country and age

Results – All-cause and large groups of causes of death

- All-cause mortality
  - All-cause mortality scales sublinearly β=0.94⇒lower mortality rates in larger cities
  - After adjusting for age and country, β was minimally attenuated to 0.97
  - Even after considering different distribution of ages across cities, all-cause mortality scales sublinearly in the entire region of the Americas



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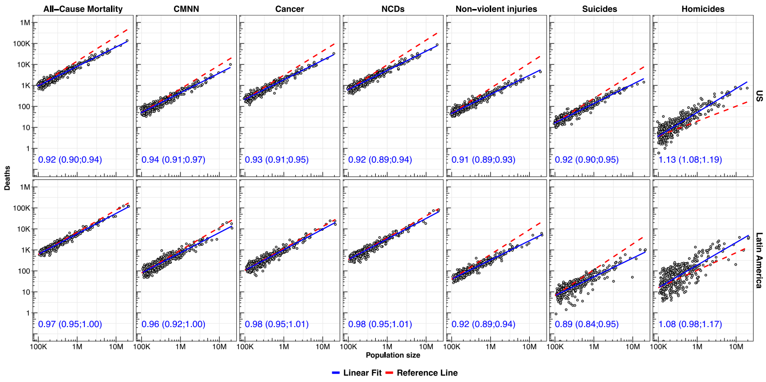
- Details of obtained results, adjusted by country and age

Results – All-cause and large groups of causes of death



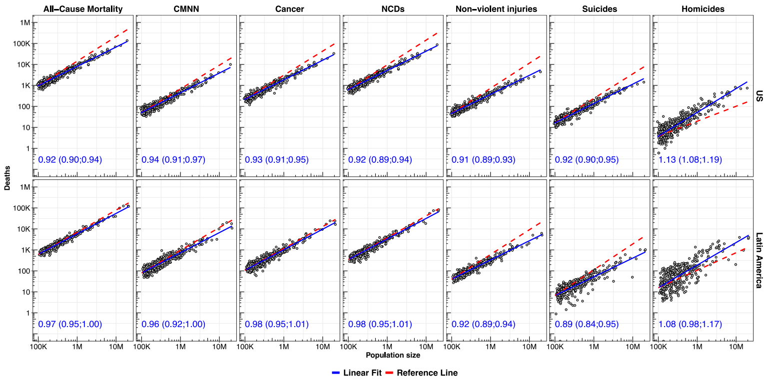
- Region age adjusted specific scaling
  - All-cause mortality:
  - β = 0.94 in US (376) and 1.00 in LA (366)
  - Mortality by large disease grouping
  - CMNN, cancer, and NCDs
  - β = 0.95, 0.95, and 0.94 in US and = 1.00, 1.01, and 1.01 in LA ⇒

health advantage of living in larger cities in US but seems irrelevant in LA

  - Mortality by injuries
  - Non-violent, suicides and homicides
  - β = 0.92, 0.94, and 1.12 in US and = 0.93, 0.88, and 1.10 in LA.

Results – All-cause and large groups of causes of death

- Country age adjusted specific scaling (BR,MX and OtherLA)
  - All-cause mortality:
    β=1.00, 1.01 and 0.99
  - Large disease groupings and injuries
    CMNN: β = 1.01, 0.99 and 1.02
    Cancer: β = 1.01, 1.01 and 1.00
    NCDs: β = 0.99, 1.02 and 0.99
    Non-violent: β = 0.93, 0.94, and 0.90
    Suicides: β = 0.88, 0.91, and 0.87
    Homicides: β = 1.17, 0.97, and 1.01



Results – All-cause and large groups of causes of death

Causes of death sorted in descending order (higher = more superlinear, lower = more sublinear)

Unadjusted	Adjusted	US	LA	BR	MX	LA (no BR/MX)
Homicides 1.14 (1.07–1.22)	Homicides 1.12 (1.07–1.16)	Homicides 1.12 (1.07–1.18)	Homicides 1.10 (1.04–1.17)	Homicides 1.17 (1.09–1.25)	NCDs 1.02 (0.99–1.04)	CMNN 1.02 (0.98–1.07)
CMNN 0.96 (0.93–0.99)	Cancer 0.98 (0.97–0.99)	Cancer 0.95 (0.94–0.97)	Cancer 1.01 (1.00–1.03)	Cancer 1.01 (1.00–1.03)	Cancer 1.01 (0.98–1.04)	Homicides 1.01 (0.91–1.12)
Cancer 0.94 (0.91–0.97)	CMNN 0.97 (0.95–0.99)	CMNN 0.95 (0.92–0.97)	CMNN 1.01 (0.98–1.03)	CMNN 1.01 (0.98–1.04)	All-cause mortality 1.01 (0.98–1.03)	Cancer 1.00 (0.97–1.03)
All-cause mortality 0.94 (0.92–0.96)	All-cause mortality 0.97 (0.96;0.97)	Suicides 0.94 (0.92–0.97)	NCDs 1.00 (0.99–1.01)	All-cause mortality 1.00 (0.99–1.01)	CMNN 0.99 (0.95–1.03)	NCDs 0.99 (0.96–1.01)
NCDs 0.93 (0.91–0.96)	NCDs 0.96 (0.95–0.97)	NCDs 0.94 (0.92–0.95)	All-cause mortality 1.00 (0.99–1.01)	NCDs 0.99 (0.98–1.01)	Homicides 0.97 (0.80–1.13)	All-cause mortality 0.99 (0.97–1.01)
Nonviolent injuries 0.91 (0.89–0.93)	Nonviolent injuries 0.93 (0.91–0.94)	All-cause mortality 0.94 (0.93–0.95)	Nonviolent injuries 0.93 (0.90–0.95)	Nonviolent injuries 0.93 (0.90–0.97)	Nonviolent injuries 0.94 (0.90–0.99)	Nonviolent injuries 0.90 (0.85–0.95)
Suicides 0.88 (0.84–0.93)	Suicides 0.92 (0.89–0.94)	Nonviolent injuries 0.92 (0.90–0.94)	Suicides 0.88 (0.84–0.92)	Suicides 0.88 (0.83–0.93)	Suicides 0.91 (0.82–1.00)	Suicides 0.87 (0.79–0.95)

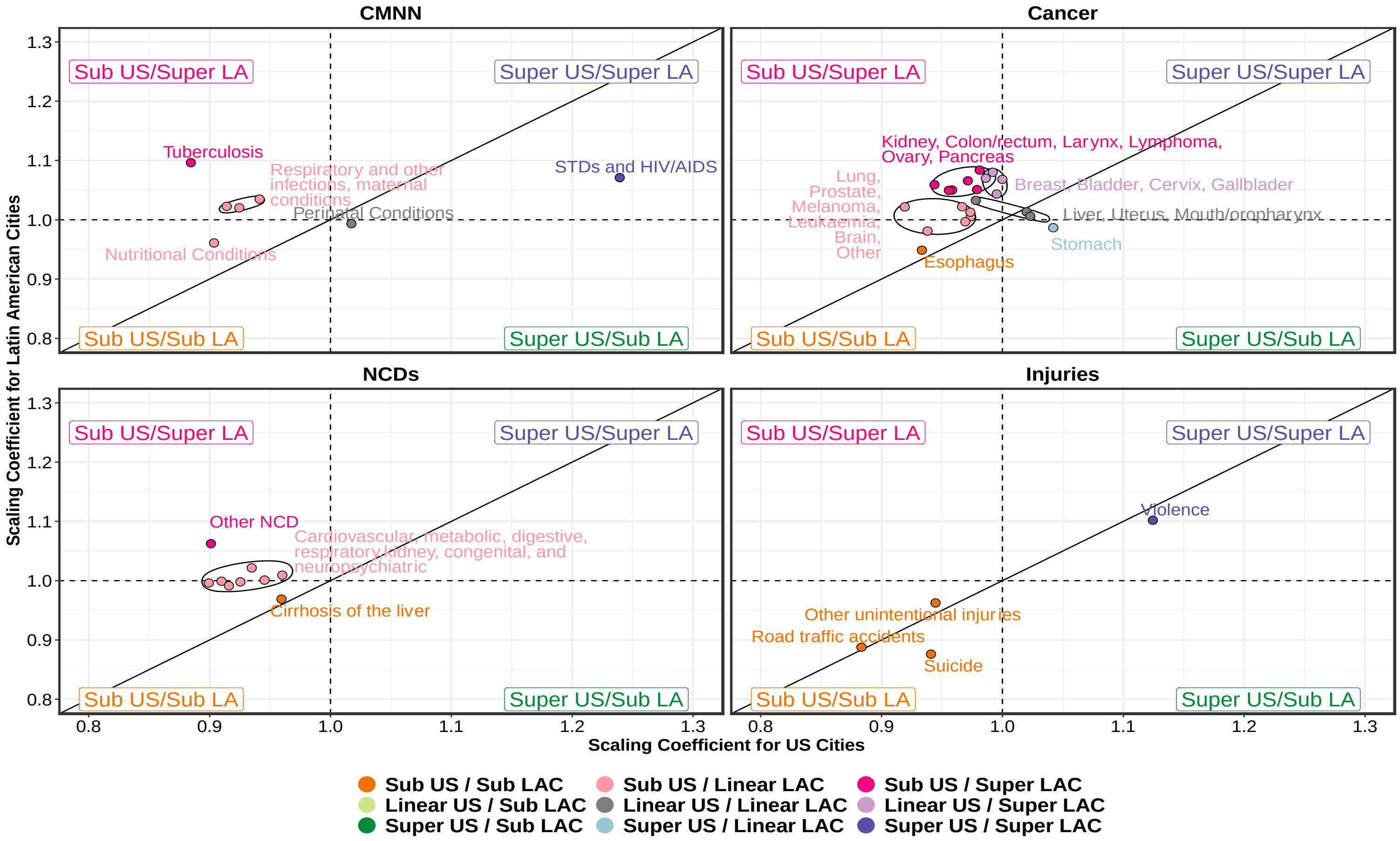
All-cause mortality, CMNN, Cancer, NCDs, Injuries

Fig. 2. Large groupings of causes of death sorted by scaling coefficient. Fully colored cells indicate a statistically significant superlinear or sublinear pattern; cells with a solid outline indicate a superlinear pattern; cells with a dashed outline indicate a sublinear pattern; non–fully colored cells with no outline indicate a coefficient whose 95% CI crosses the null of linearity.

Results – Fine-grained analysis on specific causes of death

- Fine-grained study of specific causes
  - CMNN: sexually transmitted (STDs) and HIV/AIDS, tuberculosis, respiratory infections, and all other infectious diseases besides Maternal, Neonatal and Nutritional conditions
  - Cancer: 21 types of tumors in different organs and systems
  - NCD: Cardiovascular, metabolic, digestive, respiratory, kidney, congenital, neuropsychiatric, cirrhosis of the liver
  - Injuries: Violence, road traffic accidents, suicide, other unintentional injuries
- Comparison of scaling behavior between US and LA cities
  - β (US,LA) or β(US,LA,BR,MX,OtherLA)

Results – Fine-grained analysis on specific causes of death



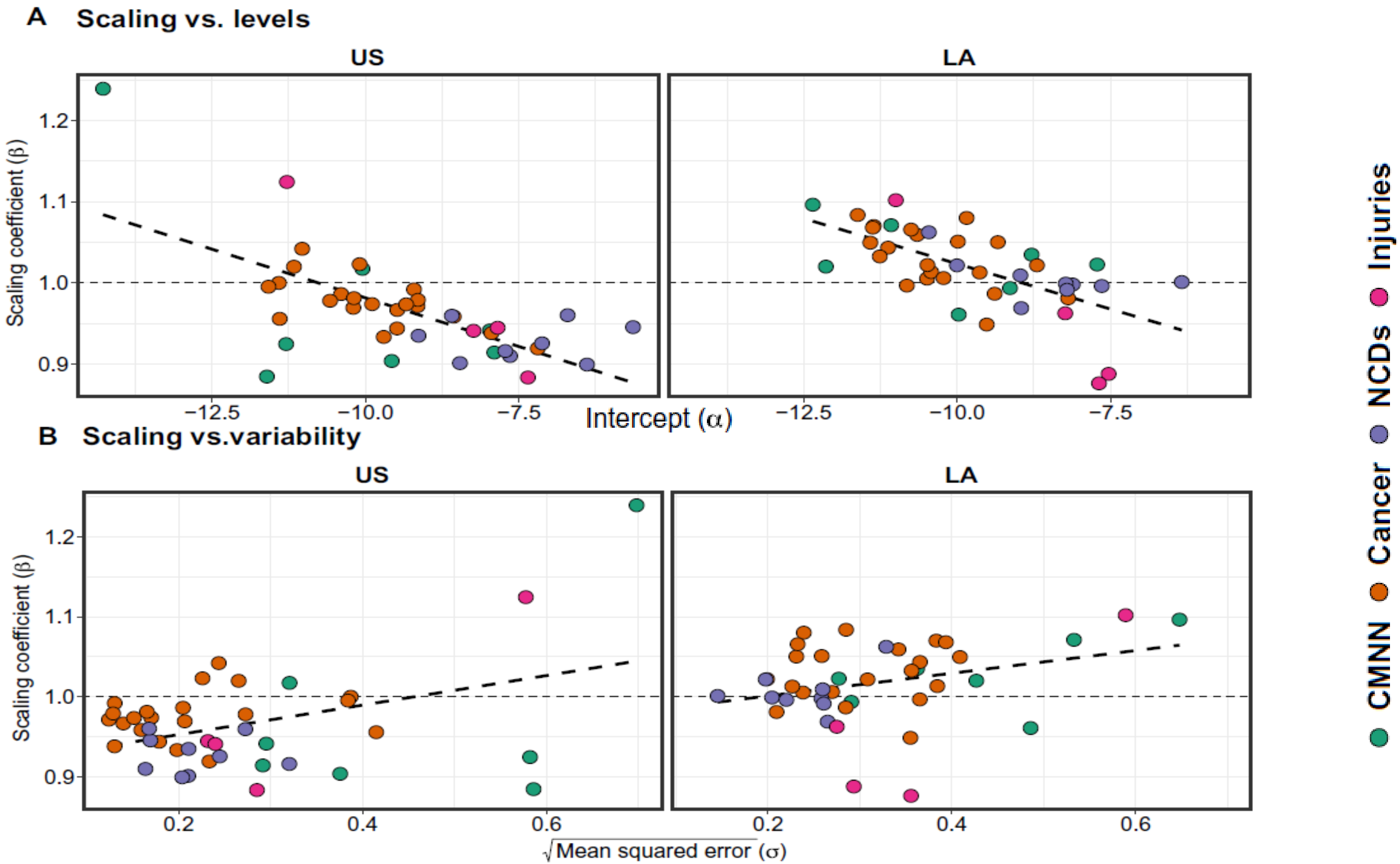
Results – Fine-grained analysis on specific causes of death

- CMNN
  - STDs and HIV/AIDS: $\beta = (1.24, 1.07, 1.07, 0.90, 1.17) \Rightarrow$ Most superlinear CoD in US and LA-BR/MX, but second most sublinear in MX
  - Tuberculosis: $\beta = (0.88, 1.10, 1.18, 1.09, 0.83) \Rightarrow$ Second most sublinear in US, second most superlinear in LA with wide spread values
  - All other CMNN: Sublinear in US. cities (among most sublinear CoD) and linear LA, with two superlinear exceptions: Maternal conditions ($\beta = 1.09$) in BR and respiratory infections in MX ($\beta = 1.10$)
- Cancer
  - Equally occurrence of linear and superlinear (10 of 21) pattern in LA
  - Mostly sublinear in US, with only 1 superlinear and 7 linear occurrences

Results – Fine-grained analysis on specific causes of death

- CV/NCD
  - Overall sublinear in US and linear or superlinear in LA, where the single exception is cirrhosis with $\beta = 0.97$
- Injuries
  - Patterns mostly consistent between US and LA: β=(0.94, 0.88) for suicides, β = (0.88,0.89) for road traffic deaths, and β = (0.94,0.96) for other unintentional injuries
  - Position within respective ranking exhibit large differences
  - Homicides scale superlinearly with β = (1.12,1.10)
  - Exception for MX (β =0.97) and OtherLA (β = 1.01)

Results – Relation between scaling, prevalence, and variance



Results – Relation between scaling, prevalence, and variance

- Scaling x prevalence
  - Negative correlation between β and α with ρ = (−0.58,−0.67) indicates that more frequent CoD (higher intercepts) tend to be more sublinear, while less frequent CoD (lower intercepts) tend to be superlinear
- Scaling x variance
  - Weak positive correlation between β and σ with ρ = (0.40,0.31) indicates that CoD with large variability across cities tend to be more superlinear, as compared with those with lower variability

Conclusions

- Summary
  - Analysis (> 560 million residents in 366 LA and 376 US cities) revealed a heterogeneous scaling landscape of mortality across the continent
  - Some CoD show a consistent scaling pattern across regions
  - Other infectious diseases, and maternal, neonatal, and nutritional conditions and cancers display different patterns by region
  - The scaling of NCDs varies widely by specific cause
  - Despite the presence of some commonalities, they coexist with important differences in the scaling behavior of specific CoD in one same region and the same CoD across regions or countries.

Conclusions

- Strong points of analyses
  - Inclusion of cities in 10 different countries of LA and US and access to curated data on multiple CoD allowed us to explore heterogeneities by region and cause of death.
- Implications
  - Findings have implications for understanding the phenomenon of urban scaling and prevailing urban scaling theories
  - Key assumption is that the phenomenon is driven by common universal mechanisms rather than by place-specific effects
  - Despite that, associations of health-relevant city characteristics including social, environmental, health care–related, and behavioral factors with city size may differ by domain and by region.

Conclusions

- Implications
  - Such features may relate differently to different CoD
  - As already proposed by others (Arcaute, Pumain), scaling patterns may be affected by path dependencies influencing specific features of cities regardless of their size (San Francisco x technological development)
  - The context in which each city grew to its current size may affect the relationship between size and mortality.
  - Further, scaling might be (Gomez-Lievano) function of the nature of multifactorial causal processes, more evident in outcomes that require the presence of multiple less common factors with more variability

Arcaute et al. Constructing cities, deconstructing scaling laws. *J. R. Soc. Interface* **12**, 20140745 (2015).

Conclusions

- Consequences for health and urban policy
  - Knowing how health outcomes scale with city size may allow for more precise resource allocation.
  - E.g. if two diseases show opposing scaling patterns, resources to prevent one with superlinear (sub linear) scaling could be focused on larger (smaller) cities
  - Greater understanding of the drivers of the scaling phenomena might provide insights on whether there is an optimal city size, an important consideration for urban policy that has been extensively studied from a productivity perspective

Thank you
for the attention

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Outline

- Introduction
- Data
  - Sources
  - Variables
- Methodology
- Results
  - Urban scaling of all-cause mortality
  - Urban scaling of detailed causes of death and regions
- Conclusions

Data

- Sources
  - LA: Salud Urbana en America Latina (SALURBAL) study ⇒ compiled and harmonized vital registration and other health data
  - US: National Vital Statistics System and the Census Bureau
  - Mortality records with CoD for the period georeferenced to county or county-equivalent level.
  - Intercensal population estimations or postcensal projections by county or county-equivalent and age
- Variables
  - Average yearly city population
  - Average yearly mortality counts by cause by city of residence

Results – Large groups of causes of death

- All-cause mortality
  - All-cause mortality scales sublinearly β=0.94⇒lower mortality rates in larger cities
  - After adjusting for age and country, β was minimally attenuated to 0.97
  - Even after considering different distribution of ages across cities, all-cause mortality scales sublinearly in the entire region of the Americas
  - Very good fit for most groupings (independent of countries), with R^2 > 80% (most > 90%) but one single exception