A geohistorical theory of systems of cities: co-evolution of urban trajectories

Denise Pumain
Université Paris I Panthéon-Sorbonne
UMR Géographie-cités

SoDUCo BNF seminar Spatial Analysis of geo-historical data May 23rd, 2023

Urbanization pattern in North India

Source : https://www.earthdata.nasa.gov/learn/backgrounders/nighttime-lights#data

Central Henan neolithic settlements (China around 5000 BP)

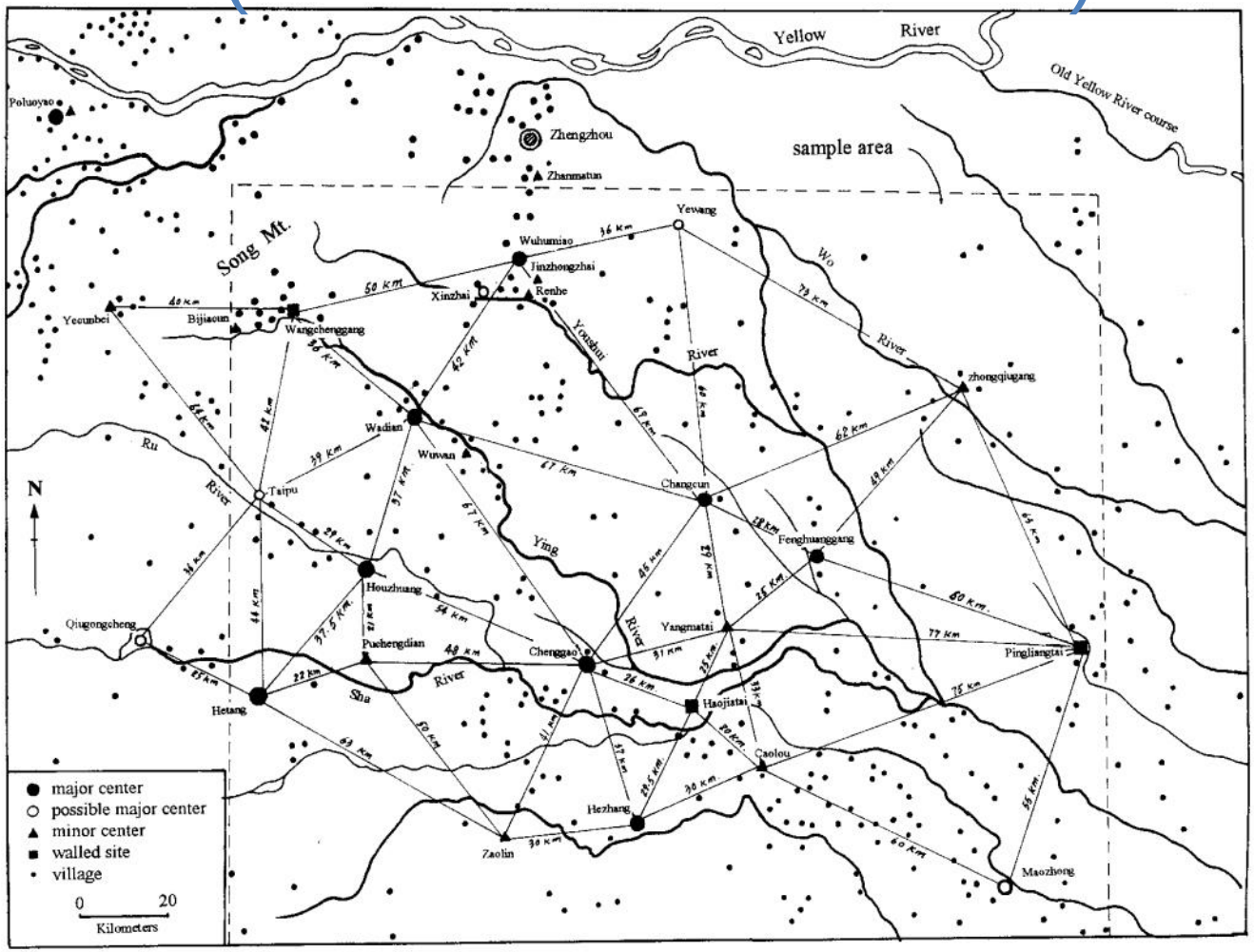
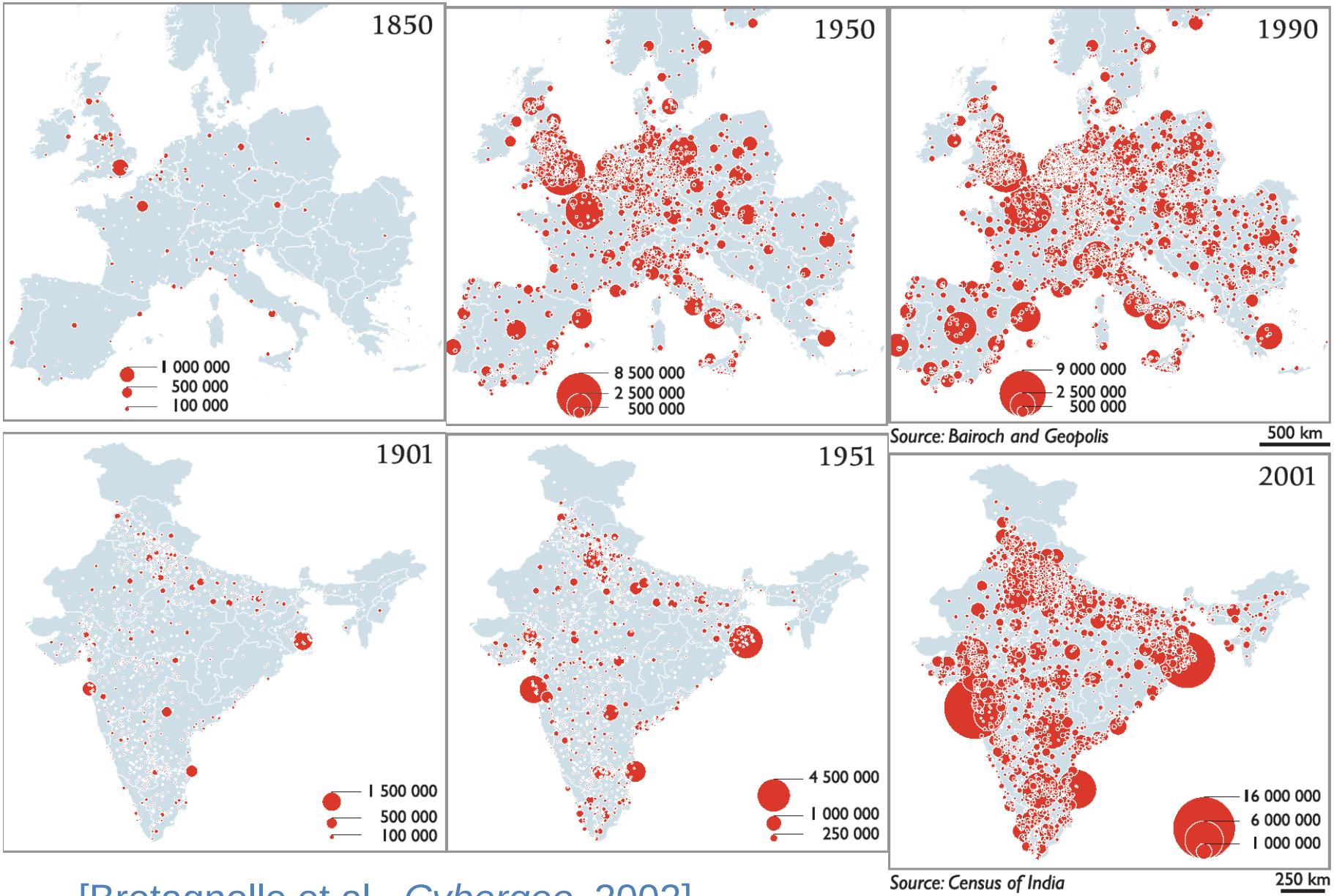


FIG. 23. Distribution of Longshan sites in the central Henan cluster (redrawn from NBCR 1991: maps 60–91, 184–187).

Source: Liu, 1996

Persistency of urban hierarchies



[Bretagnolle et al., *Cybergeo*, 2002]

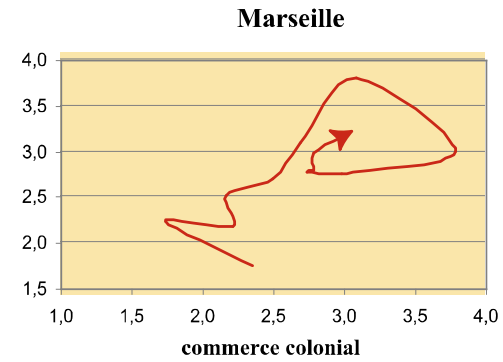
Reversals in urban trajectories

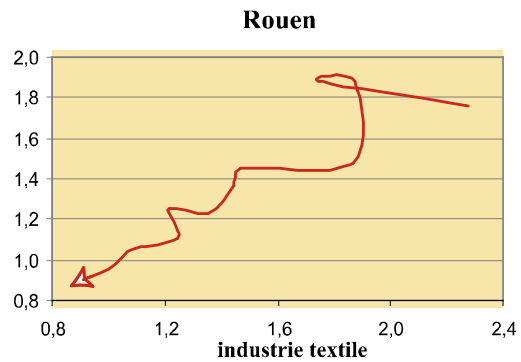
$X = Pi_t / PU_t$

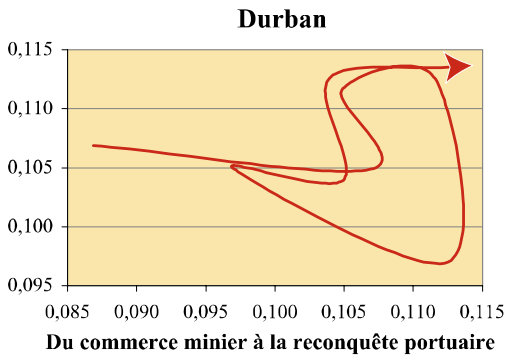
(Pit = total population city i time t
PU_t = total population system of cities time t)

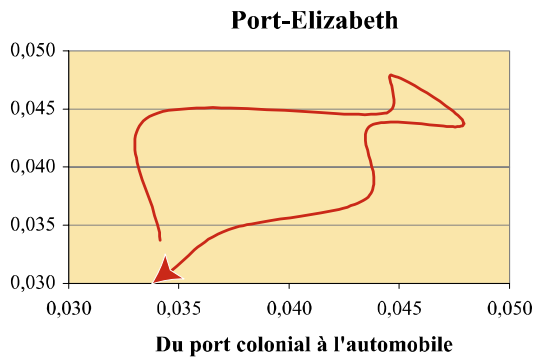
$Y = Pi_{t+1} / PU_{t+1}$

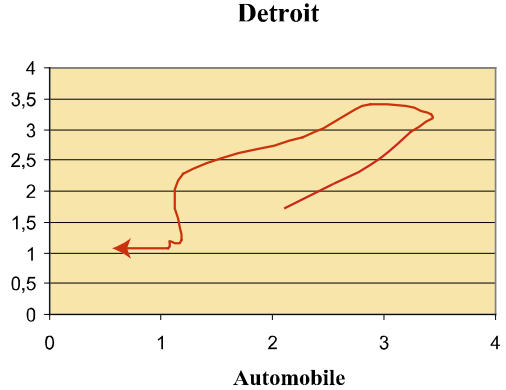
[Bretagnolle, Vacchiani-Marcuzzo, Pumain 2007]

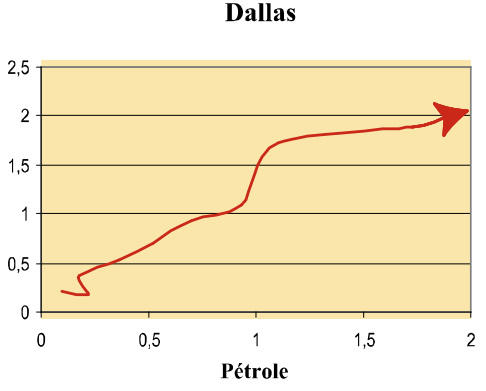










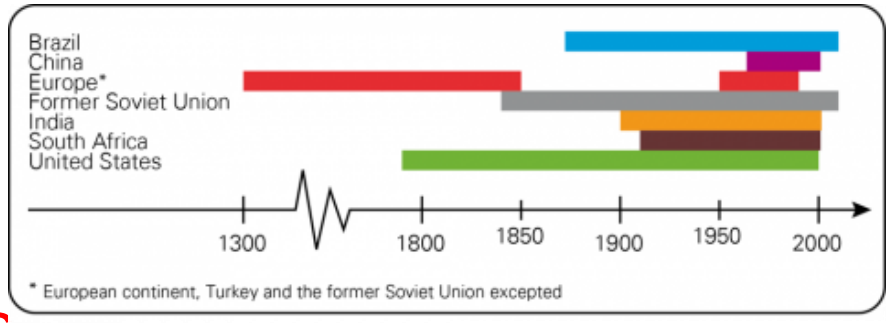


en abscisses x = P i t / P u t
en ordonnées y = P i t+1 / P u t+1

P i t : population de la ville au temps t
P u t : population totale du système des villes au temps t

Lessons from GeoDiverCity for complex urban systems

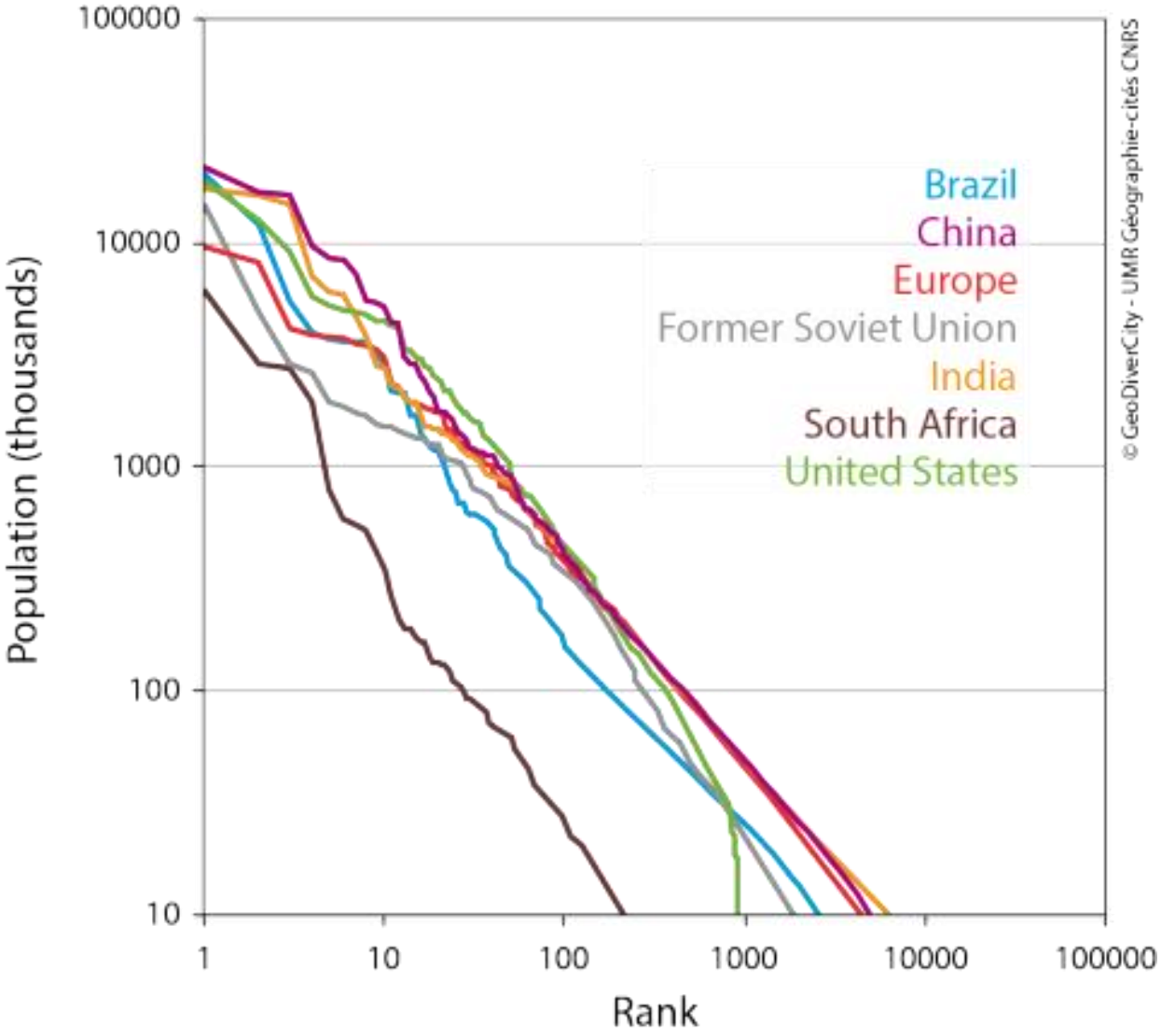
- A worldwide comparison
  USA, Europe, Brazil, Russia, India, China, South Africa



- Harmonised data bases
  - 25000 Functional Urban Areas >10 000 inhab.
  - Trajectories 1900-2010 (pop size, urban functions)
- Statistical analysis and multi-agent modelling

Size distributions in 7 systems of cities

Zipf's law:
Urban sizes continuum over more than 4 orders of magnitude (10^3 à 10^7 inhab.)



[GeoDiverCity, Pumain et al. *Cybergeo* 2015]

Cities' sizes are relative to the size of the system they belong to (approximate figures for 21st century)

Qualitative sizes of cities and quantitative thresholds

Country	Large	Medium	Small
China	10 millions	5 millions	500 000
India	10 millions	5 millions	200 000
South Africa	1 million	50 000	5 000
Europe	2 millions	200 000	20 000
USA	5 millions	500 000	50 000

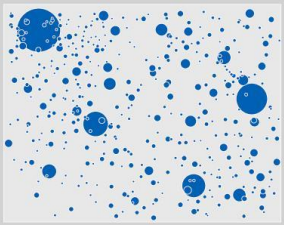
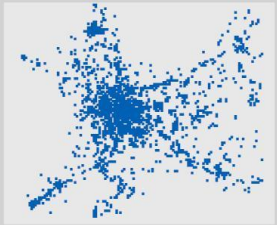
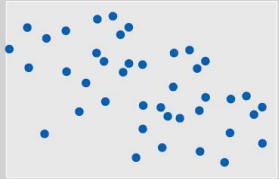
Geographical ontology for urban systems

Two levels: Cities and Systems of cities

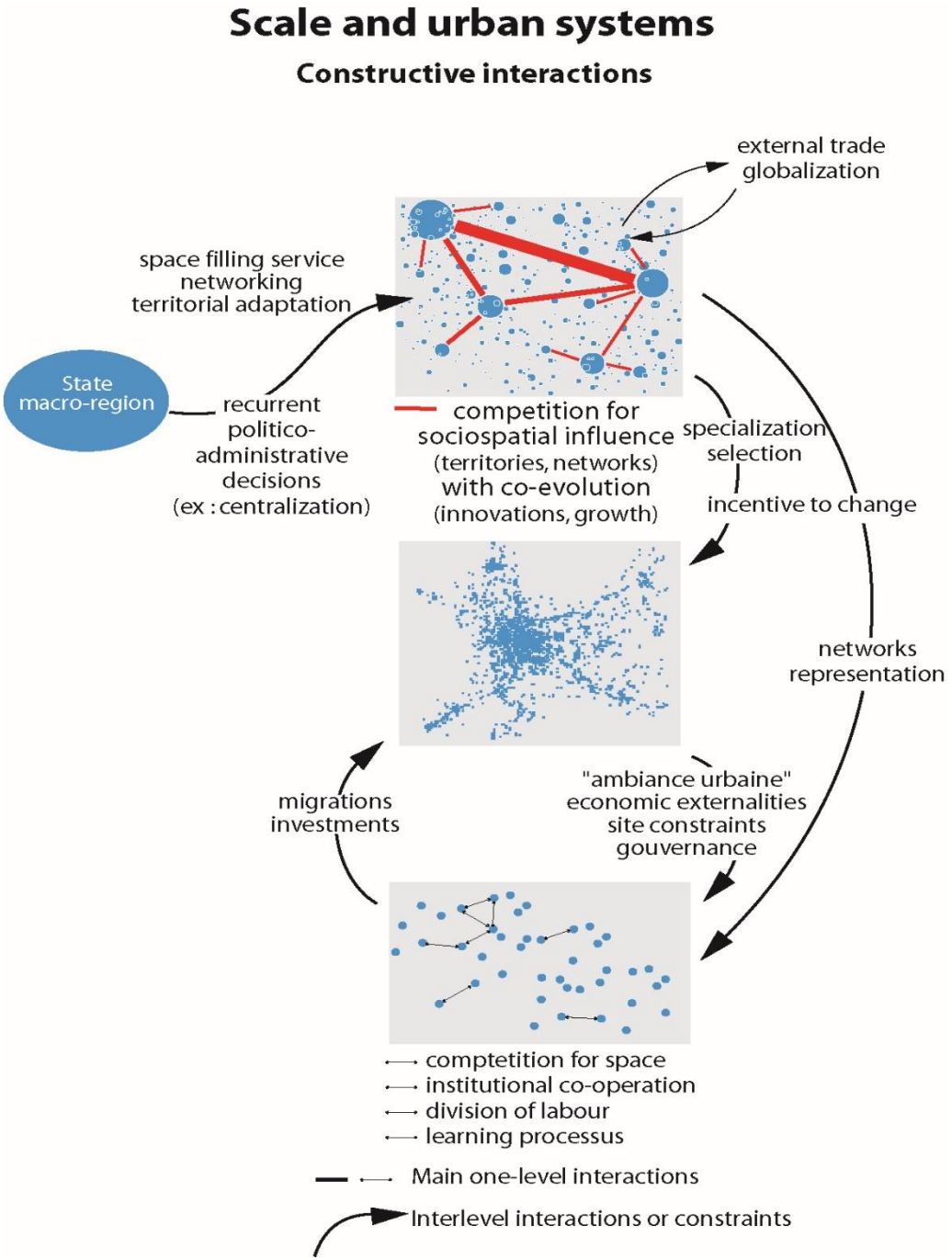
[Pumain D. Hierarchy in natural and social sciences, Springer, 2006]

Scale and urban systems

Emerging structural properties

Spatio-temporal scales	Emerging properties	Organization levels
 1day	Hierarchy Functional diversity Spatial pattern	**Macro: System of cities** (urban networks)
 1 hour	Centrality Function Morphology "Ambiance urbaine"	**Meso: City** (urban areas)
	Descriptors	
	Life cycle Profession Power	**Micro: Actors** (households, firms, institutions)

Adaptive multi-levels interactions ➔ cities' co-evolution



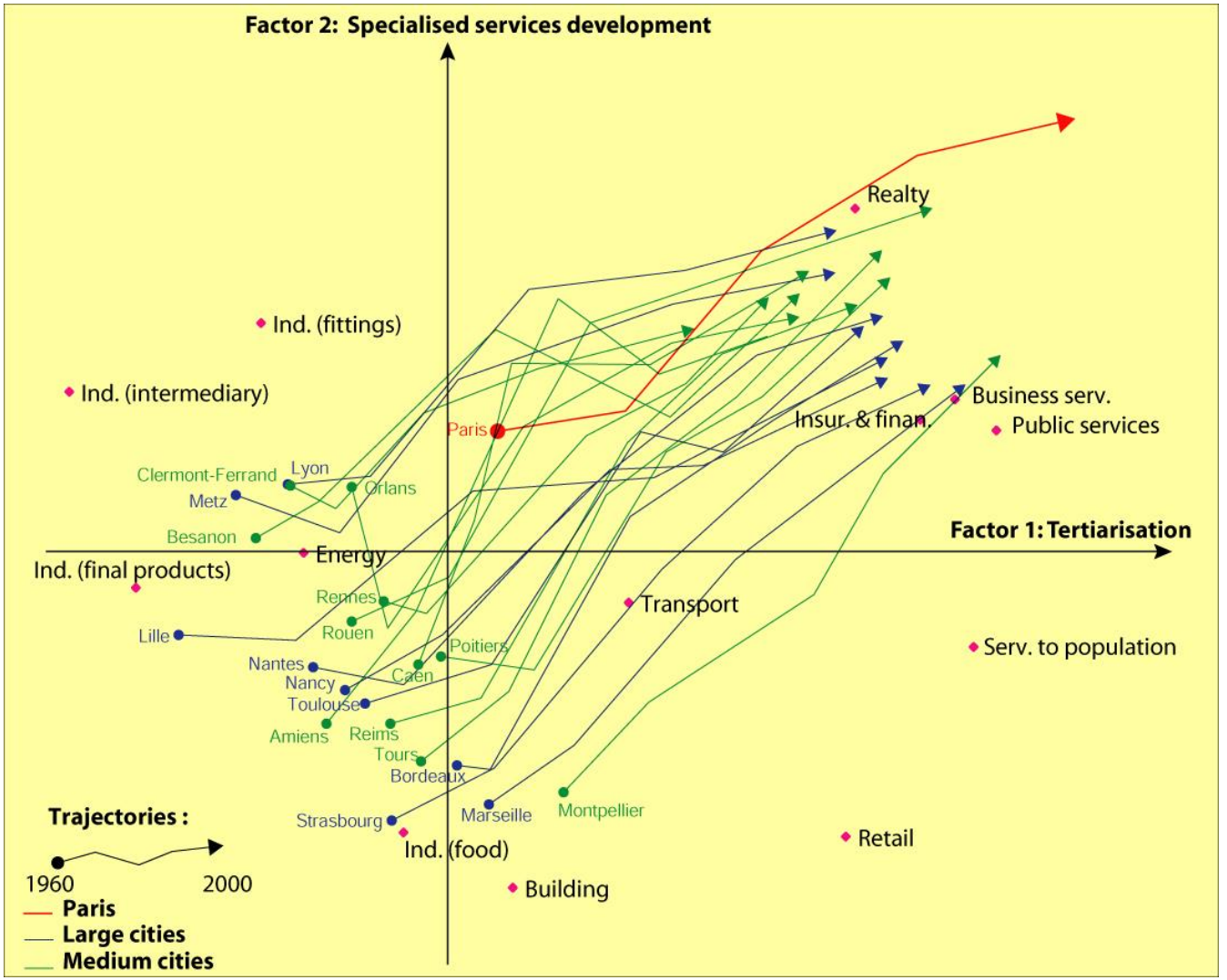
[Pumain (ed), 2006 Hierarchy in Natural and Social Sciences, Springer]

Interpreting urban function

- <1950 : taxonomy, role, profession of the city
- 1950-70: a synthetic geographical concept (economic base theory, systemic paradigm)
- 1970-90: mutivariate attributes and multiscale temporal processes; discovery of co-evolution
- 1990-2010: emerging property in complex systems and partial analogy with biological simplexity

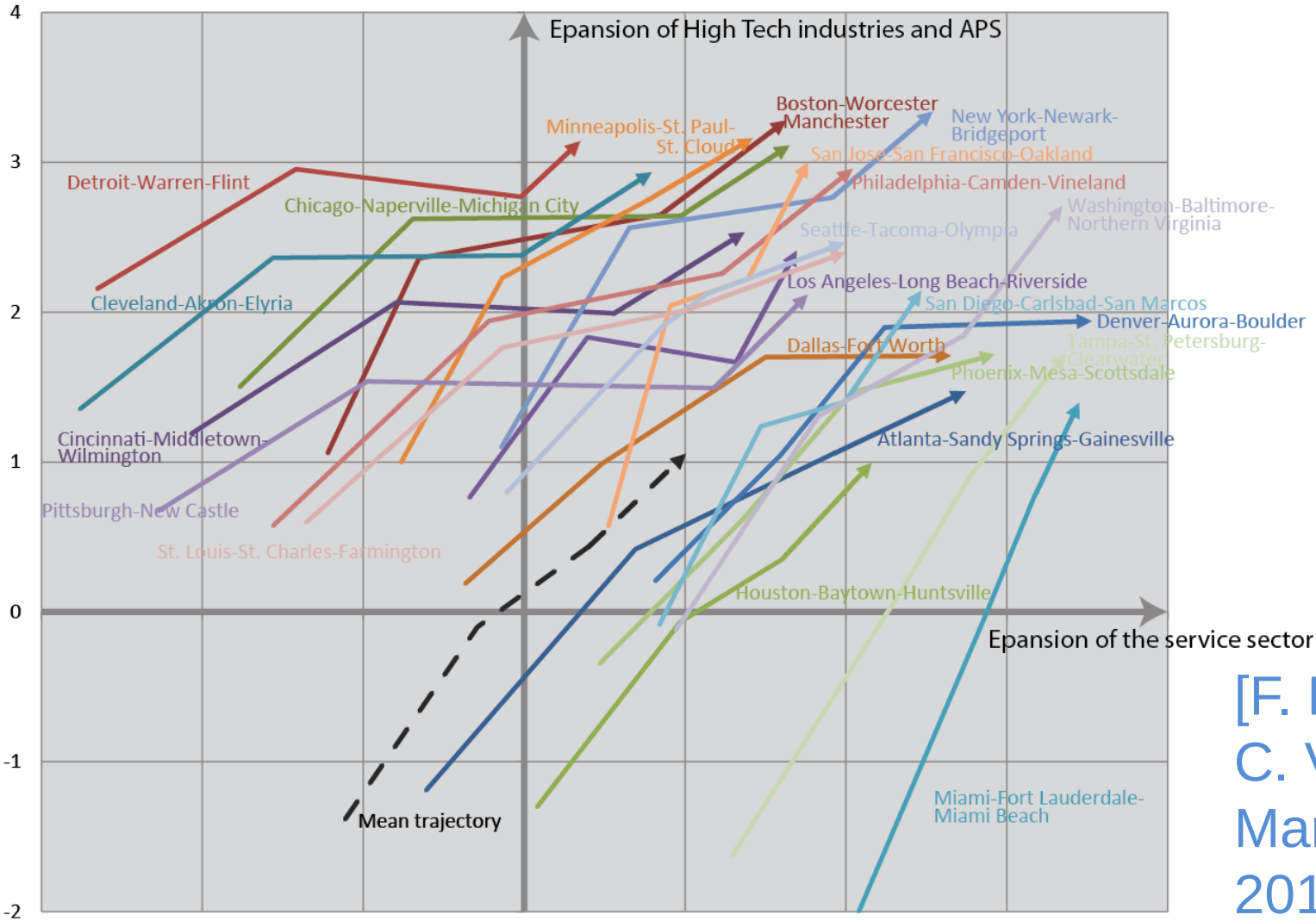
Qualitative socio-economic co-evolution = propagation of societal innovation

PCA on French cities' economic profiles 1960-2000



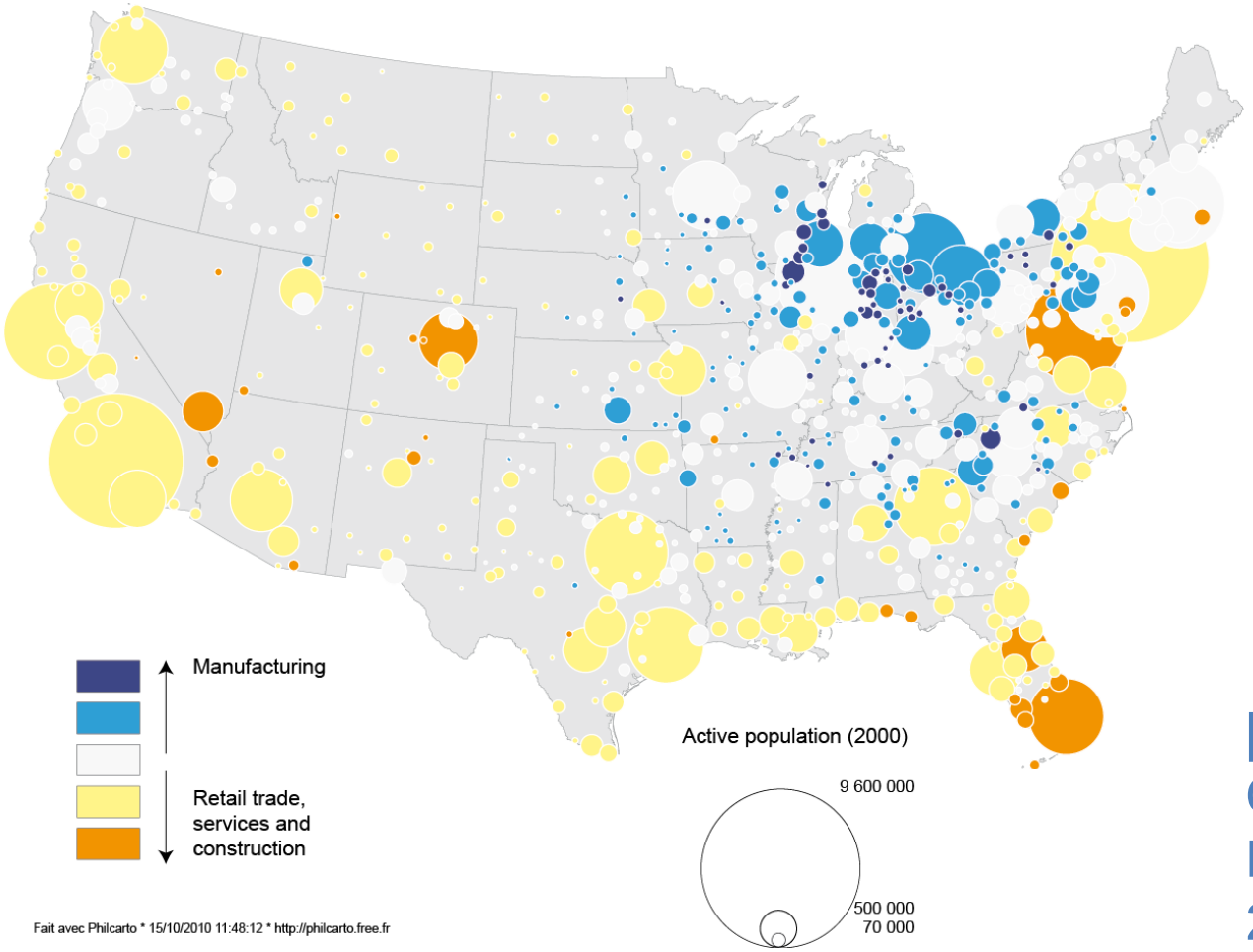
[F. Paulus, 2003]

Co-evolution US cities >2 M inhab.



[F. Paulus C. Vacchiani-Marcuzzo, 2011]

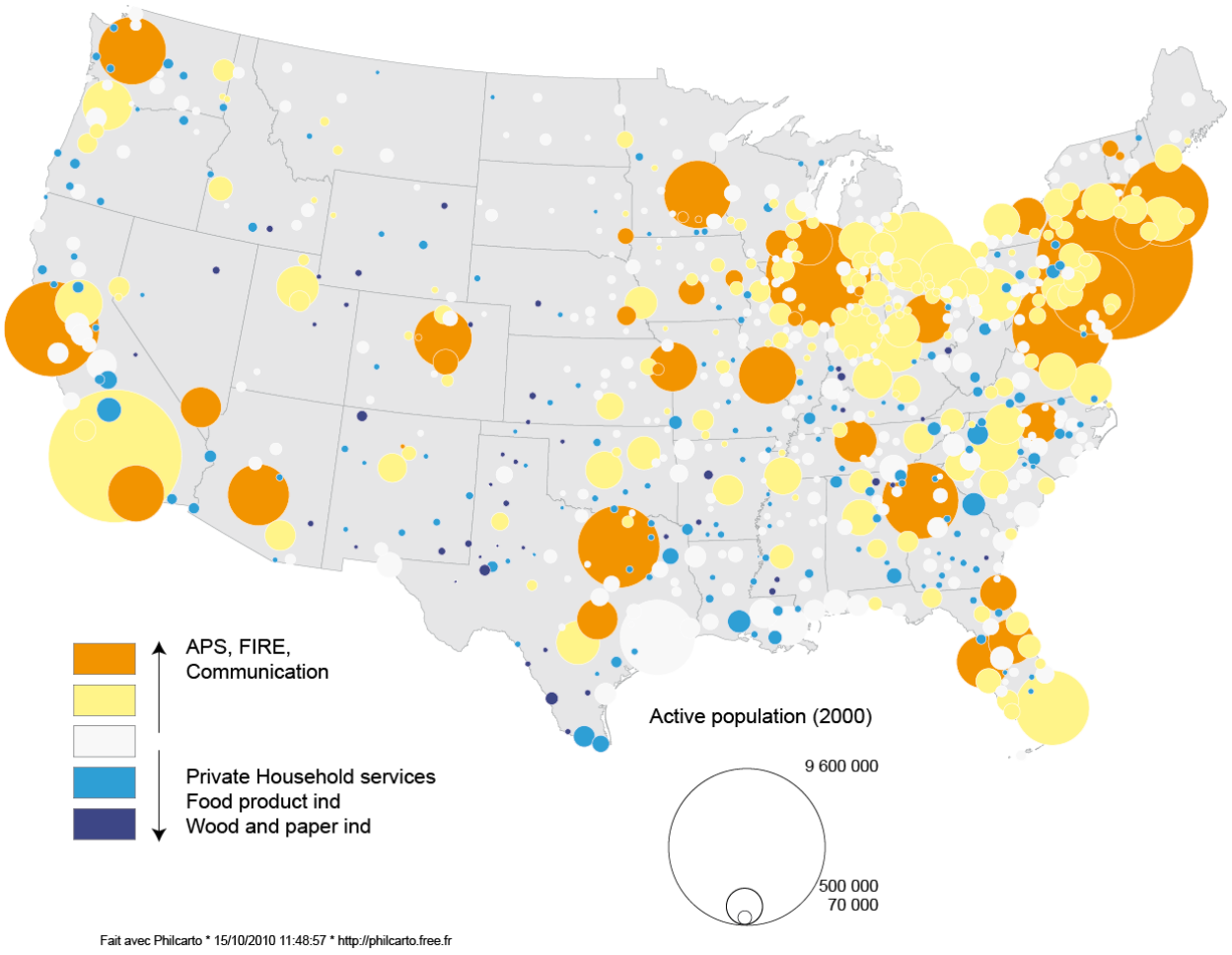
Major economic differentiation of US cities =trace of ancient innovation wave (1850-1950)



1st factor of PCA= manufacturing/ services (differentiation at regional scale)

[F. Paulus C. Vacchiani-Marcuzzo, 2011]

Second economic differentiation in 2000 = trace of recent economic cycles (1950-2000)

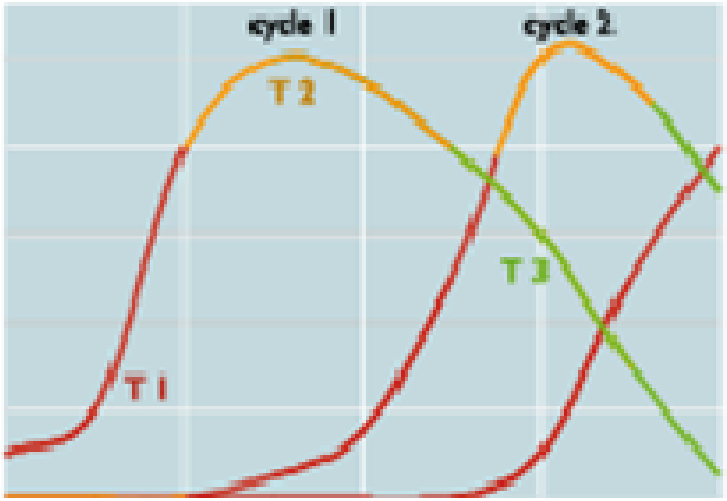


2d factor of PCA
= new/old services (hierarchical diffusion)

[F. Paulus C. Vacchiani-Marcuzzo, 2011]

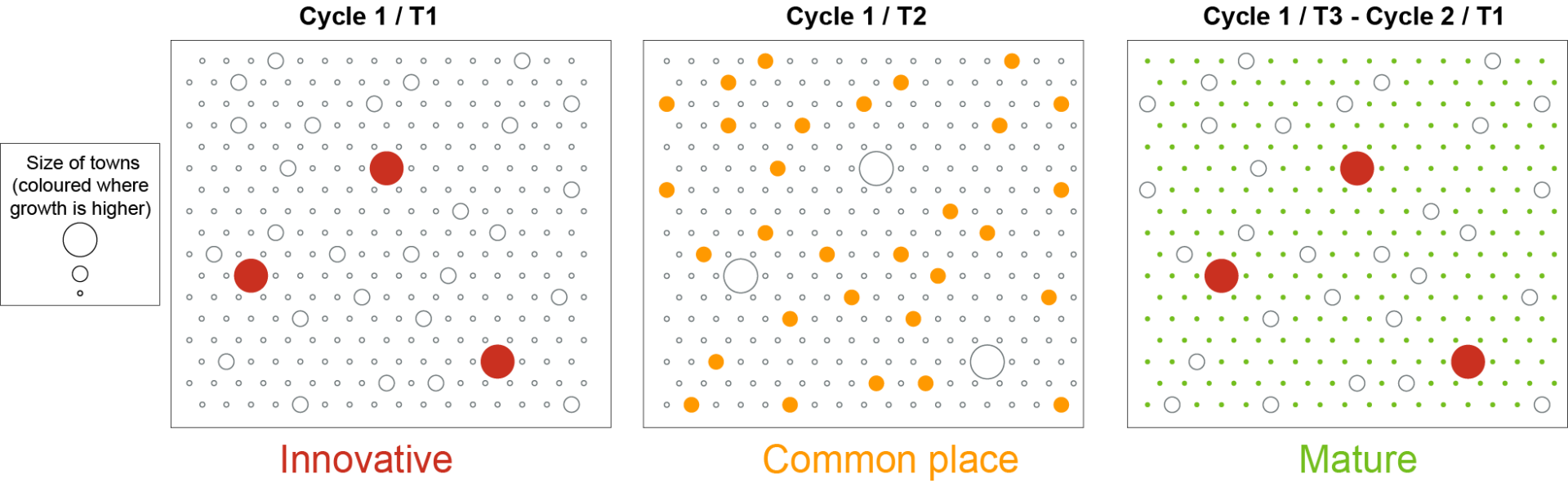
Hierarchical diffusion of innovations (T. Hägerstrand, 1952)

Scaling parameters reflect innovation cycles generating urban growth

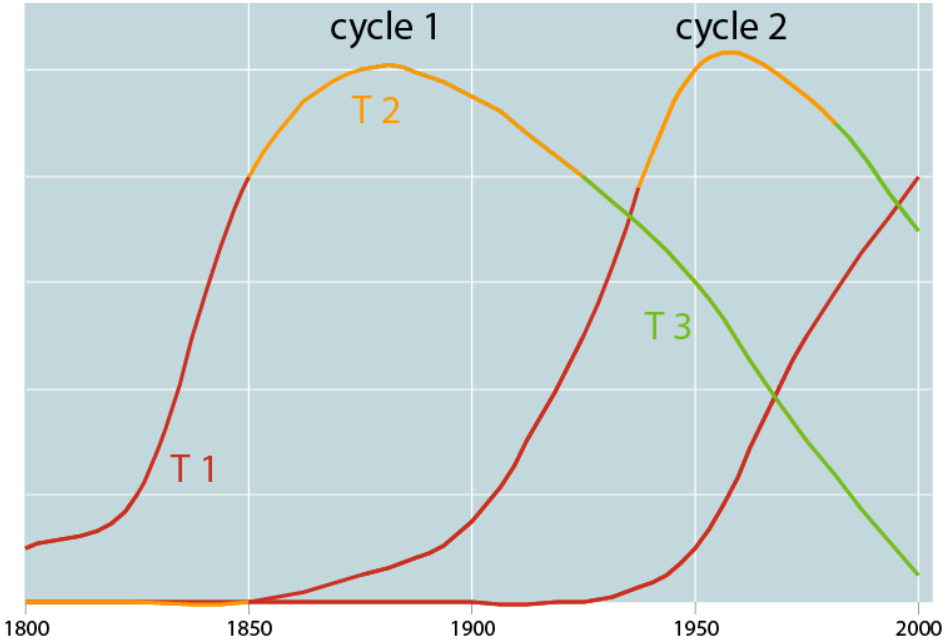
	Stages in cycles	Location	Evolution
ß > 1	Innovative Hight return	Concentration in large cities	
ß = 1	Common place Normal return	Diffusion everywhere	
ß < 1	Mature Low return	Resudual in small town	

Source : Paulus, Vacchiani-Marcuzzo, Pumain, 2006

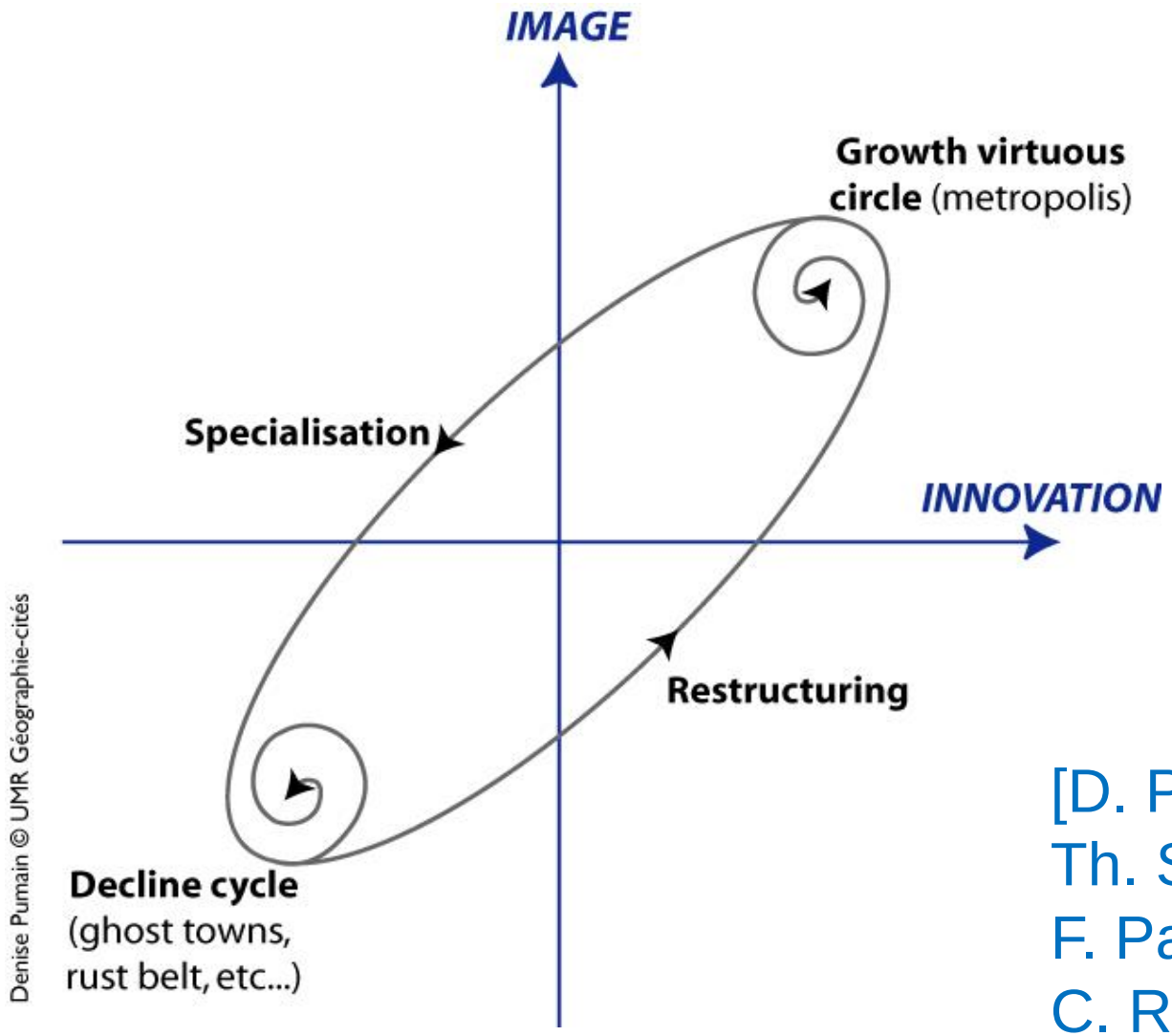
Innovation cycles and substitution process



[F. Paulus C. Vacchiani -Marcuzzo, Pumain D. Cybergeo 2006]



Innovation as key factor of urban adaptive process



[D. Pumain
Th. Saint-Julien
F. Paulus
C. Rozenblat]

Scaling laws in complex systems

- Scaling laws: Non-linear relationships between size of entities and some of their functional attributes ➔ reveal physical constraints on the structure and evolution of complex systems, spatial distribution of energy through fractal networks in biology:

West, Brown & Enquist, *Science*, 1997 & 99)

- ➔ Application to urban systems:

D. Lane, D. Pumain, S. van der Leeuw, G. West: *Complexity perspectives in Innovation and Social change*, Springer, 2009

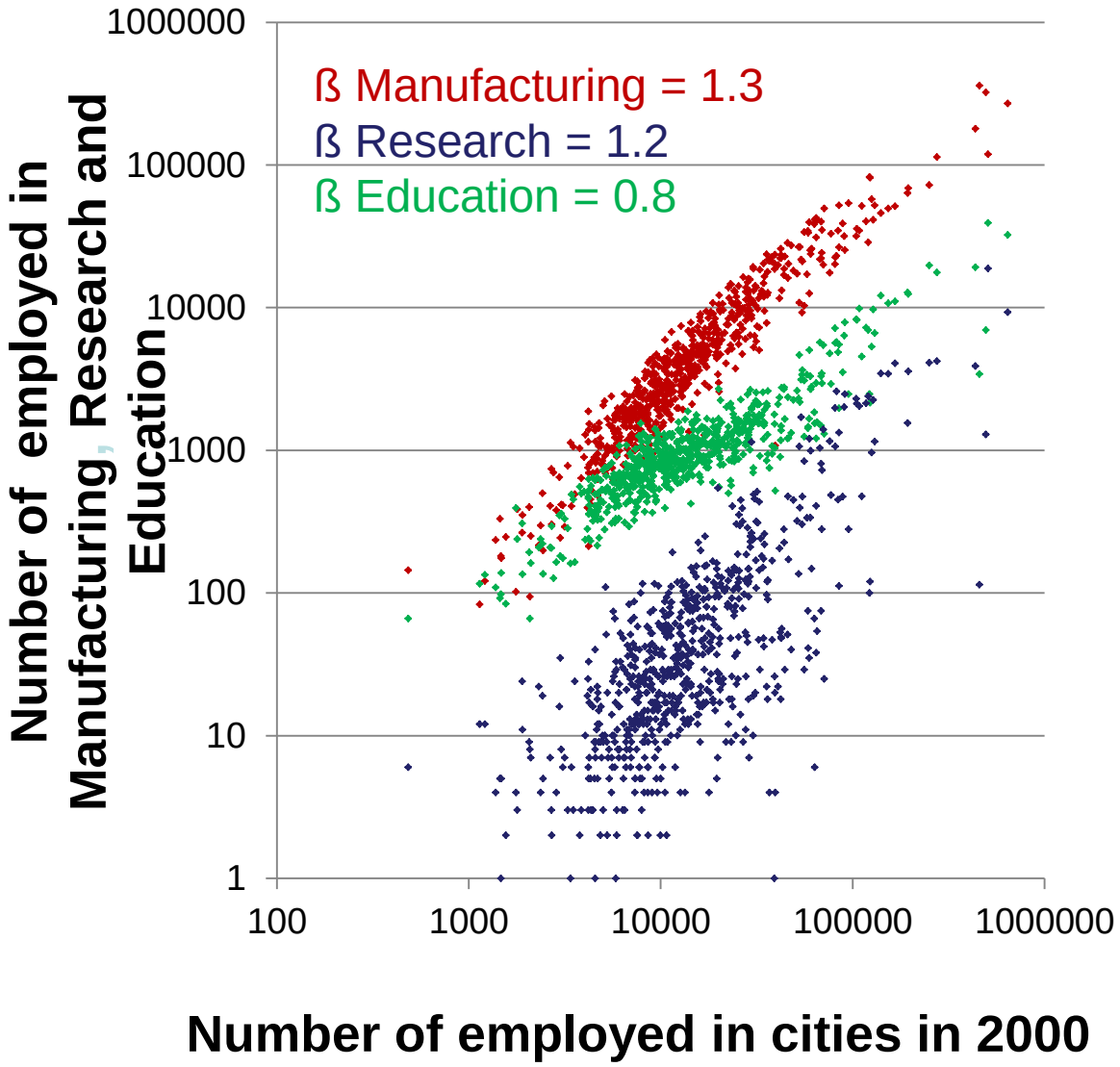
[FET EU programme: ISCOM (Information Society as a Complex System) 2002-2006]

A geographical interpretation: stages in innovation waves

Stages in innovation cycle	France	USA	South Africa
Innovative sectors **β > 1**	- Financial activities, Insurance, Real Estate		
	- Research and development - Business services, Consultancy		- Manufacturing
Common sectors **β ≈ 1**	- Hotels and Restaurants - Community, social, personal services		- Retail Trade - Community, social and personal services - Utilities
Mature sectors **β <1**	- Manufacturing	- Retail Trade - Utilities	- Private Households

[Paulus et al. in Lane et al., 2009]

Scaling laws according to innovation waves



Chinese cities

[Elfie Swerts 2013]

Reconstructing urban trajectories with multi-agents systems

- Reconstructing past urban trajectories within their historical and geographical context is a first necessary step for testing the relevance of our theoretical explanation

- = a condition for ensuring the quality of projections estimating future relative positions of cities within inter-urban competition, thus for adjusting intelligent urban policies.

Urban size and urban growth

- Apparent direct causes : intentions/actions from urban actors (policies, locational strategies from firms, residential migrations…)
- But statistical observation (thousands of cities, over centuries) : each city has a probability of growing similar to other cities belonging to the same territorial system

= « distributed growth » on the long run with many local and temporal fluctuations

Statistical formalization

Gibrat's model

« proportional » (i.e. multiplicative) growth = growth rates are equiprobable ∀ city size and not correlated with previous rate

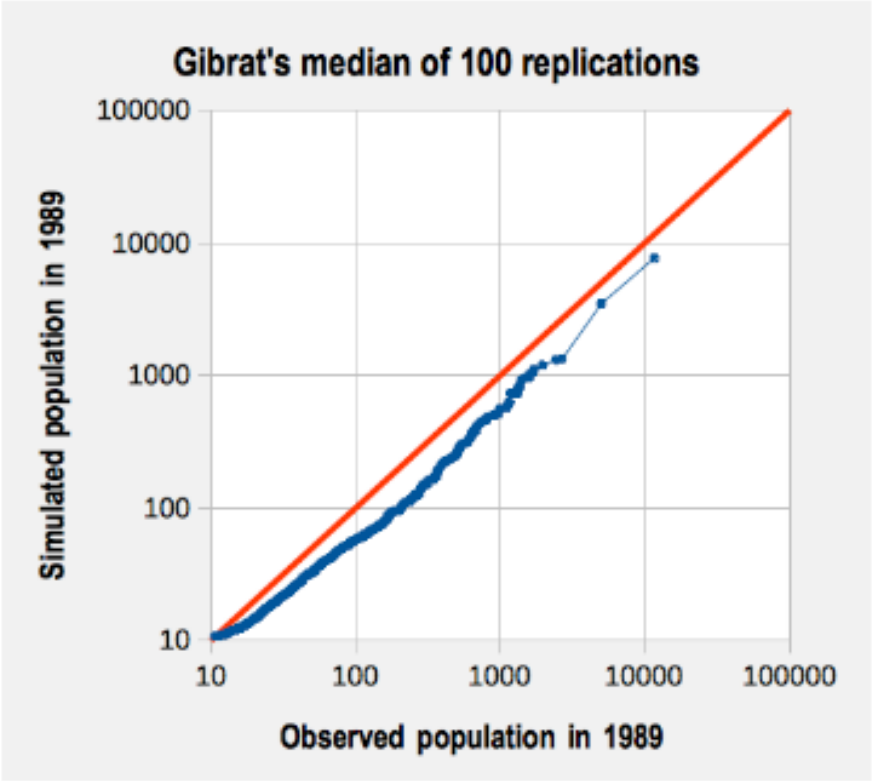
Good fit ➔ double gain in explaining:

- Persistency of urban spatial patterns and hierarchies
- The statistical shape of urban sizes distribution (Zipf's law or lognormal ≈ H. Simon ≠ P. Krugman) as generated from growth process through innovation adoption

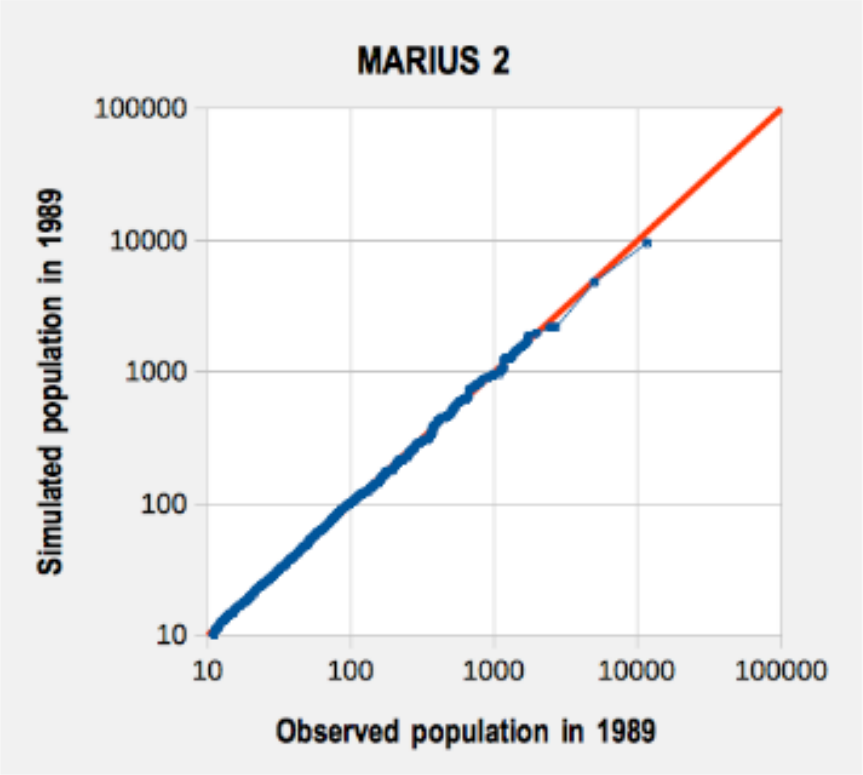
[Gibrat, 1931, Robson, 1973, Pumain, 1982]

Networking boosts urban growth: model with interaction fits better than random growth

Gibrat's model



model with interactions



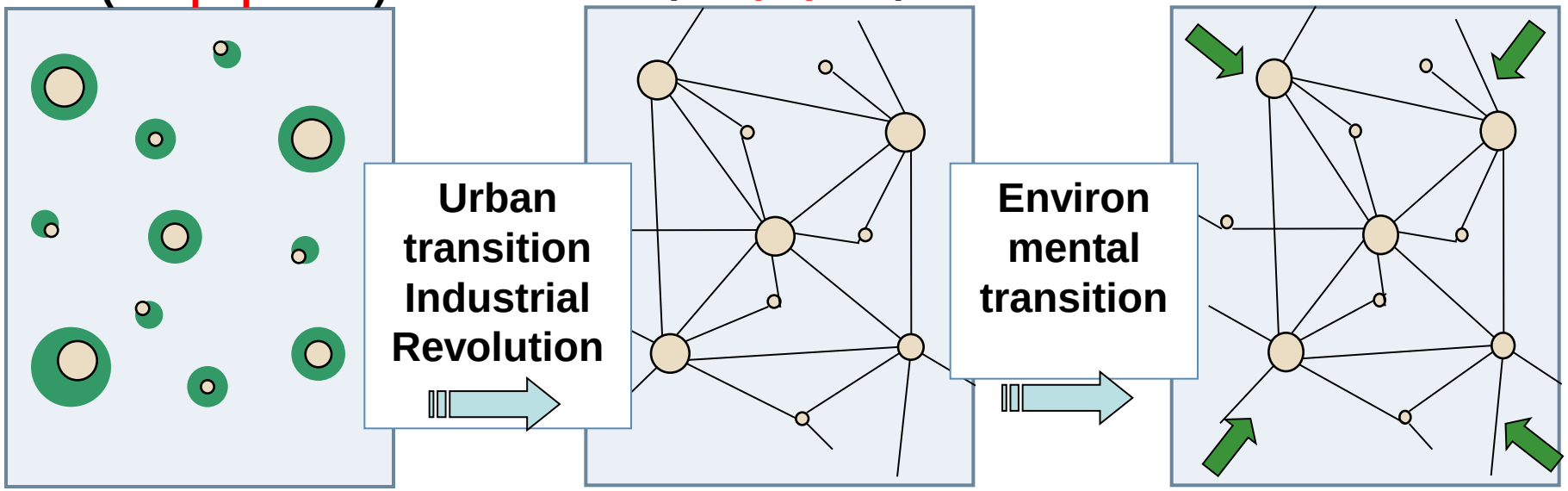
[Cottineau, 2014]

Three stages in the evolution of urban systems (series of Simpop models)

1- Agrarian economy
Local resources
(SimpopLocal)

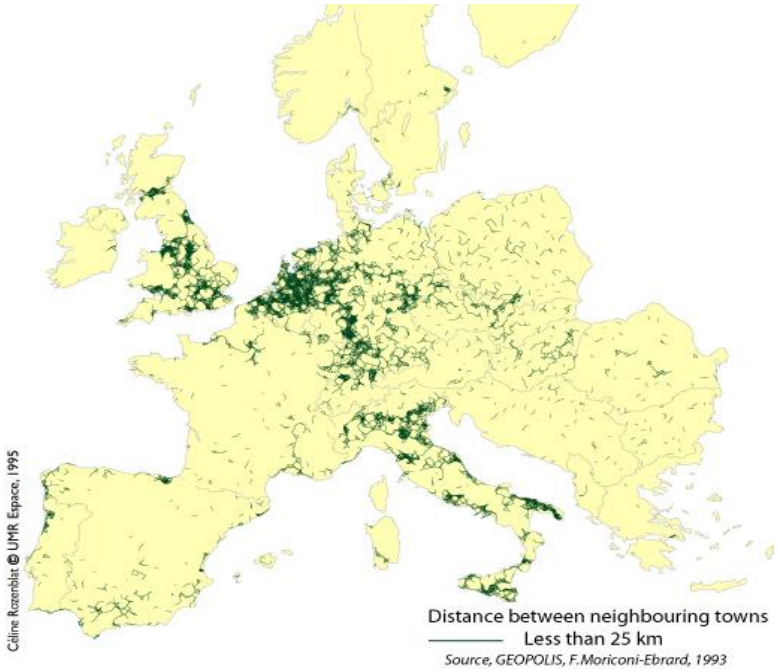
2- Market economy
Network returns
(SimpopNet)

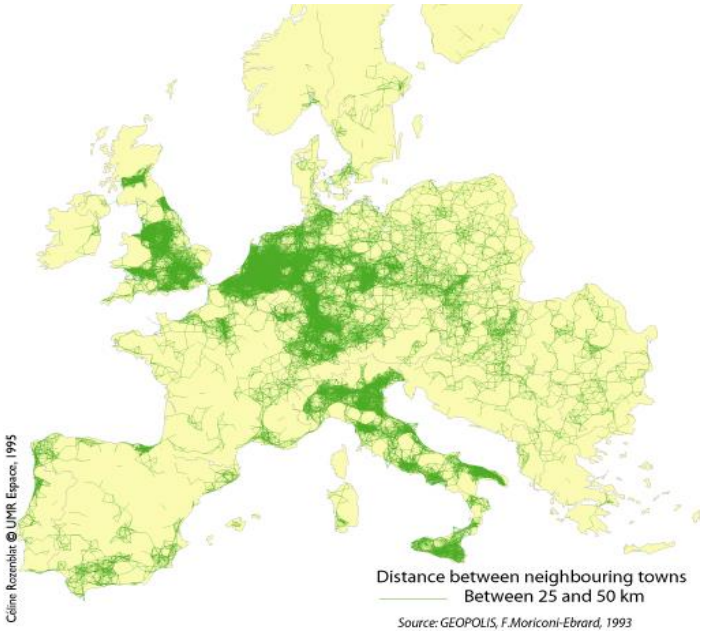
3- Knowledge economy
Environmental intelligence
(SimpopClim)

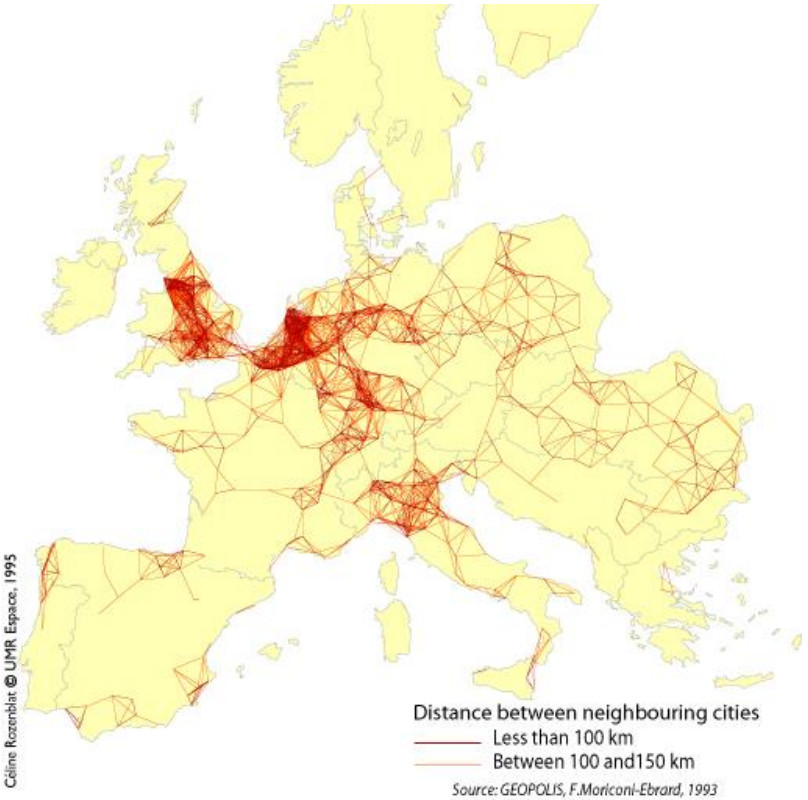


[SIMPOP models: France Guérin-Pace, Lena Sanders, Hélène Mathian with Stéphane Bura, Benoît Glisse, Thomas Louail (and Jacques Ferber, Alexis Drogoul, Jean-Louis Giavitto, Guillaume Hutzler). Anne Bretagnolle, Clara Schmitt, Sébastien Rey, Clémentine Cottineau, Elfie Swerts, Céline Vacchiani-Marcuzzo (with Romain Reuillon, Mathieu Leclaire, Paul Chapron, Guillaume Cherel)]

Three settlement styles in Europe shaped by centuries-old coevolution





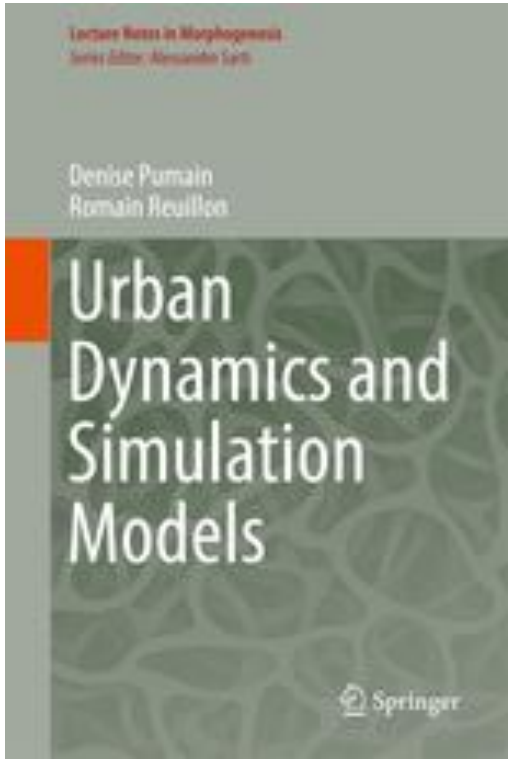


[Céline Rozenblat, Mappemonde,1995]

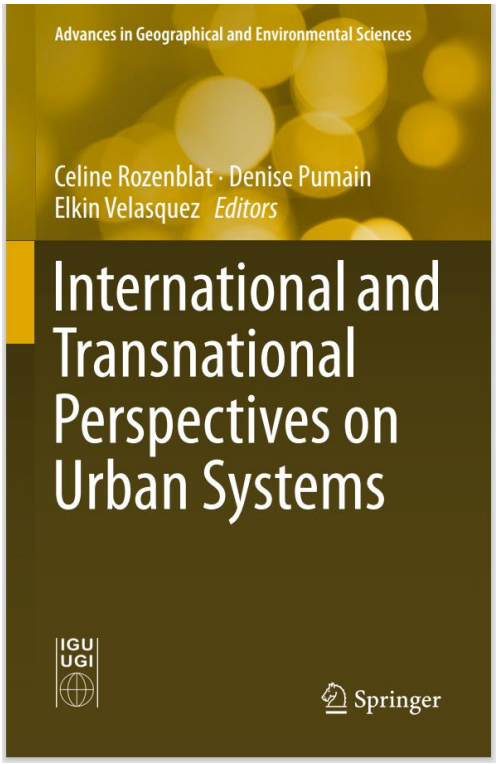
Cognitive dissonances in data interpretation: individual aspirations vs system's dynamics and present fads vs long term trends

- Individual residents: nostalgia, rural past, well-being, dreams of nature…
- Intermediary (institutions): hard and soft marketing, story telling, narratives, proactive adaptation, misinformation…
- Macro geography (cities): expansive trends through rivalries, competition, rankings, valuing imitation and homogeneization…
- ➔ complex system with multilevel feedbacks

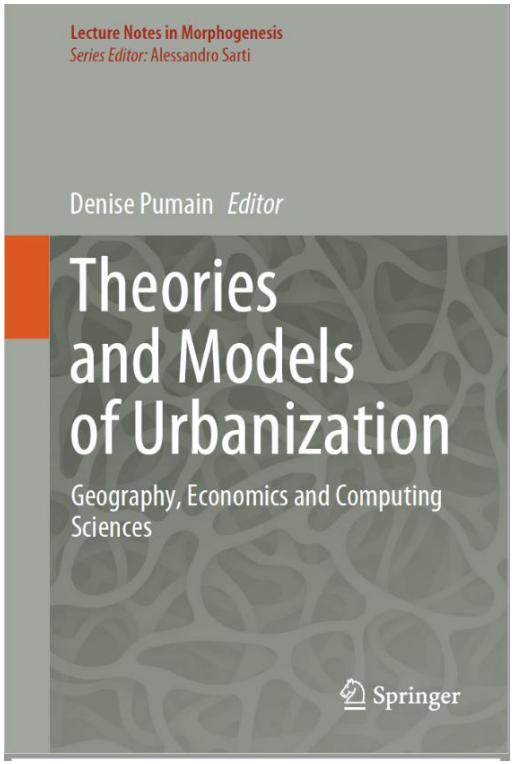
Thank you for your attention!



2017



2018



2020