Cityrise and Cityquake: Network Dynamics of City Growth, Trade Networks, and Conflict

Five Alternations Between Global Economy and Regional Economies in Eurasia in the Last Millennium: Definitive Evidence of Macro Civilizational Dynamics

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Outline: Cityrise and Cityquake

1) What are cityquakes & how they are measured?
   Cityquake/rise city size scaling definitions
   $q$-exponential measure of cityrise&fall (cityquakes)
   Tsallis non-extensive statistical mechanics & theory –
   network trajectories and long-range correlations

2) Introduction to the Historical Slides
   Network definitions for trade routes
   Chronological network slides of Eurasian cities
   How $q$ for cities changes over time

3) Summary of dynamics
   Interesting things (many!) to do with these data
(1) What is a cityquake?

• Imagine a sandpile experiment, pouring sand on the top of the pile, until the pyramid of sand undergoes little quakes until it finally collapses into a flatter heap.

• In a cityquake, when a city size distribution collapses, it isn’t quite so dramatic, but goes from this (low-q) to this (with a Zipf-like tail) (high-q) … and then builds back up again (cityrise)
The sand pile model has a complex dynamic with power law scaling of the size and recurrent timing of rises and quakes.

Cityquakes and cityrises, & their rises and falls over centuries, were only discovered in 2005 by White and Kejžar, using methods of Tsallis.

They have a more complex dynamic: of growth, innovation, and exchange, affecting capacity for sustainability, and conflict over resources.

Coming to understand this dynamic may be essential for our species’ sustainability on earth.
The discovery of cityquakes builds on Chandler’s 1987 study of the sizes of the largest 75 world cities in 28 historical periods, and -- instead of measuring the tendency of the very largest cities of size $s$ to form a power law distribution in which $\text{freq}(s) \sim 1/s^\alpha$, or the rank-size method of Zipf -- used a new scaling method, the q-exponential. It converges to a power law in the tail and is both theoretically motivated and ideal for measuring distribution curves like these:

1. cityquakes
Constructing the size distributions

To see differences in city size distributions clearly over centuries, and for the whole spectrum of sizes rather than just the extreme tails, we bin the $\log(s=\text{sizes})$ of cities as the $x=\log(s)$ axis, and put the cumulative number of people in cities of size $s$ or greater on the $y$ axis. We then get varying distributions over time like these.
the usual entropy $S=K \ln W = S_1$ as defined by
$S_q = K (1 - \sum \pi_i^q)/(q-1)$
$\pi_i$ is the probability for size logbin $s$
low $q$ distributions converge toward
exponential, thin power-law tails
(sometimes exaggerated in actuality)

*Low–q fittings for years in 1000 – 2000*

$q$ entropy scaling function:

$$y = y(0) (1 + (1 - q) \frac{s}{\kappa})^{-1/(q-1)}$$

$y(0)$=intercept parameter
$\kappa$=scale parameter
$q$=q-exponential parameter

Cumulative log-log city size distributions

(low $q$) more equal populations in body
compared to tails

*High–q fittings for years in 1000 – 2000*

high $q$ distributions have
thicker power-law tails and
more differentiated body
What does fitting this $q$-function mean?

One way to fit a null hypothesis for completely random behavior is to fit the data to a maximum entropy function $S = K \ln W = ( S_q = K(1 - \sum p_i^q)/(q-1) \mid q = 1 )$

Optimizing $q$ to get best fits to a $q$-entropy function means finding the best description of departure from randomness ($q = 1$) in which there is nonlinear, multiplicative, or proportionality effects for which only the tail of the distribution conforms asymptotically to a power law (e.g., rich get richer, but less so for the poor).
scaling definitions related to $q$

Pareto (Power-law) for city sizes – usually applied to larger tails of size distributions only – linear in log-log.

Pareto slope coefficient – larger for thin tail, smaller for thick tail. Zipf law specifies $\alpha + 1 = 1/(q - 1) = 2$

$q$ parameter scaling – inverse to Pareto coef. $\beta$ for tails: $q = 1 + 1/\beta$. Zipfian $q$ is 1.5

$q = 1$ is exponential; maximum $q=2$.

$q$ values differ in long historical periods.
(2) Introduction to historical slides

- Network of cities within 800 miles of each other
- Cityquake index $q$ – to be explained – drawn on lower left showing how $q$ for cities changes over time relative to spatial networks (& trade)
  - Black line for China; lighter Grey line for the World
- Largest 5 cities will be shown in red ;
  next largest 5 cities shown in cyan.
- These slides start with a cityquake in 1300
- Dashed lines as placeholders for silk routes
Cityquakes: world city size q-population distributions & conflict events: (two sorts: resolved and unresolved w.wars) 25-100 year intervals – led by China (heavy line)
What are $q$-cityquakes historically?

They represent a decades-long slumping of the urban size hierarchy, especially as measured by weighting the points in the logged distribution for cities of size $s$ proportionally to the numbers of people in cities at that size or larger.

They tend to occur at the scale of world cities, continent-wide distributions, or large integrated and bounded macroregions.

There is a long duration of slumps (hi-$q$ continuity) at these scales, as long as 200 years.
What is a $q$-rise historically?

They represent a decades-long rise in the urban size hierarchy, especially as measured by weighting the points in the logged distribution for cities of size $s$ proportionally to the numbers of people in cities at that size or larger.

They tend to occur at the scale of world cities, continent-wide distributions, or large integrated and bounded macroregions.

There is a long duration of rises (low-$q$ continuity) at these scales, as long as 200 years.
Network definitions

Potential trade connections – cities within a trading radius of two cities (e.g., 800 miles)

Biconnected pairs of nodes: 2 or more independent routes

Bicomponent – a largest subnetwork in which all pairs of nodes (cities) are biconnected

N = the effective number of separate or intersecting bicomponents, e.g., N=3
Focusing on Eurasia, slides will show 23 historical periods, starting in 900 CE, each with a network of major trade route potentials among the biggest 70 world cities (data from Chandler 1987). Trading zone radius for these illustrations is 800 miles, e.g., 1 month travel in medieval period.

We make multiple networks at different radii for purposes of finding boundaries of replication.

Where and How many (N) are the bicomponents?

Co-variations in q on lower left, sequentially

N leads q?

Explanatory correlates of q?

Predictors of growth contributing to q?
The statistical question for describing cityrise&fall: what are the correlates of $q$ that we can expect to see in the slides?

- Ratio of average distances (DD/AA) large/large over small/small: divided by World Average distances between cities (rationorm)
- Laurent has a result (which I haven’t checked as yet as he is in Indonesia)
- in a 1400 mile radius (2200km) $R^2 = .43$ (R=-.665)
- (hi dist ~ low q): *a result we were searching for to describe q*, holds to 1925 1400 mile radius (2200km)
- in a 600 mile radius (1000 km) Rationorm $R^2 = .286$ (-.252 adj)

→ of $R^2 = .64$ using differences in $q$ and differences in radius pop measures for successive periods
q varies inversely to large/large city distances within and 1000 km divided by the average intercity distance

\[ R^2 = 0.4234 \]
Other results still under investigation: here q varies inversely to populations within distances 800 and 1000 km
How to “describe” changes in $q$?

In a cityquake period, trade shrinks spatially to smaller regions as a result of conflicts at the boundaries of large regions. The net result of “safer cities” that shrink the average distances between them and those of large cities.

I.e., The location of multiple largest-hubs also shrinks to within regions. These regions eventually become our megacity regions of today.

In cityrise periods trade expands to broader interregional networks with a net result of increasing average distances between them and those of large cities.

I.e., Also true for the largest hubs – these become the global cities, farther apart.
CITYQUAKE FOR EURASIA (following one for China) AND FOR THE WORLD

Broken network links characterize high q (here: tenuous interregional connectors)

1300 AD

4-Khanate conflicts lessen Mongol trade

Mongols conquer Southern Song 1279: Kublai Khan becomes Yuan emperor

Mongol use and spread paper money after 1264

Khanate conflicts lessen Mongol trade

Mongol use and spread paper money after 1264

CITYQUAKE FOR EURASIA (following one for China) AND FOR THE WORLD

Broken network links characterize high q (here: tenuous interregional connectors)
Mongols refocus on Yuan administration of China. Silk routes now less important

Black Death spread in China, then to Mongols, then the West

Broken network links characterize high \( q \) (tenuous interregional connectors)
1368 Ming retake China

Silk routes cut by Ming, Turkmeni marching lords to the West

Renewed network links characterize low q (power law tail)
1450 AD
Silk routes unimportant

3rd Ming reign explores spice routes to Africa:
1421 Ming move capital to Peking; edict to end treasure voyages;
China turns inward

1421: All land and sea routes for Europeans to the East are closed.

high q again led by China, 100 years, although Europe will sail to the New World
World population growth turns super-exponential (with resources from the new world?)

Renewed network links characterize low $q$ (power law tail) – but China high $q$ leads change
Broken network links characterize high q
Renewed network links will lead change to low q (here: tenuous interregional connectors)
Renewed network links characterize low $q$ (power law tail) – **China synchronized**
1700 AD

Broken network links return to high q – esp. for China leading
Broken network links typify high \( q \) – China leading – bifurcated world
Circum-European cities start to overtake China in number

Broken network links typify high q – bifurcated world
European cities overtake China in number and size

Industrial revolution

Broken network links typify high q – trifurcated world – best example of high local navigability
Broken network links typify high q – trifurcated world – but **China developing power-law tail**

(here: tenuous interregional connectors)
1875 AD

Broken network links typify high q – bifurcated - China power-law tail thinning toward low-q

(here: tenuous interregional connectors)
1900 AD

Broken network links typify high $q$ – trifurcated Eurodominant - China leads shift to low-$q$ 50 yrs
Broken network links typify high q – trifurcated - rise of Japan - China returns to high q
Start of a low q Zipfian tail for world city distribution – trifurcated – but linked by airlines
q from China and World dataset over time
A statistical question: what causes city growth generally?

- 50 years time lag:
  - Back Population in 600 mile radius
    - $R^2 = 0.29$ (adj)
  - Population in 120 mile radius
    - $R^2 = 0.64$ (adj) (total)
  - Back pop partial $R^2 = 0.36$
  - Fractal property of same backpop correlation for 400-1200 miles

- No time lag:
  - Control for: 120 mile radius
  - Control for: 250 mile or greater radii
  - $(R^2 \geq 0.50$ for each)

- Control for: 250 mile or greater radii
  - $(R^2 \geq 0.50$ for each)

- (R2 $\geq 0.50$ for each)
comment

• Population change is a generational variable, changing in say 25 year intervals
• Our data are coded in 50
• If we interpolated our data into 25 intervals, would we get a better test?

Sequel: early transition from 900-1000 (high q quake); 1100-1250 lo-q cityrise
Tracing a cityrise in Eurasia from the year 900

- Three regions:
- Some separations: 800 miles btwn large cities.
- Silk road connections:
- Islamic isolate in Spain:
- Baghdad a huge capital:
- After the rebellion of An Lushan, 755, the Tang (618-907) were in decline. Arab ships loot Canton in 758.

- Near East, India, China
- Some small cities, peter out.
- Arab conquests very wide.
- Arab fleets in Mediterranean
- Changan (Xi’an) in China a declining center of the Tang dynasty, who had lost the northwest to the Arabs in 751 and shifted to xenophobia.
In these slides we connect the city network & city size distributions and power-law tails connected to q-exponential scaling of city sizes low q with thin power law tails of global hubs CORRELATES with global network links
1000 AD (cityquakes)

- Two regions:
- One cut-node city:
- Silk road connections:
- Islamic isolate in Spain:
- Baghdad taken by Shi’ite Buyids, pop shrinks 85%:
- Probable cityquake collapse (high q):
- Venetian trade begins
- Near East vs. India&China
- Ghazna-Afghanistan, expands
- More small cities, peter out.
- Arab polities in conflict.
- Arab fleets fall into neglect
- 5 Dynasties in north, 10 Kingdoms to the south to 960,
  Kaifeng becomes the capital of the No. Song, civil service based on talent, but tribute paid to the northern tribes.
960: Song capital startup at Kaifeng.

City sizes in collapse - Seems to be high q (cityquake), population flattening. But global network fosters small-scale trade that will build more global centers over time.

1000 AD
The time is 1100 (cityrise)

• One connected world:  
• One cut-node: Bougie  
• Silk road connections:  
• High point of trade  
• Islamic Spain tied in  
• Large cities spread out  
• Cityrise (low q)  
• Venetian trade connects to Milano, radiates to Europe

• Kyoto to Marrakesh  
• Mediterranean trade rising  
• More small cities, peter out.  
• Byzantium struggles with Normans in Palermo ….  
• Venetian fleets expand  
• High point of Song innovation and trade, capital at Kaifeng. Invention of national markets, credit mechanisms, and paper money diffuse
CITYRISE

Global network links characterize low q (more exponential body with power law tail for city sizes)
1150 AD

1127: Northern Song capital of Kaifeng conquered, Song to south at Hangzhou

Global network links characterize low $q$ (more exponential body with power law tail for city sizes)
Song capital at Hangzhou

Golden Horde silk routes

Global network links characterize low $q$
QITYQUAKE FOR CHINA

Broken network links for China lead change to high q – lead the west by 50 years

1250 AD

1215: Jin lose Beijing to Mongols

1234: Mongols conquer Jin

Song capital stays at Hangzhou in South but silk route trade disrupted by conflict
1300 AD

4-Khanate conflicts lessen Mongol trade

Mongols conquer Southern Song 1279: Kublai Khan becomes Yuan emperor

CITYQUAKE FOR EURASIA (following one for China) AND FOR THE WORLD

Broken network links characterize high q (here: tenuous interregional connectors)
Some findings, reiterated and extended:

- Zipfian for city sizes not invariant

- Actual city size distributions are $q$-governed and reflect spread or self-enclosure that is greatly affected by war and trade

- Trade zone $N$ biconnectedness (as affected by conflict) interacts with city size $q$ distributions ($p<.003$) varying by a fitted $q$-exponential parameter (time-lag effect higher, $p < .001$)

- (We give the rest of the dynamics in other papers), especially those dealing with the medieval period in Europe but the interesting things to do are these
Does N (effective bicomponents) lead q?

Can we find dynamics such as: external war breaking links → city quakes in q → population cycle → internal war diminishing external boundaries → allowing links to reconfigure at a global level
N leads q more clearly when dichotomized
(3) Interesting things to do with the data

• Looking at the *correlative dynamics* for Turchin’s dataset on secular cycles. Secular rise/fall to *q-rise/fall two-to-one timing*. Involves breaking out regions: China, England, Continental Europe, USA, Japan; and scaling *q* for each.

• Relating the *q*-quake timings to world and regional population growth in general.

• Finding the relations of all this to upsweeps of global empires (the Chase-Dunn project at UCR) and networks of royals and nobles (Ben Jester) …

• And more: possibly a joint NSF HSD grant …?
$q$-periods have a close fit, at different time scales of doublings, with: 2:1 Secular Population cycles (not shown) ~4:1 Modelski world leadership cycles, circa 8:1 Kondratiev cycles.
N converges for different distances: MEGACITIES and GAPS

(3) Things to do