Network Dynamics of City Sizes, Trade Networks, and Conflict

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We have all seen the reemergence of networks in the sciences
What to do with SFI and the future?

Some concepts are great – small world, scale-free – but they are not going to get us where we need to go

What are the possibilities – where to go?

New methods, substantive foci → to get new results
Network realism :: in understanding process :: informative data about central soc. sci. issues

What areas of networks & dynamics need new techniques such as cohesion analysis, network dynamics, new kinds of scaling analysis, richer complex datasets, generalized network theory?

A problem for illustrative purposes: city size hierarchies and how they are likely to be driven by trade networks

connect processes and big events in civilizational history-
City growth & sizes :: trade networks :: conflicts/wars, disruptive and peacemaking :: innovation and industry :: world events
Outline

• Network definitions for trade routes
• Scaling definitions for city size distributions – q-exponential measure – Tsallis non-extensive statistical mechanics & theory – constraints and long-range correlations
• Chronological slides of Eurasian cities showing how q for cities changes over time in relation to trade networks
• Summary of dynamics
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
Scaling definitions

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
This function optimizes the entropy $s_q$.

Cumulative log-log city size distributions

Q-scaling / Q-history

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

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

Low $q$ distributions converge toward exponential, thin power-law tails (sometimes exaggerated in actuality).

High $q$ distributions have thicker power-law tails.
Coevolution dynamic of trade networks, city size distributions & conflict events: 25-100 year intervals – q-population Eurasian history led by China (heavy line)
Slides will show 23 historical periods, starting in 900 CE, each with a network of major trade route potentials among the biggest 73 world cities—focusing on Eurasia. 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 boundaries of replication.

Where are the bicomponents? How many (N)?

Co-variations in Q on lower left, sequentially N leads Q?
From first stirrings of globalization to the 21st Century

Europe

Central Asia

Near East

India

In these slides I will 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
960: Song capital at Kaifeng, invention of national markets, credit mechanisms diffuse

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

1150 AD

1127: No. Song capital of Kaifeng conquered, Song move to south, capital at Hangchow.
1200 AD

Song capital at Hangchow

Golden Horde silk routes

Global network links characterize low q from China and World dataset over time
Broken network links lead change to high $q$ – led by China, 50 years
Broken network links characterize high $q$ (here: tenuous interregional connectors)

1300 AD

1279: Mongols conquer Song

Kublai Khan Mongol trade

From China and World dataset over time
1350 AD

Mongols refocus on Yuan administration of China

Silk routes unimportant

Broken network links characterize high q (here: tenuous interregional connectors)
1400 AD

1368 Ming retake China
Silk routes unimportant

Renewed network links characterize low q (power law tail)
World population growth turns super-exponential

1450 AD
1421 Ming move capital to Peking
Silk routes unimportant

Renewed network links characterize low q (power law) – high q led by China, 100 years
Renewed network links characterize low q (power law tail) – but China high q leads change
Broken network links characterize high $q$
For the next series q-periods fit with

2:1 Secular Population cycles (not shown) 3-4:1 Modelski world leadership cycles, circa 8:1 Kondratiev cycles (doublings)
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
Renewed network links will lead to 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
1800 AD

Circum-European cities start to overtake China in number.

Broken network links typify high q – bifurcated world.

q from China and World dataset over time
1825 AD

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

(here: tenuous interregional connectors)
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
Does N (effective bicomponents) lead Q?

Are there dynamics such that: 
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
Navigability of our city network neighborhoods is invariant through all periods. Here is our computation of the Adamic et alia (2002) measure of the average ratio of the hub degree of the largest hub in the neighborhood of cities varying by degree. Cities with degree > 13 are rare.
Findings reiterated:

• 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)

• Network neighborhood navigability–structurally invariant over all periods, low Q periods (higher N *biconnectedness*) face problem of navigating outside regions, helped by random traversal and *global financial centers*

• Zipfian for city sizes not invariant

• (We gave the rest of the dynamics in other papers)