The Global Leapfrogging of Urban Growth

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The Most Populous Cities in the World: 1500 AD – 2018 AD

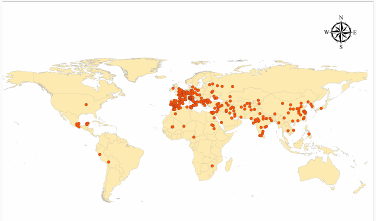
https://www.youtube.com/watch?v=pMs5xapBewM

Motivation and Research Question

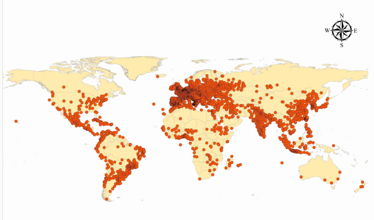
Motivation: City locations spread Widely

(a) 2000 B.C.

(b) 0



(c) 1000 A.D.



(d) 1950 A.D.

Motivation: Number and Sizes of Cities Grow

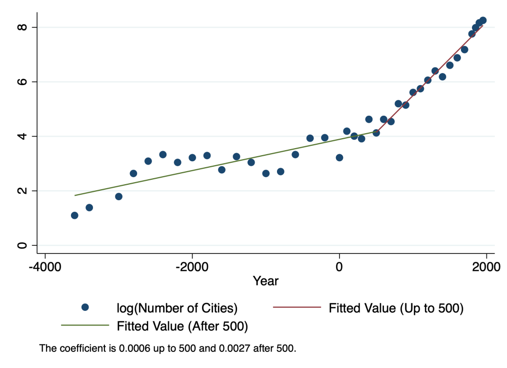


Figure 1: The number (logs) of cities worldwide

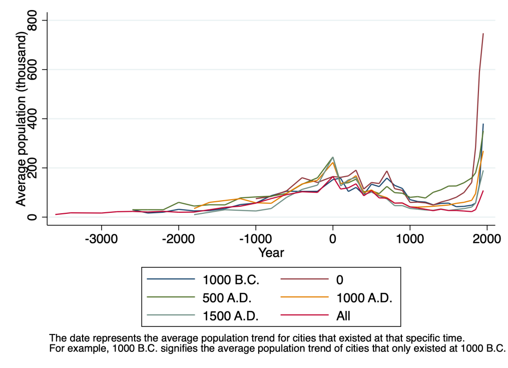


Figure 2: Average size of cities worldwide

Motivation: City Quartile Rank Transitions

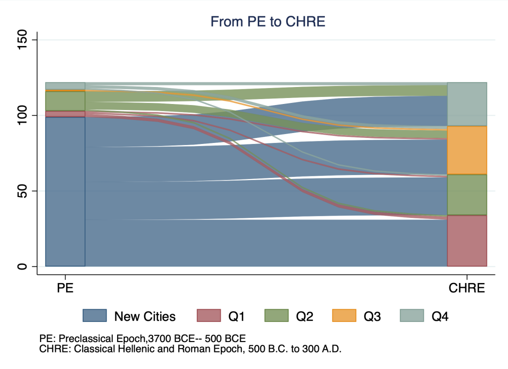


Figure 3: Quartile Rank Transitions: From PE to CHRE

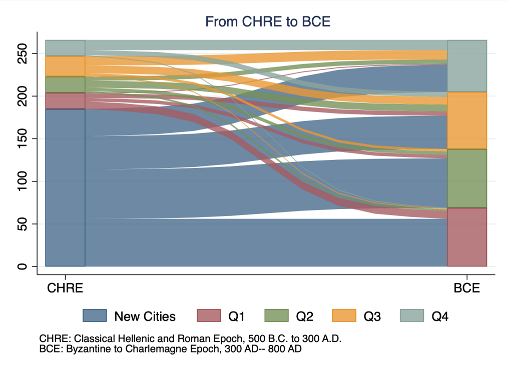


Figure 4: Quartile Rank Transitions: From CHRE to BCE

Number of cities at end epoch on vertical axis

Motivation: City Quartile Rank Transitions

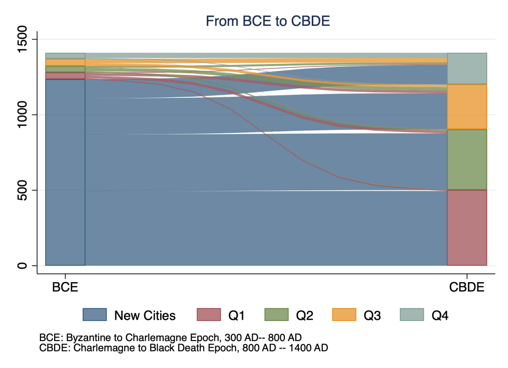


Figure 5: Quartile Rank Transitions: From BCE to CBDE

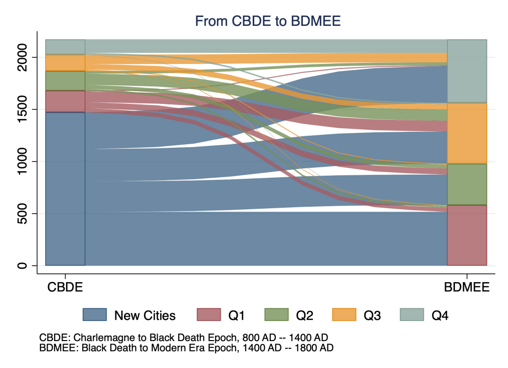


Figure 6: Quartile Rank Transition: From CBDE to BDMEE

Number of cities at end epoch on vertical axis

Motivation: City Quartile Rank Transitions

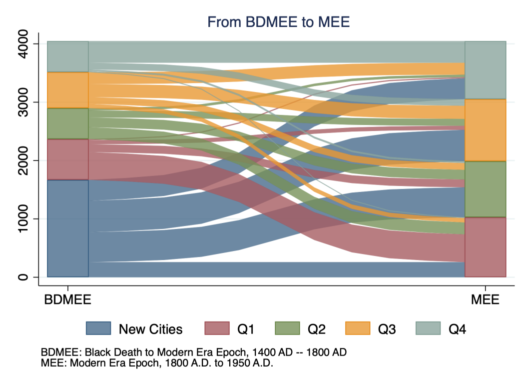


Figure 7: Quartile Rank Transitions: From BDMEE to MEE

- Cities ranking in the upper size quartiles in preceding epoch are more likely to maintain their larger size quartile rankings in succeeding epoch.
- New cities tend to distribute roughly uniformly across all four quartiles: a significant number of new cities are relatively large upon entry, without having existed in the preceding epoch.

Research Questions

- National growth leapfrogs, first Mesopotamia and China, then Egypt, Greece and Rome, back to China and India, back to Europe, the Western Offshoots, like North America, Australia, back to Europe, then on to Japan, Korea and China. Africa and South America lag behind.
- We know growth is driven by urbanization.
- Natural to look for factors that contribute to the global leapfrogging of urban growth.
  growth leaps from a city to other cities.
- Are geographical characteristics, temperature, or urban interactions determinants, the driving forces?
- How have these influences varied across different epochs and continents?
- Precursor: Our *Palimpsest of Athens* conference paper.

Contribution

We propose and examine three potential explanations for the rapid growth and development (leapfrogging) of new or small cities worldwide:

- Widespread urbanization across a country or continent can catalyze growth. E.g. North America and Oceania.
- Significance/importance of geographical characteristics change over time as new cities in newly advantageous locations: E.g. Los Angeles, Doha.
- Interactions among pre-existing cities could contribute significantly to the development of new cities: E.g. Shenzhen, near Hong Kong, Macau, and Guangzhou evolved from a village into a megacity within just 40 years; Pearl River (Zhu Jiang) Delta, a huge agglomeration (conurbation).

Literature Review

Leapfrogging of national growth, in terms of GDP per capita, has not really been studied over long periods of time.

- National borders change
- Annexed territories may be meaningless: E.g. the Empire of Japan was the largest country on earth in terms of population just prior to World War II.
- Cities are distinct entities that persist, with ups and downs.
- Unaware of quantitative economics literature of long run urban growth globally. (Bosker and Buringh, 2017, Cuberes et al., 2021, Dobkins and Ioannides, 2001).

Overview

- Geographical characteristics and temperature alone do not provide a satisfactory explanation for urban growth.
    - In most cases, the coefficients related to these factors are statistically insignificant for urban population growth and emergence of cities.
    - Additionally, the factors that do show statistical significance are not economically significant.
- Urban interactions play a crucial role in urban growth.
    - Both the number and size of neighboring cities have a statistically and economically influential impact on the growth and emergence of cities.
    - There exists a strong relationship between a city's growth rate and those of its neighboring cities.
- The lifespan of a city also contributes to explaining urban growth and emergence.

Data & Definitions

Data

- Our analysis is based on a unique dataset, a product of merging several existing datasets. It traces cities worldwide from 3700 B.C. to 1950 A.D.
  - Data Sources:
    - A comprehensive, unpublished dataset by Özak et al. (2021), amalgamating six different sources and providing global coverage from 1 A.D. to 2000 A.D. (Bairoch, 1988, Chandler, 1987, Chandler and Fox, 2013, De Vries, 2006, Eggimann, 2000, Modelski, 2003).
    - A dataset by Reba et al. (2016) that integrates data from Chandler (1987) and Modelski (2003), covering the period 3700 B.C. to 2000 A.D.
    - An expanded dataset by Buringh (2021), focusing on European cities from 700 A.D. to 1900 A.D. It builds on the work of Bairoch (1988).
  - Methodology in merging datasets:
    - Cities from different datasets were "reconciled" using geographic coordinates and names.
    - Bosker and Buringh (2017), we excluded observations with populations under 5,000 to maintain consistency in the dataset.

Definition of Epochs

Our study spans from 3700 B.C. to 1950 A.D. We segment entire span into six distinct epochs for nuanced analysis and “homogeneity”:

- Preclassical Epoch: 3700 BCE– 500 BCE, mainly centered on Europe.
- Classical Hellenic and Roman Epoch: 500 B.C. to 300 A.D., marked by the peak of Athens up to the founding of New Rome, Constantinople.
- Byzantine to Charlemagne Epoch: 300 AD– 800 AD, Roughly, Beginning of Byzantine Era to Charlemagne’s coronation as the Holy Roman Emperor; it includes developments in Asia and the Great Arab conquests post-600 AD.

…continue

- Charlemagne to Black Death Epoch: 800 AD – 1400 AD, Charlemagne's Coronation to Black Death in Europe; notably beginning of Ming Dynasty in China.
- Black Death to Modern Era Epoch: 1400 AD – 1800 AD. Spanning Sung Dynasty, China, and Zheng He's expeditions starting in 1405 AD.
- Modern Era Epoch: 1800 A.D. to 1950 A.D., after onset and spread of the Industrial Revolution.

Percentile Rank Analysis: Populations

$$pten_{it}^{wd} = a_i + \beta_1 pten_{it}^{eu} + \beta_2 pten_{it}^{af} + \beta_3 pten_{it}^{na} + \beta_4 pten_{it}^{sa} + \beta_5 pten_{it}^{as} + \beta_6 pten_{it}^{oc} + \delta_t + \epsilon_{it}, \quad (1)$$

- LHS: $pten_{it}^{wd}$, decile rank of population of city i in global population distribution at time t.
- RHS: $pten_{it}^{X}$, population decile rank of city i at time t in continent X.
- $pten_{it}^{X} = 0$, if city i not in continent X.
- δ_t: fixed time effect.
- a_i : city fixed effect.

Percentile Rank Analysis: Populations

- Urbanization varying dramatically across continents over epochs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	ALL	up to -500	-500 to 300	300 to 800	800 to 1400	1400 to 1800	After 1800
$tenths^{eu}$	0.860***	0.374***	0.671***	0.343***	0.666***	0.806***	0.881***
	(0.006)	(0.123)	(0.109)	(0.081)	(0.010)	(0.006)	(0.006)
$tenths^{as}$	0.547***	0.992***	0.782***	0.792***	0.409***	0.313***	0.628***
	(0.016)	(0.019)	(0.038)	(0.036)	(0.021)	(0.019)	(0.022)
$tenths^{na}$	0.810***	1.130***	0.279***	0.123	0.351***	0.719***	1.039***
	(0.034)	(0.175)	(0.036)	(0.120)	(0.054)	(0.052)	(0.045)
$tenths^{sa}$	0.829***				0.273***	0.732***	0.852***
	(0.016)				(0.027)	(0.051)	(0.014)
$tenths^{af}$	0.546***	0.332***	0.294***	0.615***	0.443***	0.303***	0.647***
	(0.026)	(0.107)	(0.080)	(0.118)	(0.036)	(0.021)	(0.031)
$tenths^{oc}$	0.153***						0.090**
	(0.042)						(0.036)
Constant	1.215***	0.672***	1.749***	2.094***	2.330***	1.578***	0.876***
	(0.033)	(0.084)	(0.205)	(0.172)	(0.050)	(0.035)	(0.036)
Observations	18,093	233	252	395	2,034	4,258	9,343
R-squared	0.939	0.942	0.924	0.917	0.971	0.978	0.971
N	3,668	59	64	120	560	1,383	3,342

Population Regressions Summary

- Asian cities held a position of dominance from 500 B.C. to 800 A.D.
- European cities have maintained their substantial size consistently, specifically from 800 A.D. to 1800 A.D.
- North American cities, while having a remarkable history during the ancient epoch, experienced a decline thereafter.
- The onset of the Age of Great Voyages catalyzed rapid urbanization in North America, a trend that has persisted from 1400 A.D. to the present. Similar but somewhat weaker in South America.
- African cities, in comparison, have consistently been of a relatively modest size.

Percentile Rank Analysis: Growth Rates

$$gten_{it}^{wd} = a_i + \beta_1 gtens_{it}^{eu} + \beta_2 gten_{it}^{af} + \beta_3 gten_{it}^{na} + \beta_4 gten_{it}^{sa} + \beta_5 gten_{it}^{as} + \beta_6 gten_{it}^{oc} + \delta_t + \epsilon_{it}, \quad (2)$$

- Here, $gten_{it}^{wd}$ represents the decile rank of city i in terms of growth rate at time t globally.
- On the right-hand side, $gten_{it}^{X}$ denotes the decile rank of city i in terms of growth rate at time t within the continent X.
- For cities not located in continent X, $gten_{it}^{X}$ is set to 0.

Percentile Rank Analysis: Growth Rates

- Urban growth rates varying dramatically across continents over epochs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	ALL	up to -500	-500 to 300	300 to 800	800 to 1400	1400 to 1800	After 1800
$tenths^{eu}$	0.937***	1.033***	0.933***	1.062***	0.980***	0.955***	0.916***
	(0.002)	(0.109)	(0.048)	(0.194)	(0.010)	(0.004)	(0.003)
$tenths^{as}$	0.938***	0.969***	1.009***	0.943***	0.812***	1.021***	0.918***
	(0.008)	(0.022)	(0.016)	(0.015)	(0.024)	(0.018)	(0.018)
$tenths^{na}$	0.961***	0.667**		0.849***	0.629***	0.490**	1.015***
	(0.032)	(0.322)		(0.181)	(0.133)	(0.209)	(0.026)
$tenths^{sa}$	1.123***				0.645**	1.111***	1.126***
	(0.023)				(0.266)	(0.100)	(0.024)
$tenths^{af}$	0.882***	1.011***	0.787***	0.883***	0.714***	0.952***	0.952***
	(0.023)	(0.045)	(0.192)	(0.156)	(0.051)	(0.044)	(0.040)
$tenths^{oc}$	1.947***						1.946***
	(0.557)						(0.556)
Constant	0.338***	0.529***	0.386***	0.316**	0.549***	0.223***	0.381***
	(0.014)	(0.101)	(0.101)	(0.126)	(0.055)	(0.029)	(0.021)
Observations	13,423	148	180	265	1,422	2,992	7,676
R-squared	0.936	0.887	0.930	0.915	0.902	0.964	0.949
N	2,948	38	52	80	376	955	2,758

Growth Regressions Summary

- Cities in Europe and Asia consistently demonstrated faster growth compared to other continents.
- After 1800 A.D., cities in North America, South America, and Oceania: late starters but developed rapidly.
- Overall, urban growth in Asia and Europe remains stable over time.
- Urban growth in Africa lags behind between 500 B.C. and 1400 A.D., but picks up thereafter.

Emergence

Emergence of Cities

- Geographic characteristics significantly impact global urban growth; technological advancements enable human settlement in previously inhospitable areas.
- We consider first the effects of geographic characteristics on city emergence. Founding dates of cities worldwide vary greatly – earliest dates in our data $\sim$ 3700 BCE; Greatest numbers established circa 1900 AD.
- We assume that all city locations up to 1950 AD indicate potential city sites[1]. We designate a value of 100 to $city_{it}$[2] If a city has been established by time t within epoch; = 0 otherwise.

[1] We simplify approach of Bosker and Buringh (2017), making the analysis manageable by significantly reducing the number of candidate sites.
[2] Dummy variables by 100 for ease of interpretation:

Geographical Characteristics: Emergence of Cities

$$p(city_{it}|city_{it-1} = 0) = \alpha_i + \mathsf{X}_i\beta + f(x_i, y_i) + \delta_t + \epsilon_{it}, \quad (3)$$

- α_i city random effect (panel structure within epoch);
- X_i is a vector of time-varying and time-invariant geographic characteristics, includes: proximity to a river within 10 km, proximity to an ocean within 10 km, roughness, elevation, and temperature;
- $f(x_i, y_i)$: a cubic function of longitude x_i and latitude y_i (control for global climate variations).
- δ_t : time fixed effect.

Remark: potential "choice-based sampling bias" mitigated by expansions into new continents. Or else, huge number of observations must be used and randomize among them.

Geographical Characteristics: Emergence of Cities

- The influence of geographical characteristics varies across epochs.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	ALL	up to -500	-500 to 300	300 to 800	800 to 1400	1400 to 1800	After 1800
river	0.103	0.035	0.060	1.214***	0.397	-5.469***	2.703
	(0.096)	(0.044)	(0.110)	(0.235)	(1.035)	(1.474)	(1.704)
ocean	0.110	-0.020	0.401***	0.522***	-1.179	-0.841	-0.201
	(0.096)	(0.040)	(0.126)	(0.197)	(0.902)	(1.389)	(1.528)
roughness	0.002	-0.003***	-0.003**	-0.005*	0.029**	0.104***	0.026
	(0.001)	(0.001)	(0.002)	(0.003)	(0.012)	(0.020)	(0.021)
elevation (100m)	0.003	0.015***	0.053***	0.114***	-0.178***	-0.357**	-1.145***
	(0.011)	(0.005)	(0.014)	(0.027)	(0.065)	(0.150)	(0.146)
temperature	0.008	0.025***	0.030***	0.078***	0.102**	-0.151	-1.058***
	(0.008)	(0.004)	(0.010)	(0.016)	(0.046)	(0.101)	(0.108)
Constant	48.935***				3.303***		
	(1.451)				(1.169)		
Observations	153,988	67,336	28,674	22,241	19,463	11,162	5,112
N	4,827	4,827	4,820	4,809	4,109	3,958	2,507

Geographic Characteristics on Emergence Summary

- Proximity to a river within 10km significantly increased the likelihood of city emergence from 300 A.D. to 800 A.D. However, the same proximity showed a negative influence from 1400 A.D. to 1800 A.D.
- Being within a 10km radius of an ocean notably and positively influenced city emergence from 500 B.C. to 800 A.D.
- During earlier epochs, cities were more likely to be established in flat areas, whereas in later epochs, cities tended to emerge in rougher terrains.
- In earlier epochs, cities were more likely to be founded in lower areas, but in later epochs, they tended to appear in higher regions.
- Temperature played a significantly positive role in urban emergence up until 1400 A.D., but its impact became negative after 1800 A.D.

Geographic Characteristics on Emergence Summary

- Based on these findings, we can conclude that although there are some significant effects of geographical characteristics on city emergence and urban growth, most of them are weak.
- Geographical characteristics do not adequately explain the leapfrogging of urban growth. In the following sections, we will shift our focus to the impact of urban network effects.

Effects of Urban Networks

- Numerous studies analyze the impact of city networks impact on a city's growth, using richer measures.
  Most research focuses on neighbors of cities within the 20th century.

Effects of Urban Networks

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- Research exploring earlier periods confirms network effects on urban growth (Beltran Tapia et al., 2021, Bosker and Buringh, 2017, Cuberes et al., 2021, Rauch, 2014).

Effects of Urban Networks

- Numerous studies analyze the impact of city networks impact on a city's growth, using richer measures.
  Most research focuses on neighbors of cities within the 20th century.
- Research exploring earlier periods confirms network effects on urban growth (Beltran Tapia et al., 2021, Bosker and Buringh, 2017, Cuberes et al., 2021, Rauch, 2014).
- Using Özak (2010)'s travel time dataset, superior to the commonly used distances along great circles, we define a city's neighboring area: 16-hour walking range, radius of $\approx$ 50-100 km.

Urban Network Effects on Emergence of Cities

$$p(city_{it}|city_{it-1} = 0) = a_i + D_{t-1}\beta + \delta_t + \epsilon_{it}, \quad (4)$$

- D_{t-1} : vector consisting of four dummy variables, defined by NC_{it-1} as the count of neighboring cities for "city seed" i at time $t-1$.
  - D_{1t-1} is 1 if $NC_{it-1} = 1$, and 0 otherwise;
  - D_{2t-1} is 1 if $2 \leq NC_{it-1} < 5$, and 0 otherwise;
  - D_{3t-1} is 1 if $5 \leq NC_{it-1} < 11$, and 0 otherwise;
  - D_{4t-1} is 1 if $NC_{it-1} \geq 11$, and 0 otherwise.
- a_i : city fixed effect (no time invariant controls).
- δ_t : time fixed effect.

4678 cities ever existed; 4317 survived into Nodern Epoch (after 1800 AD).

Urban Network Effects on Emergence of Cities

- Network effects vary across epochs. Estimation implies an optimal number of neighboring cities influencing a city's emergence; they differ by epoch.

Neighboring Cities (NC_{it-1})	(1) ALL	(2) up to -500	(3) -500 to 300	(4) 300 to 800	(5) 800 to 1400	(6) 1400 to 1800	(7) After 1800
$NC_{it-1} = 1$	1.292***	2.875***	0.216	-0.665	2.161***	0.973	13.908***
	(0.439)	(1.073)	(0.340)	(0.615)	(0.750)	(1.694)	(3.598)
$2 \leq NC_{it-1} < 5$	3.488***	8.502**	-0.481	-0.101	1.281	4.912	22.201***
	(0.867)	(4.062)	(0.423)	(1.968)	(0.920)	(3.012)	(4.311)
$5 \leq NC_{it-1} < 11$	-3.921*	20.158***			0.404	19.259***	-16.896**
	(2.080)	(7.714)			(1.387)	(5.009)	(8.081)
$11 \leq NC_{it-1}$	-14.925***				-0.898	37.150***	-50.933***
	(3.096)				(0.686)	(9.150)	(12.172)
Constant	3.155***	0.117***	0.368***	0.986***	1.506***	5.756***	25.436***
	(0.026)	(0.008)	(0.015)	(0.034)	(0.094)	(0.321)	(1.426)
Observations	154,012	67,350	28,673	22,210	18,943	9,859	4,328
R-squared	0.259	0.109	0.307	0.282	0.303	0.377	0.523
N	4,828	4,828	4,814	4,776	3,589	2,655	1,723

Urban Networks Summary

- The optimal counts of neighboring cities differ across epochs, suggesting that network effects on urban emergence are not consistent throughout history.
- The influence of neighboring city counts is significant and strong up to 500 B.C., becomes less significant from 500 B.C. to 800 A.D., and then regains significance and strength after 800 A.D.
- After 1800, the influence of neighboring city counts exhibits an inverse-U shape, with the optimal number of neighboring cities ranging from 2 to 5.

Population Growth

Geographical Characteristics: Population Growth

$$\log(\frac{\text{population}_{it}}{\text{population}_{it-1}}) = \alpha_i + \delta \log(\text{population}_{it-1}) + \text{X}_i\beta + f(x_i, y_i) + \delta_t + \epsilon_{it}$$

- LHS: population growth rate.
- α_i, X_i, $f(x_i, y_i)$, and δ_t as defined earlier:

$$\log(\text{population}_{it}) = \alpha_i + (\delta + 1) \log(\text{population}_{it-1}) + X\beta + f(x_i, y_i) + \delta_t + \epsilon_{it}$$

Geographical Characteristics: Population Growth

- Geographical characteristics: strong and significant influence on urban growth; especially during 1400 AD – 1800 AD and 1800 AD – 1950 AD.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	ALL	up to -500	-500 to 300	300 to 800	800 to 1400	1400 to 1800	After 1800
river	0.096***	0.053	-0.112	0.047	0.041	0.047**	0.110***
	(0.020)	(0.121)	(0.071)	(0.083)	(0.027)	(0.022)	(0.024)
ocean	0.189***	-0.414*	-0.074	-0.056	0.045	0.079***	0.217***
	(0.020)	(0.247)	(0.083)	(0.085)	(0.030)	(0.024)	(0.023)
roughness	-0.003***	0.000	-0.002	-0.001	-0.001**	-0.001*	-0.003***
	(0.000)	(0.003)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
elevation (100m)	0.006***	-0.007	-0.012*	0.004	0.005	-0.009**	0.007**
	(0.002)	(0.016)	(0.007)	(0.007)	(0.004)	(0.004)	(0.003)
temperature	-0.012***	-0.014	0.003	-0.006	-0.000	-0.011***	-0.017***
	(0.002)	(0.018)	(0.007)	(0.008)	(0.004)	(0.004)	(0.002)
Constant	1.222***	1.304		1.537***			1.423***
	(0.267)	(0.800)		(0.333)			(0.069)
Observations	14,118	168	197	311	1,610	3,478	8,354
N	3,647	58	69	126	564	1,442	3,438

Geographical Characteristics: Summary of Population Growth

- Most geographical characteristics significantly impacted urban growth after 1400 A.D.
- Proximity to a river or ocean within 10km notably enhanced the rate of urban population growth after 1400 A.D.
- Cities located in flat areas tended to experience a higher population growth rate.
- From 1400 A.D. to 1800 A.D., cities situated at lower elevations exhibited faster growth, but after 1800 A.D., cities at higher elevations began growing more rapidly.
- After 1400 A.D., cities in cooler climates showed faster growth rates.

Urban Network Effects on Population Growth

$$log(\text{population}_{it}) = a_i + (\delta + 1)log(\text{population}_{it-1}) + D_{t-1}\beta + \delta_t + \epsilon_{it}, \qquad (5)$$

- D_{t-1} is a vector consisting of four dummy variables. Define NC_{it-1} as the count of neighboring cities for city seed i at time $t-1$.
  - D_{1t-1} is 1 if $NC_{it-1} = 1$, and 0 otherwise.
  - D_{2t-1} is 1 if $2 \leq NC_{it-1} < 5$, and 0 otherwise.
  - D_{3t-1} is 1 if $5 \leq NC_{it-1} < 11$, and 0 otherwise.
  - D_{4t-1} is 1 if $NC_{it-1} \geq 11$, and 0 otherwise.
- a_i : city fixed effect.
- δ_t : time fixed effect.

Urban Network Effects on Population Growth

Network effects become most significant in the two most recent epochs

VARIABLES	(1) ALL	(2) up to -500	(3) -500 to 300	(4) 300 to 800	(5) 800 to 1400	(6) 1400 to 1800	(7) After 1800
log(population$_{it-1}$)	0.647***	0.196**	0.156	0.455***	0.464***	0.364***	0.367***
	(0.013)	(0.079)	(0.132)	(0.058)	(0.044)	(0.034)	(0.016)
Neighboring Cities (NC_{it-1})							
$NC_{it-1} = 1$	0.092***	0.235*	-0.195*	0.409	-0.013	0.074	0.136***
	(0.028)	(0.125)	(0.103)	(0.257)	(0.068)	(0.056)	(0.049)
$2 \leq NC_{it-1} < 5$	0.149***	-0.060	-0.151	0.047	0.078	0.167***	0.138**
	(0.032)	(0.119)	(0.239)	(0.123)	(0.080)	(0.062)	(0.061)
$5 \leq NC_{it-1} < 11$	0.240***	-0.061			0.177*	0.214***	0.169**
	(0.037)	(0.232)			(0.098)	(0.066)	(0.081)
$11 \leq NC_{it-1}$	0.363***				0.266	0.273***	0.279***
	(0.044)				(0.211)	(0.073)	(0.088)
Constant	1.171***	2.604***	4.048***	2.336***	1.713***	1.721***	2.114***
	(0.043)	(0.240)	(0.625)	(0.257)	(0.140)	(0.097)	(0.066)
Observations	13,423	148	180	265	1,422	2,992	7,676
R-squared	0.896	0.844	0.825	0.826	0.885	0.921	0.929
N	2,948	38	52	80	376	955	2,758

Urban Network Effects on Population Growth Summary

- The impact of urban network effects on population growth intensifies over time.
- Cities with a larger number of neighboring cities experienced faster growth after 1400 A.D.

Sequential Growth

Sequential Growth

- Regional population significantly influences city formation and growth, highlighting its role in urban development despite a constant count of nearby cities.
- Large cities foster not only their own growth but also stimulate surrounding urban development, demonstrating a synergistic impact on the region.
- Our following work will explore additional factors driving urban growth beyond regional population, geographical traits, and existing urban presence, guided by the framework proposed by Cuberes (2011).

Sequential Growth

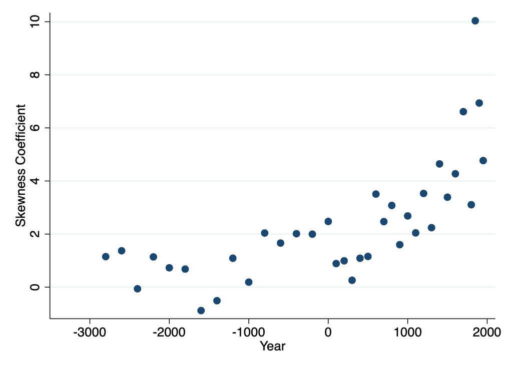

Figure 8: Scatter of the Coefficient of Skewness of Cities' Growth Rates

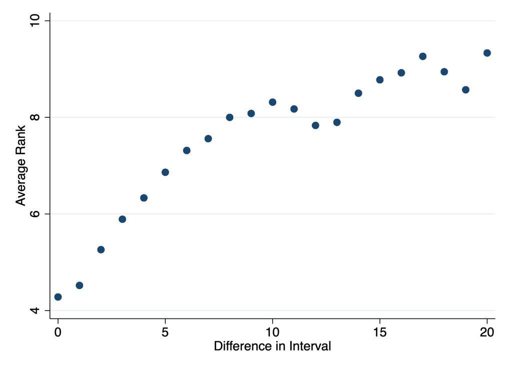

Figure 9: The evolution of the average rank of the fastest-growing cities global

- Revealing a consistent rightward skew in the cross-sectional distribution of city growth rates, which is in line with the sequential city growth theory.

Sequential Growth

Our analysis utilizes a panel data approach to estimate urban growth dynamics via the equation:

$$Decile_{25,j,t} = \eta_j + \beta_1 I_{jt} + \beta_2 NC_{jt} + \beta_3 NC_{jt}^2 + \epsilon_{jt}, \tag{6}$$

- $Decile_{25,jt}$ is the mean growth decile for city j in the top 25%.
- NC_{jt} is the number of neighboring cities.
- η_j controls for city-specific fixed effects.
- I_{jt} denotes the difference between the current interval and the initial interval when city j first emerged as a star-growth performer.

Sequential Growth

	(1)	(2)	(3)	(4)
I_{it}	0.220***	0.170***	0.144***	0.148***
	(0.020)	(0.023)	(0.024)	(0.026)
NC_{it}		0.078***	0.205***	0.214***
		(0.013)	(0.027)	(0.025)
NC_{it}^2			-0.003***	-0.003***
			(0.000)	(0.000)
log(Regional Population)$_{it}$				-0.030
				(0.049)
Constant	4.928***	4.391***	3.922***	3.962***
	(0.060)	(0.099)	(0.140)	(0.172)
Observations	6,752	6,752	6,752	6,752
R-squared	0.782	0.789	0.793	0.793

- Star-growth performers became large over time.
- The dynamics of sequential growth differ fundamentally from those of network effects.

The Life Spans of Cities

The Life Spans of Cities

- We have so far focused on the influence of geographic characteristics and urban networks on urban growth.
- Is a city's history an important factor?
  We find that countries with a long history have hosted relatively larger cities.
- Have older cities maintained their large sizes?
  Does this effect vary across continents?

The influence of a city's history on its population and growth rate.

Two alternative specifications:

$$\log(\text{population}_{it}) = \alpha_i + \beta_1 \text{age}_{it} + f(x_i, y_i) + \delta_t + \epsilon_i \tag{7}$$

and

$$\log(\text{population}_{it}) = \alpha_i + \gamma \log(\text{population}_{it-1}) + \beta_2 \text{age}_{it} + f(x_i, y_i) + \delta_t + \epsilon_i, \tag{8}$$

where: age_{it}, city i's age as of time t; α_i is a random effect.

The Life Spans of Cities

- The impact of a city's age on its size and population growth grows.

	ALL	up to -500	-500 to 300	300 to 800	800 to 1400	1400 to 1800	After 1800
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Panel A: City Size						
age (100 yr)	0.066***	-0.004	0.024***	0.042***	0.066***	0.080***	0.061***
	(0.005)	(0.010)	(0.009)	(0.009)	(0.008)	(0.006)	(0.005)
Constant	3.325***	2.646***		4.274***		2.995***	
	(0.183)	(0.257)		(0.154)		(0.051)	
Observations	19,103	270	310	541	2,278	5,386	10,318
N	4,678	96	122	266	804	2,511	4,317
	Panel B: Population Growth						
	(8)	(9)	(10)	(11)	(12)	(13)	(14)
log(population$_{it-1}$)	0.794***	0.730***	0.818***	0.637***	0.823***	0.774***	0.805***
	(0.008)	(0.056)	(0.065)	(0.041)	(0.018)	(0.017)	(0.011)
age (100 yr)	0.004**	-0.002	-0.000	0.013***	0.000	0.006**	0.004**
	(0.001)	(0.007)	(0.005)	(0.004)	(0.002)	(0.002)	(0.002)
Constant	0.917***	0.863**		1.396***	0.713***		
	(0.267)	(0.419)		(0.236)	(0.092)		
Observations	14,123	168	197	311	1,610	3,480	8,357
N	3,648	58	69	126	564	1,443	3,439

Age Regressions Summary

- Older cities are more likely to persist.

Why Do Cities Disappear?

Why do Cities Disappear?

- After exploring factors behind city emergence and growth in previous sections,
- we now turn our attention to understanding why cities disappear.
- Despite the long history of urbanization that has seen many cities emerge and endure,
- we delve into the reasons behind the disappearance of numerous others.

Why do Cities Disappear?

We model the probability of a city's discontinuation, given its existence in the prior period, as follows:

$$p(city_{it} = 0 | city_{it-1} = 1) = \alpha_i + X_i\beta + f(x_i, y_i) + \delta_t + \epsilon_{it}, \quad (9)$$

where:

- α_i represents a city-specific random effect.
- X_i encompasses time-invariant and time-varying geographic attributes, including proximity to rivers and oceans (within 10 km), terrain roughness, elevation, and categorical temperature ranges.
- $f(x_i, y_i)$ specifies a cubic relationship with longitude (x_i) and latitude (y_i), reflecting geographic positioning.
- δ_t accounts for time-specific fixed effects.

Why do Cities Disappear?

- The influence of geographical characterises on city vanish

VARIABLES	(1) ALL	(2) up to -500	(3) -500 to 300	(4) 300 to 800	(5) 800 to 1400	(6) 1400 to 1800	(7) After 1800
river	0.010	-0.084	0.054	0.049	0.011	0.007	0.011
	(0.010)	(0.096)	(0.092)	(0.059)	(0.023)	(0.014)	(0.011)
ocean	-0.003	0.163	0.120	0.061	-0.064**	-0.034**	0.004
	(0.010)	(0.123)	(0.085)	(0.060)	(0.027)	(0.014)	(0.011)
roughness	-0.000	-0.000	0.004***	0.002*	-0.000	0.000	-0.000
	(0.000)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
elevation (100m)	0.005***	-0.011	-0.002	-0.010*	0.004	-0.001	0.004**
	(0.001)	(0.016)	(0.007)	(0.005)	(0.003)	(0.002)	(0.001)
temperature (°C). Note: 25 $\geq$°C is the baseline group							
°C $<$ 5	-0.070***		-0.252*	0.093	-0.048	0.023	-0.054*
	(0.026)		(0.130)	(0.163)	(0.091)	(0.054)	(0.030)
5 $\leq$ °C $<$ 15	-0.079***	0.010	0.202	-0.023	-0.082	-0.024	-0.062***
	(0.018)	(0.170)	(0.132)	(0.109)	(0.067)	(0.042)	(0.020)
15 $\leq$ °C $<$ 25	-0.069***	0.018	0.106	-0.076	-0.028	-0.039	-0.080***
	(0.017)	(0.087)	(0.129)	(0.086)	(0.056)	(0.037)	(0.018)
Constant	-0.172**		0.525***	0.012	0.406***	0.307***	0.126***
	(0.081)		(0.184)	(0.113)	(0.064)	(0.042)	(0.018)
Observations	15,150	242	288	410	1,786	3,619	8,805
N	4,027	82	126	184	642	1,524	3,730

Why do Cities Disappear?

We explore an alternative model to understand city exits, emphasizing the influence of neighboring cities. The exit probability, given a city's prior presence, is modeled as:

$$p(city_{it} = 0 | city_{it-1} = 1) = a_i + D_t\beta + \delta_t + \gamma \log(\text{regional pop})_{it} + \epsilon_{it}, \qquad (10)$$

where:

- D_t includes dummy variables representing the count of neighboring cities, structured as follows:
  - $D_{1t} = 1$ if $NC_{it} = 1$, otherwise 0.
  - $D_{2t} = 1$ for $2 \leq NC_{it} < 5$, otherwise 0.
  - $D_{3t} = 1$ for $5 \leq NC_{it} < 11$, otherwise 0.
  - $D_{4t} = 1$ if $NC_{it} \geq 11$, otherwise 0.
- a_i represents city-specific fixed effects, and δ_t captures time-specific fixed effects.

Why do Cities Disappear

- The network effect on city vanish

VARIABLES	(1) ALL	(2) up to -500	(3) -500 to 300	(4) 300 to 800	(5) 800 to 1400	(6) 1400 to 1800	(7) After 1800
Neighboring Cities (NC_{it})							
$NC_{it} = 1$	26.836***	50.489***	37.368***	52.411***	29.598***	24.184***	37.362***
	(1.720)	(7.948)	(13.160)	(12.876)	(5.144)	(4.224)	(2.459)
$2 \leq NC_{it} < 5$	35.277***	64.138***	95.183***	57.163***	34.829***	29.022***	47.097***
	(1.870)	(13.976)	(22.723)	(15.996)	(6.071)	(4.787)	(2.654)
$5 \leq NC_{it} < 11$	45.067***	76.008***			38.981***	32.178***	51.027***
	(2.234)	(14.690)			(7.246)	(5.450)	(2.960)
$11 \leq NC_{it}$	56.101***				44.227***	34.777***	56.013***
	(2.727)				(8.746)	(6.048)	(3.143)
log(Regional Population)$_{it}$	-10.922***	-22.088***	-13.841***	-20.947***	-13.257***	-9.780***	-12.552***
	(0.418)	(1.814)	(2.044)	(3.163)	(1.718)	(1.473)	(0.400)
Constant	11.868***	27.317***	16.470***	15.490***	12.740***	10.370***	16.539***
	(1.029)	(3.314)	(1.409)	(0.977)	(1.588)	(1.578)	(1.731)
Observations	14,236	214	230	323	1,559	3,096	7,935
R-squared	0.473	0.641	0.415	0.580	0.443	0.529	0.680

Conclusion

Conclusion

- Our investigation spans thousands of years to trace the evolution and expansion of cities, using a comprehensive historical dataset to understand global urban growth dynamics.
- We discover that while geography modestly influences urban development, the internal networks of cities significantly fuel urban renewal and growth.
- The study identifies a pattern of sequential growth among urban agglomerations, suggesting a predictable progression in how cities expand over time.
- Additionally, the age of a city emerges as a crucial determinant of its population size and growth rate, underscoring the complex relationship between urban geography, social networks, and the historical trajectory of urbanization.

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