ERC GeoDiverCity

# How validation through model exploration empowers theories of spatial complexity: example of urban systems

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*DAFNI, 22/11/2021 ISC-PIF-UCL*

# How to explain 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

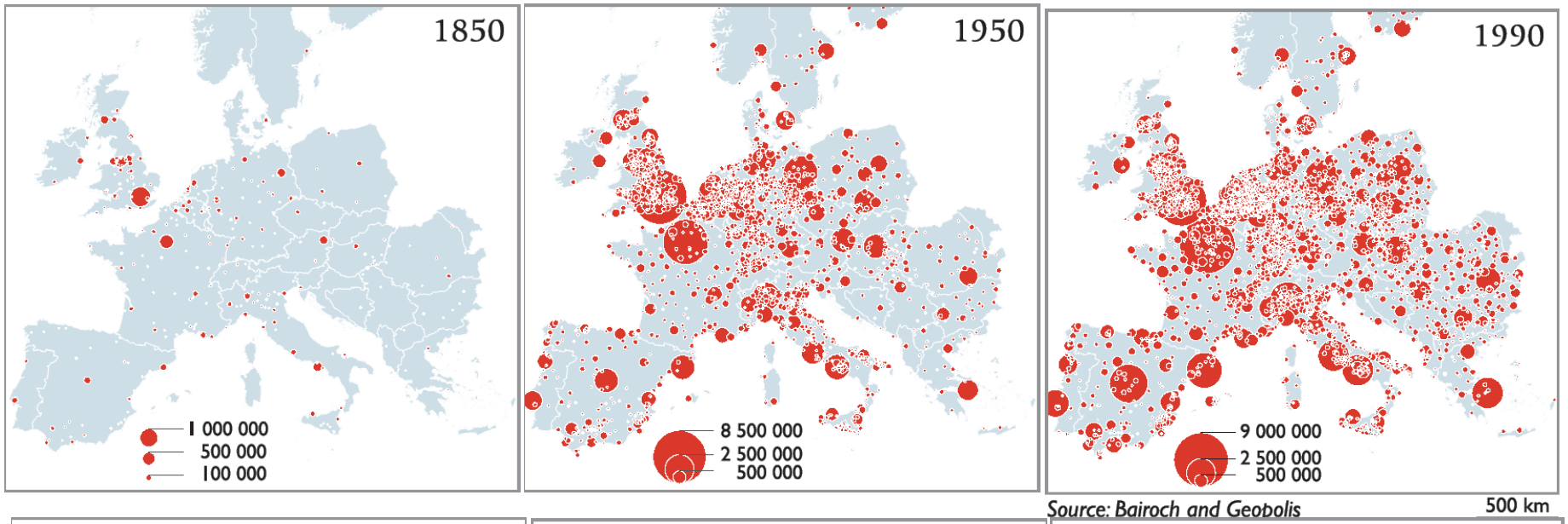
(« proportional » growth = growth rates are equiprobable ∀ city size and not correlated with previous rate)

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

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

# Persistency: Europe and India




[Bretagnolle et al., Cybergeo, 2002]

# Persistency: former Soviet Union

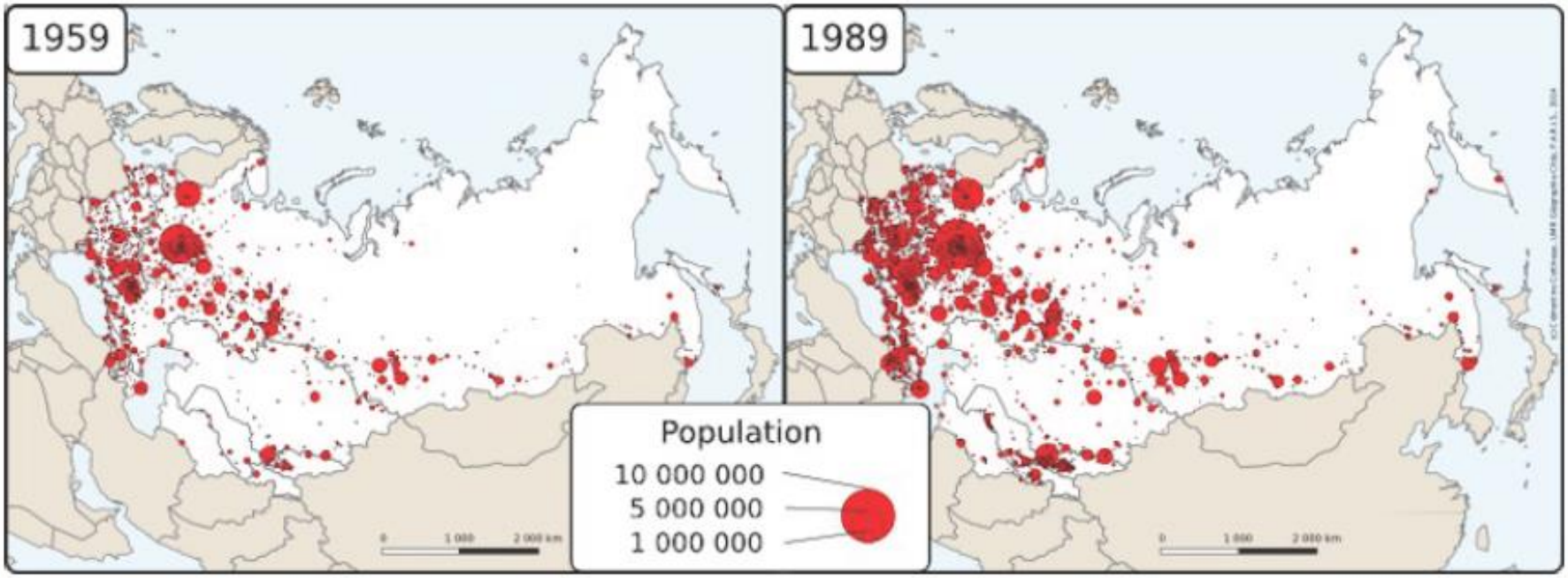
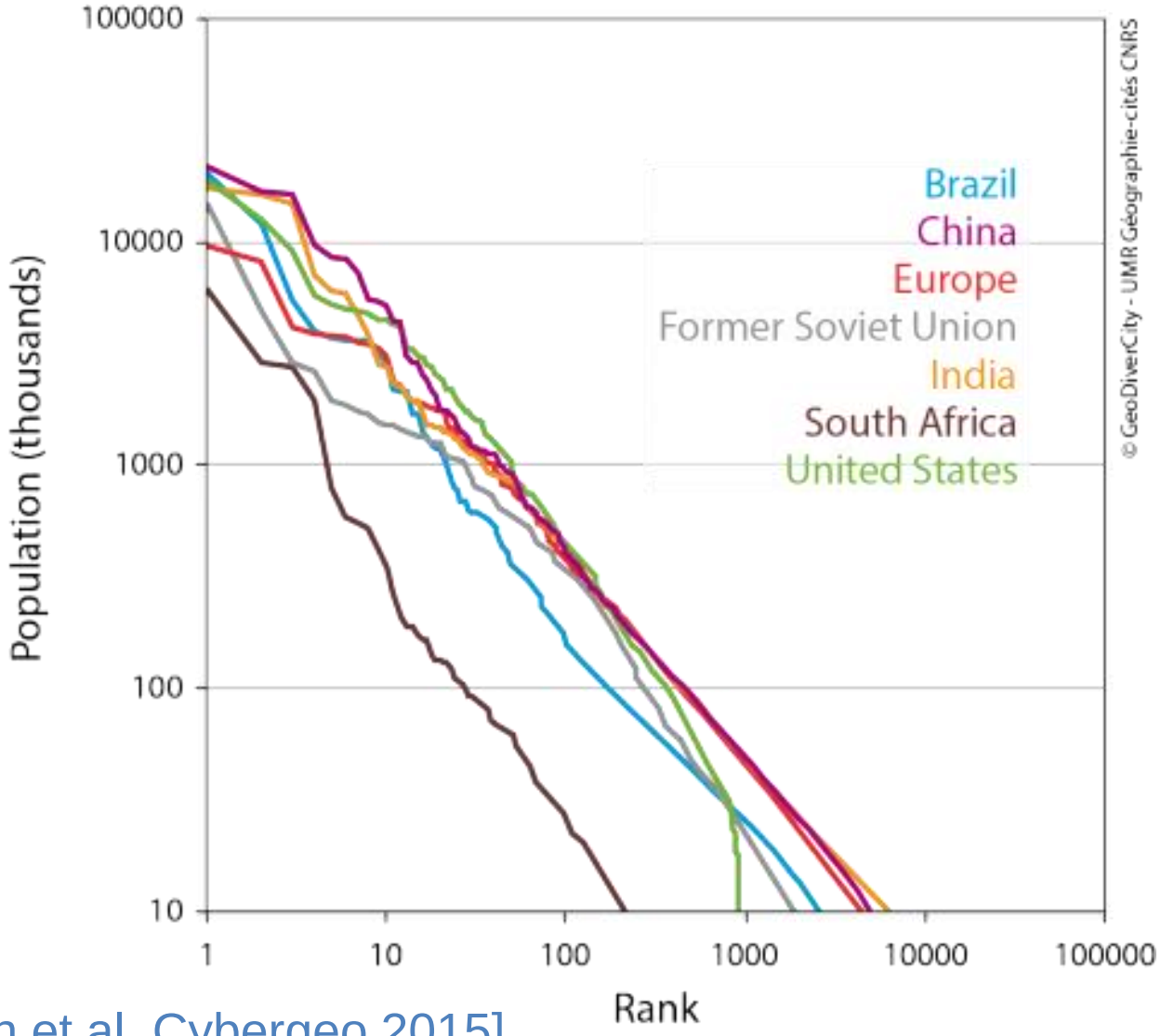



Figure 2. Empirical spatial and hierarchical distribution of cities in the post-Soviet space
source: DARIUS, 2014

[Cottineau et al., 2015, JASS]

# Zipf's law for 7 systems of cities

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

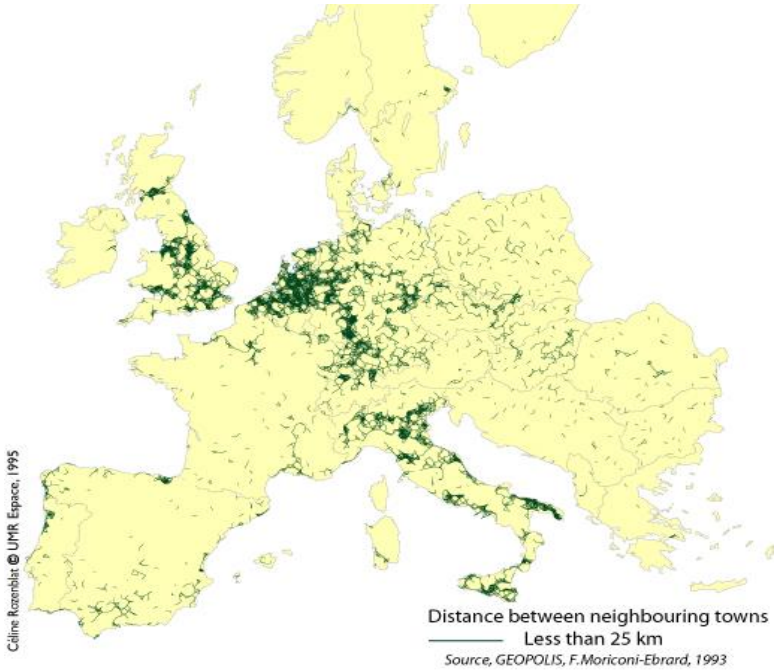


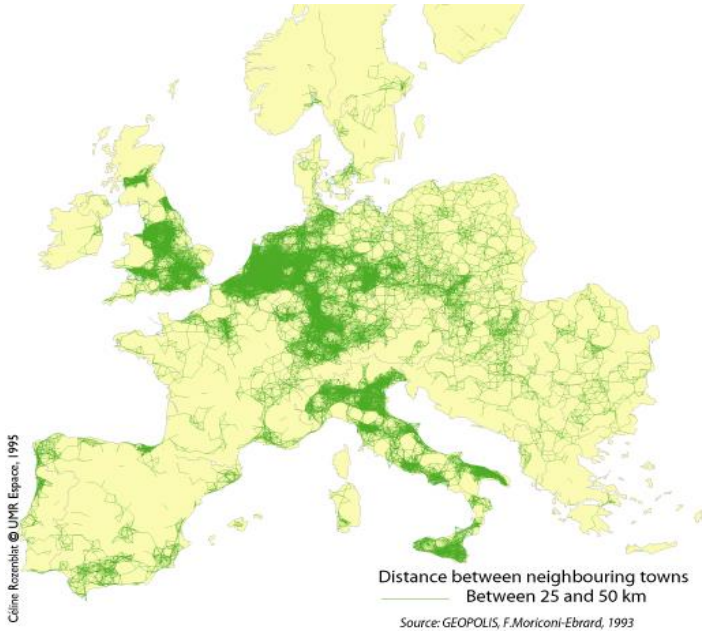

[GeoDiverCity, Pumain et al, Cybergeo 2015]

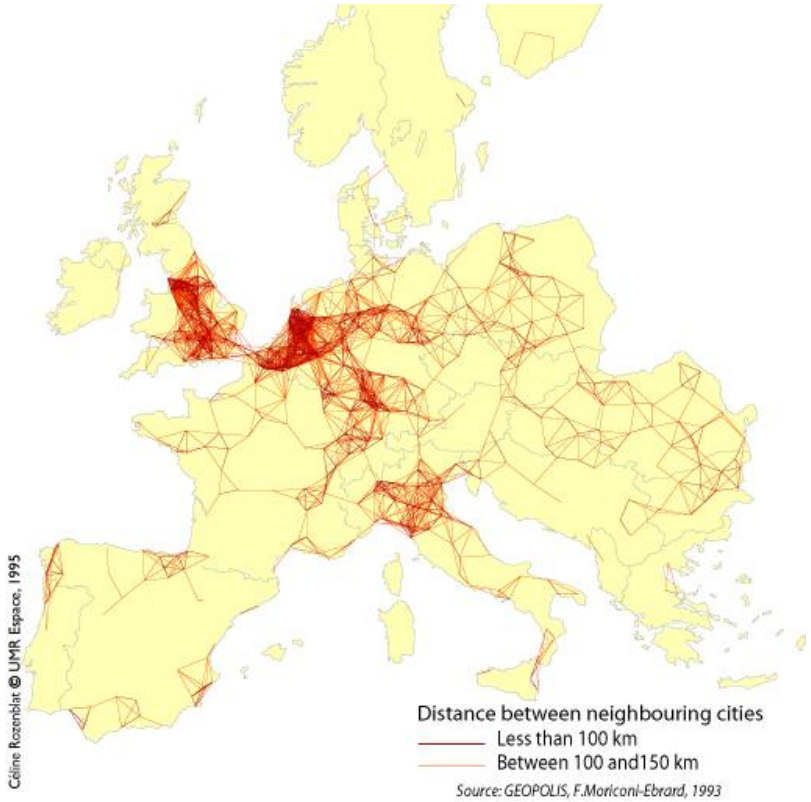
# Applicable knowledge

- Statistical predictability of city growth and size for a few decades
- Largest metropolises are not « monstruopolises »
- Complexity ➔ proactive adaptive strategies are necessary (imitation, or anticipation and risk), emulation (co-opetition)
- Robustness, variation and sustainability of urban systems (neither norm nor optimum)

# Robustness of three settlement styles in Europe




*Céline Rozenblat, Mappemonde,1995*

# Socio-economic transformation: « discovery » of urban co-evolution with temporal multivariate analysis

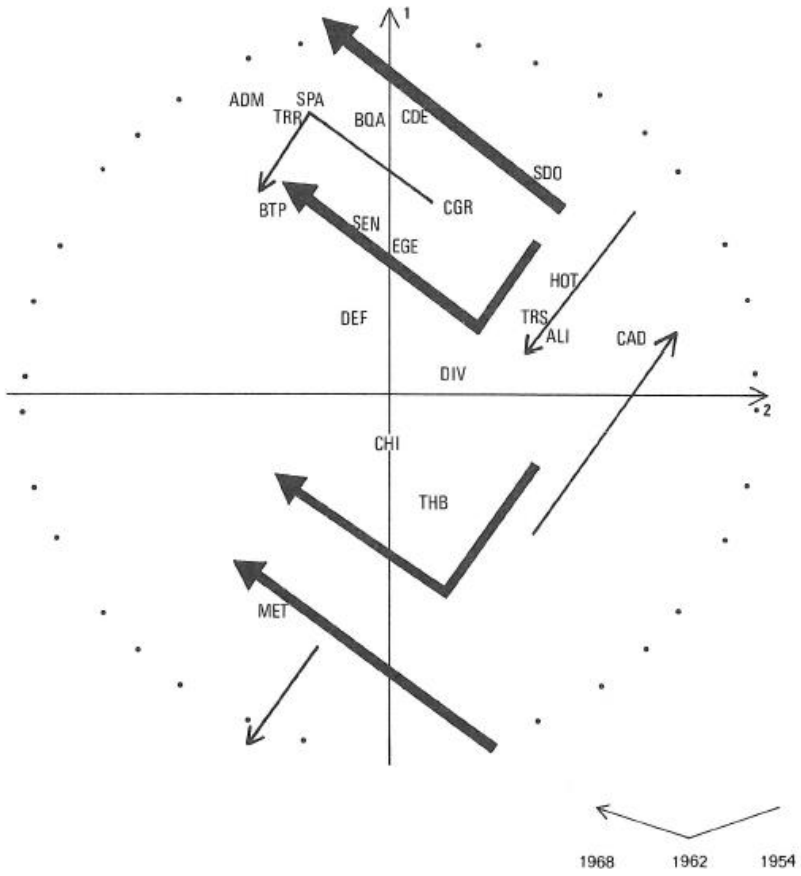
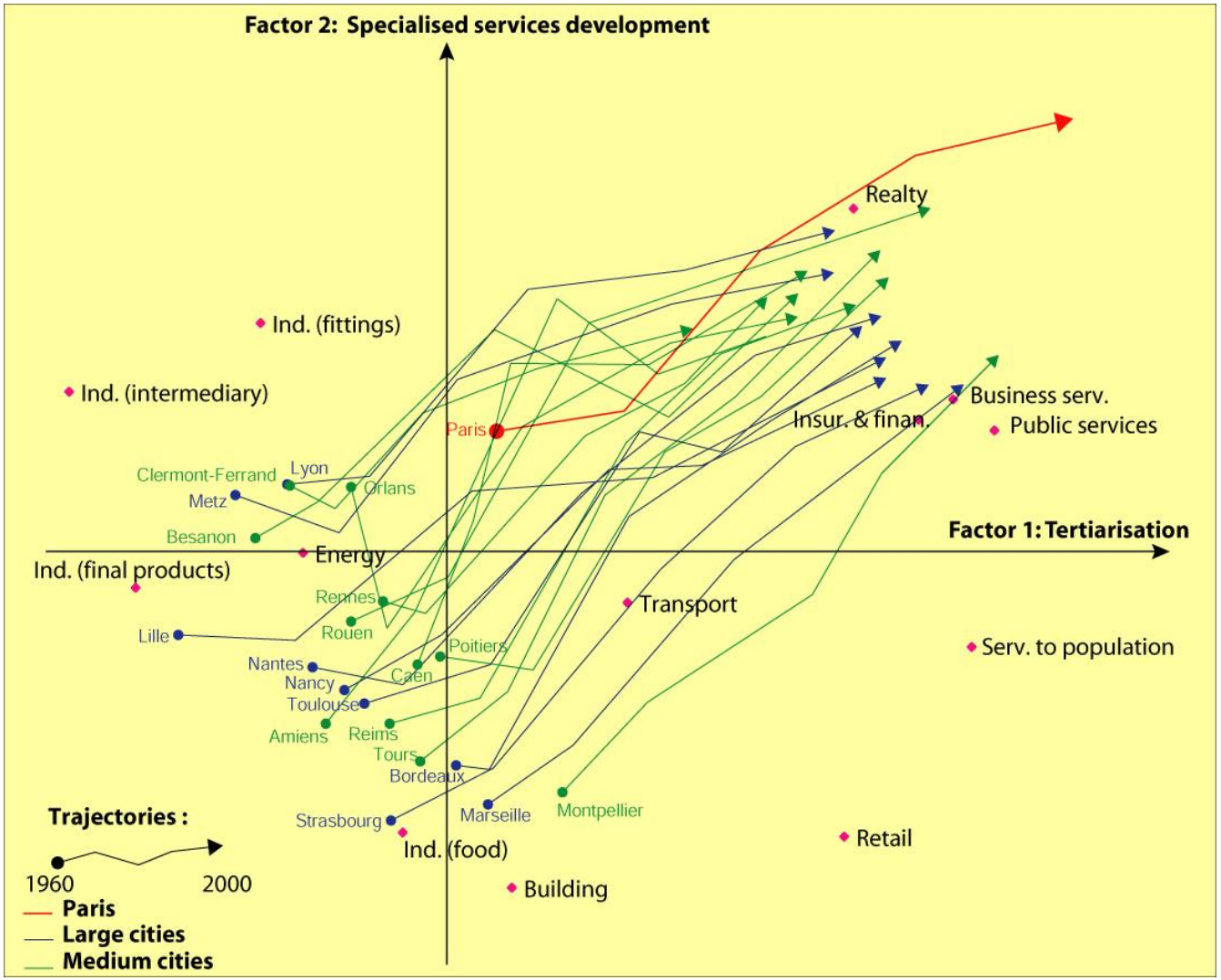



Figure 10 — Déplacements des villes dans la structure d'activité

[Pumain, Saint-Julien, 1978, Les dimensions du changement urbain]

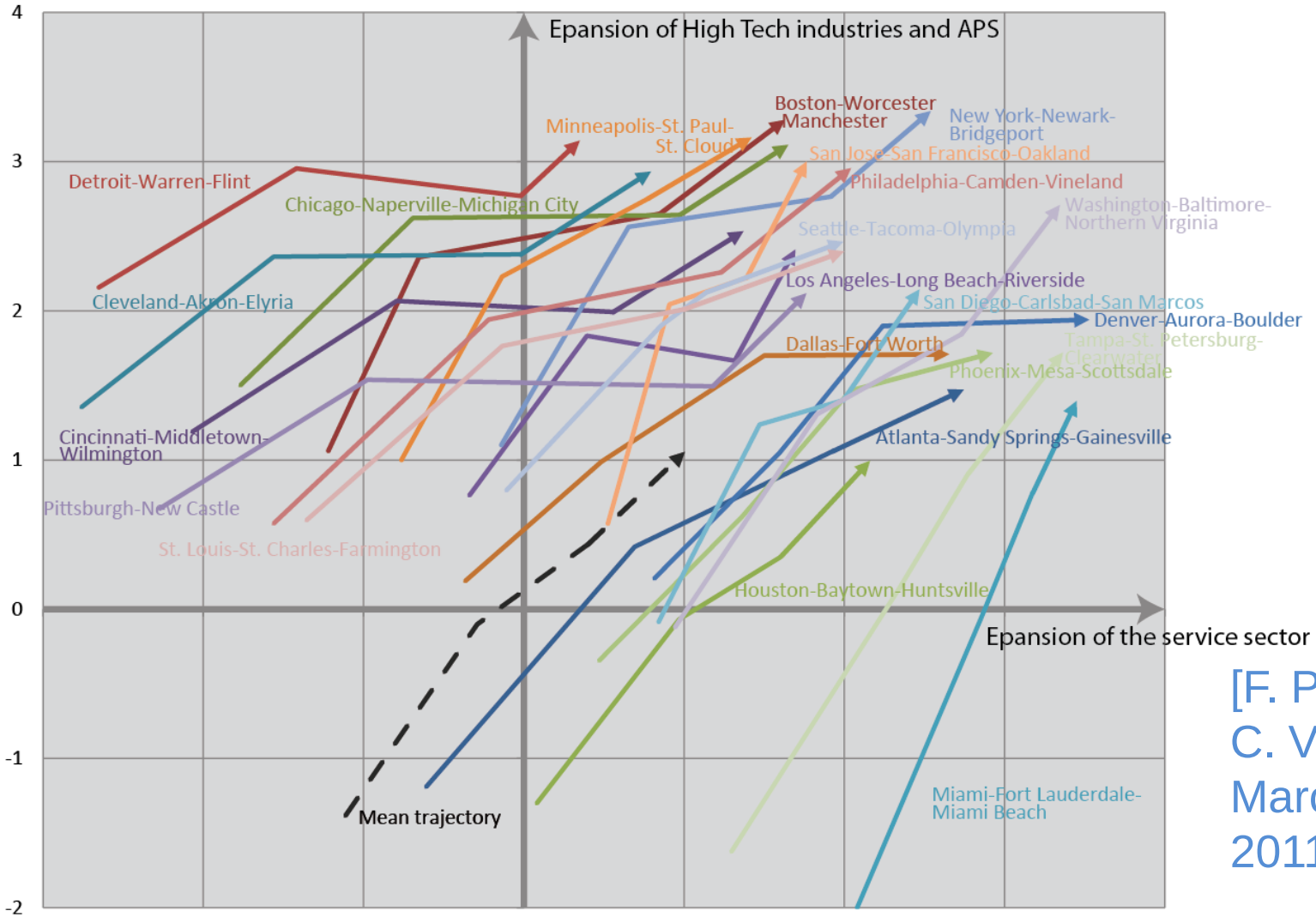
# Qualitative socio-economic co-evolution = propagation of societal innovation

PCA on French cities' economic profiles 1960-2000



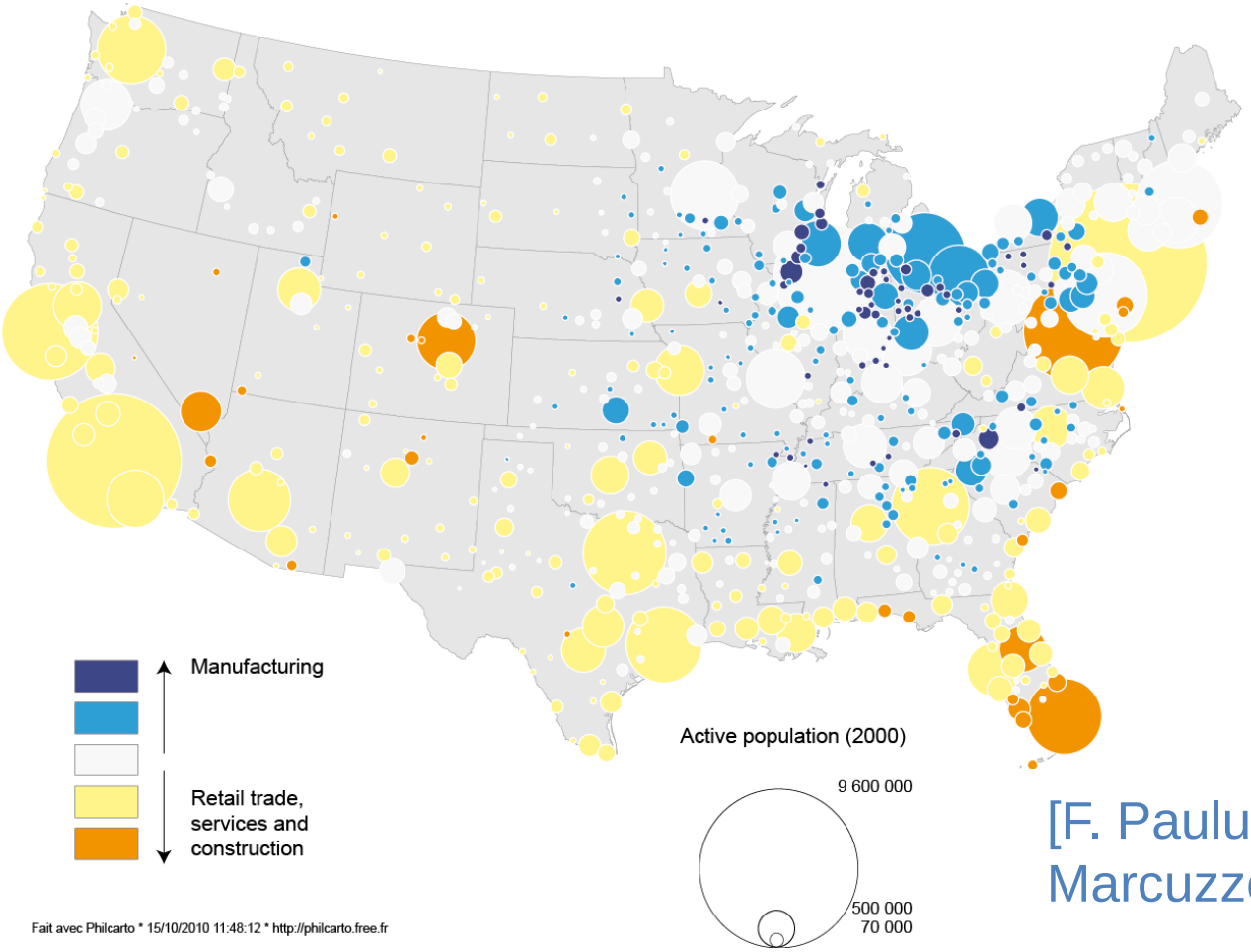

[F. Paulus, 2004]

# Co-evolution US cities >2 M inhab.




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

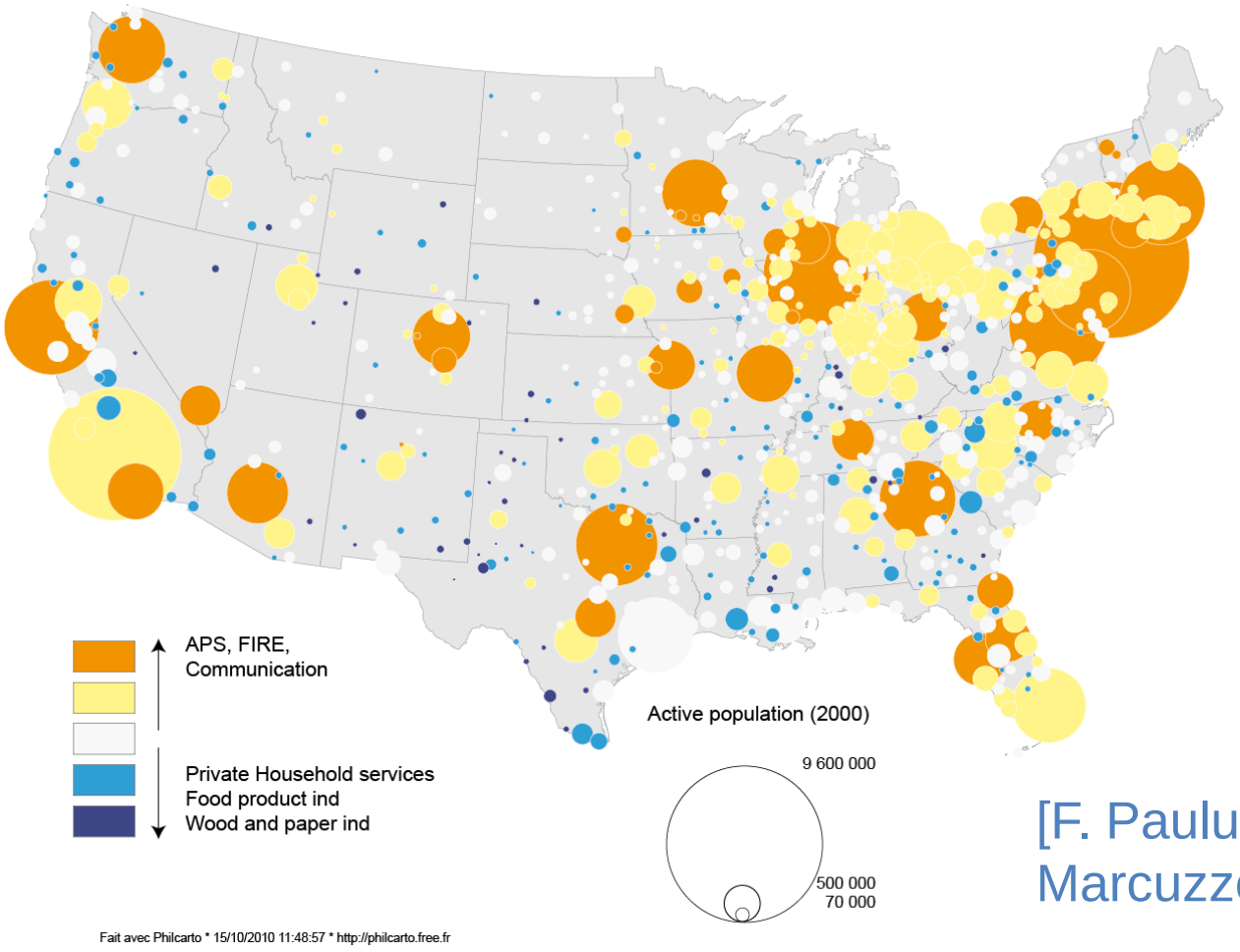
# Major economic differentiation of US cities =trace of innovation wave 19th century




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

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

# Second economic differentiation
# = trace of recent economic cycles




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

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

# Another progress in explanation

Size unequalities and qualitative socio-economic differences beyween cities are traces of their co-evolution (= interactive adaptation with feedbacks to the innovations they create)

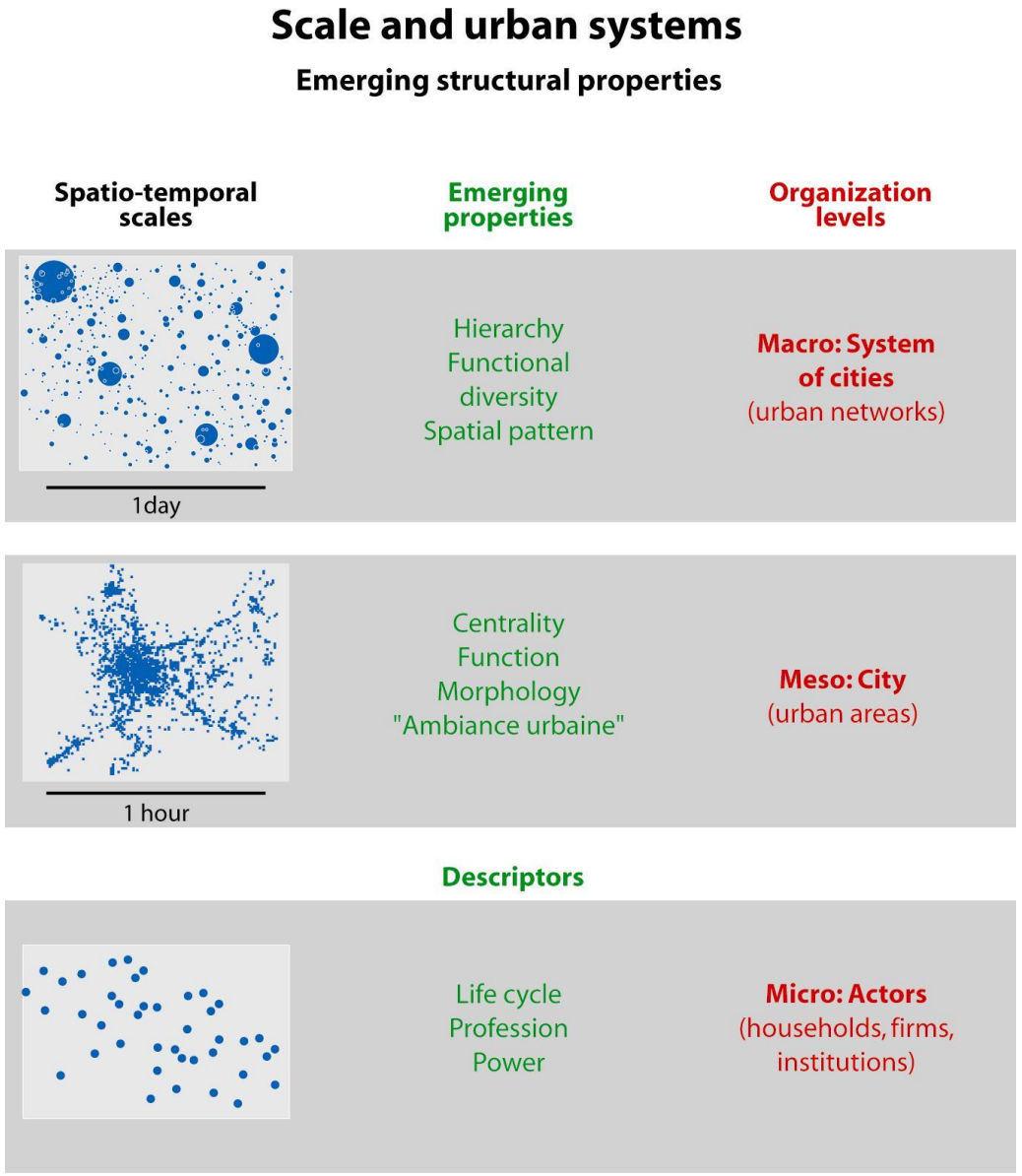
Are now explained :

- systematic observed deviations / Gibrat's statistical model
- emerging properties of systems of cities (hierarchy and functional diversity)
- bifurcations of individual urban trajectories

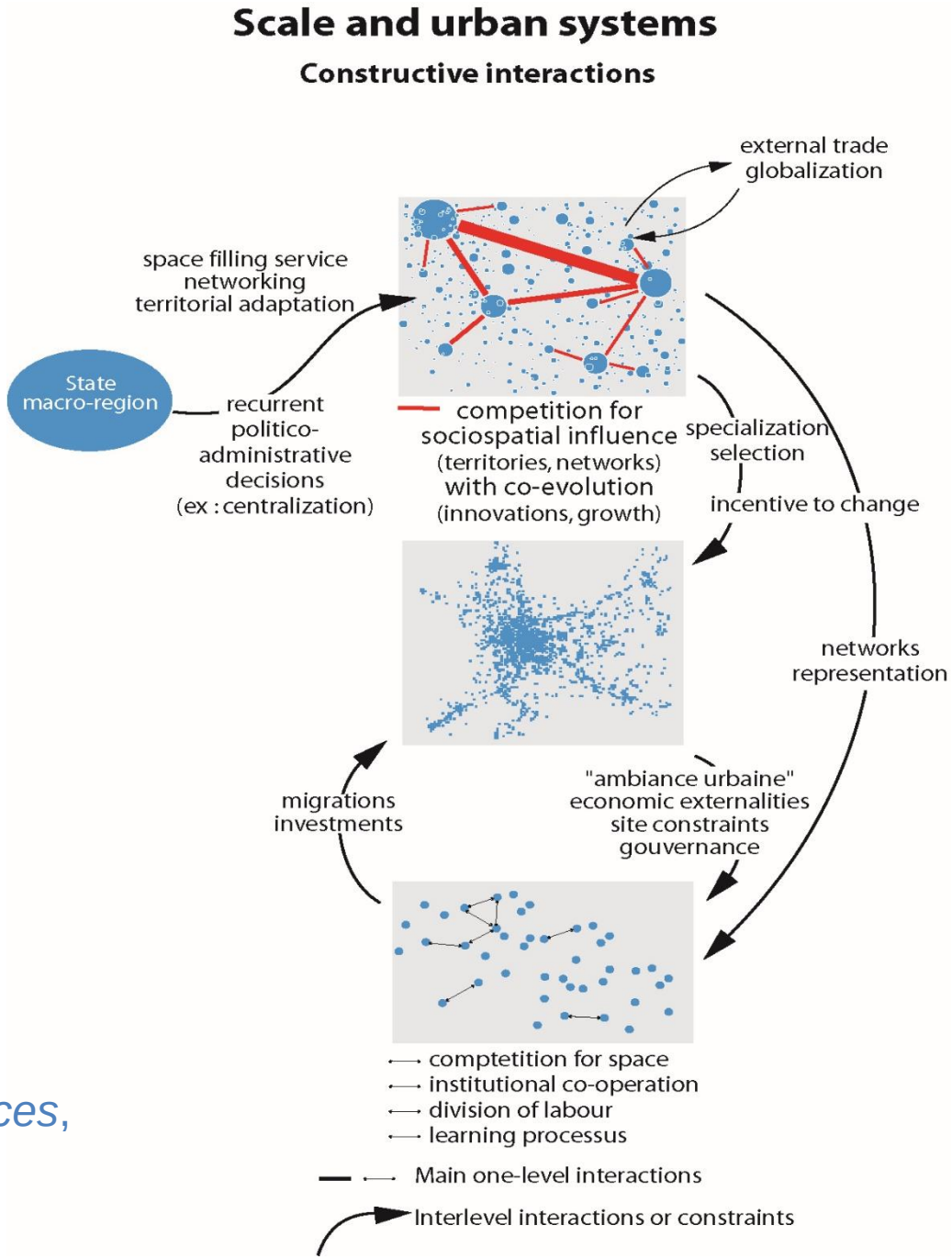
# Geographical ontology for urban systems

**Two levels: Cities and Systems of cities**

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



# Constructive multi-levels interactions



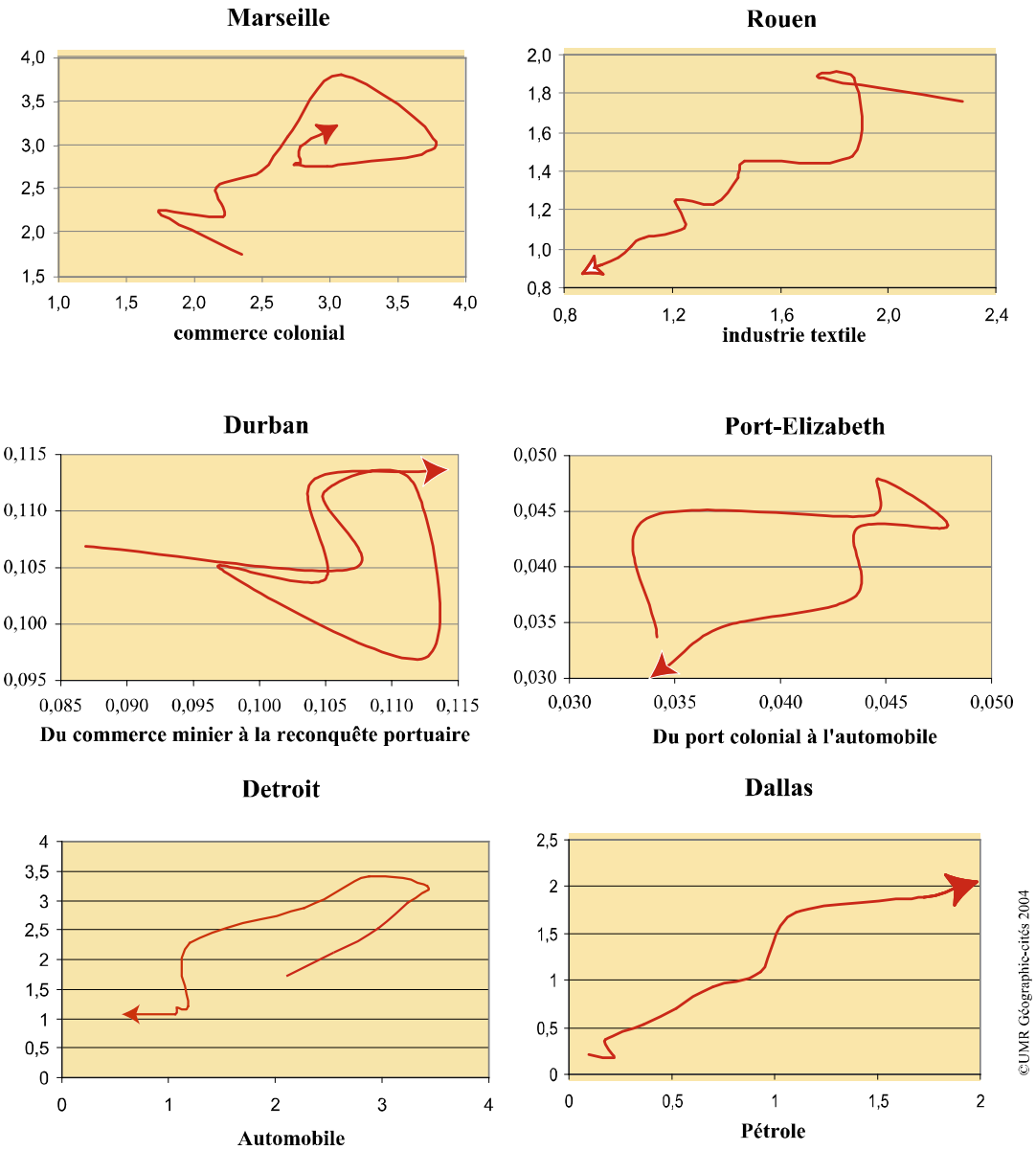

[Pumain D. *Hierarchy in natural and social sciences*, Springer, 2006]

# Urban trajectories/specialisation

$X = Pi_t / PU_t$
(Pit = population city i time t
PU = urban system's total population time t)

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

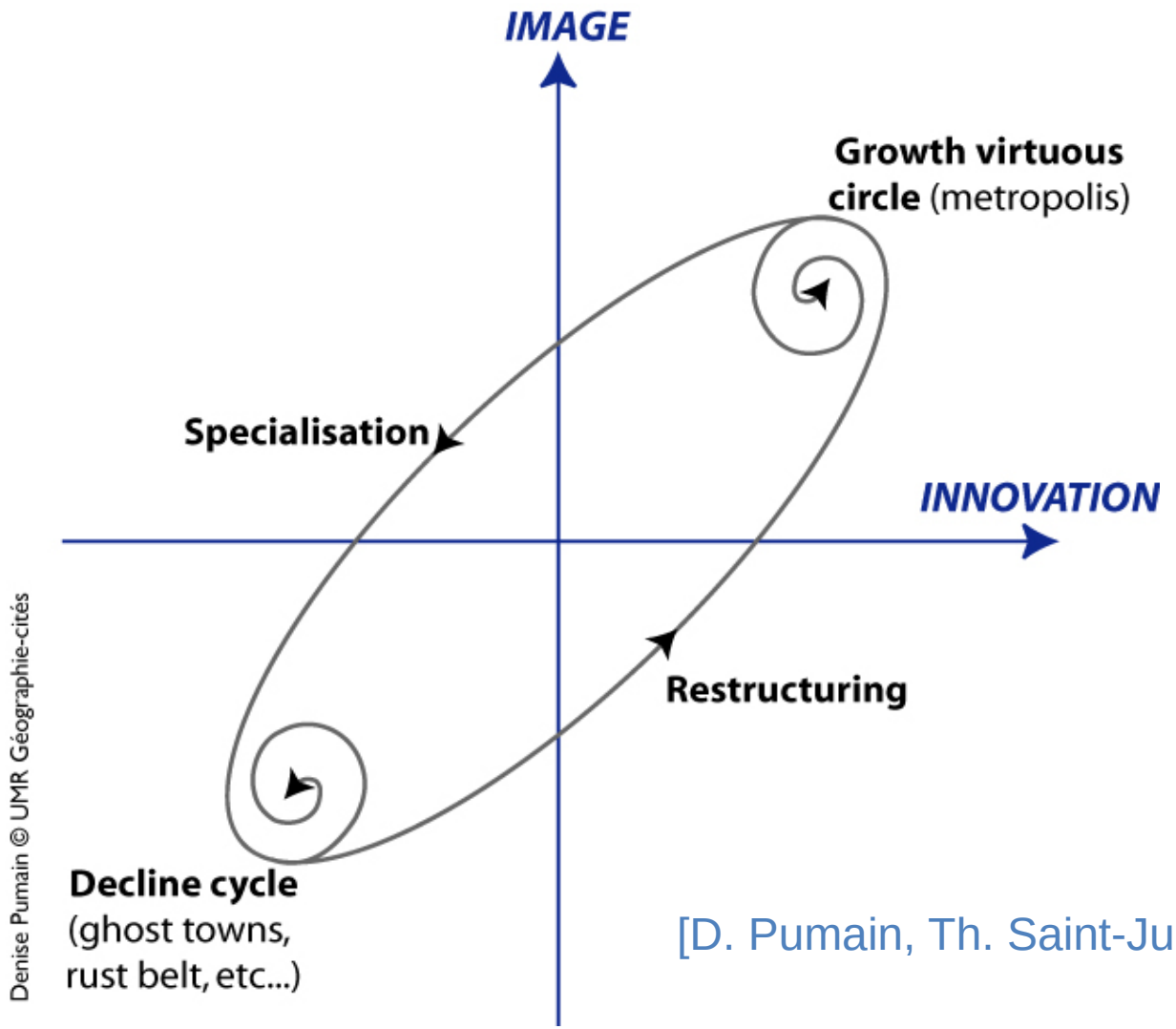
[Bretagnolle, Vacchiani-Marcuzzo, Pumain, 2007]




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

# Innovation as key factor of urban adaptive process




[D. Pumain, Th. Saint-Julien, F. Paulus]

# 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

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

# SIMPOP: a multi-agents system

First application of MAS in geography !

Bura, Guérin-Pace, Mathian, Pumain, Sanders, Multi-agent systems and the dynamics of a settlement system. *Geographical Analysis*, 1996, 2, 161-178

Main results:

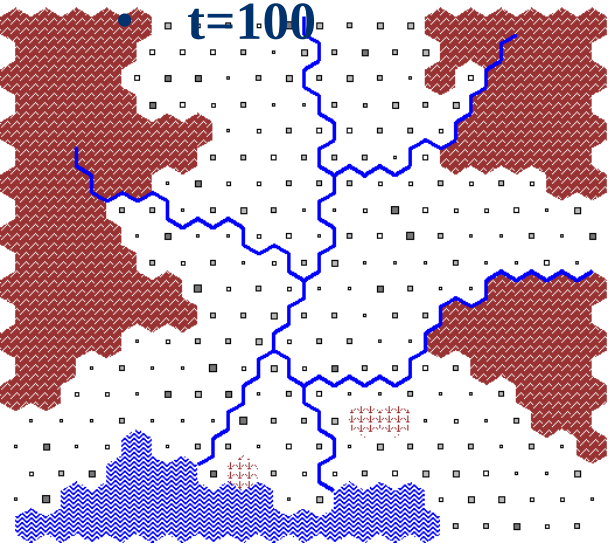
- No emergence if no spatial interactions
- Emergence of a polycentric hierarchised system of cities even if homogeneous initial conditions
- A renewed innovation flow is necessary for maintaining structural properties of the system of cities

Pending questions: which validity of estimated parameters?

Conditions are sufficient , are they necessary?

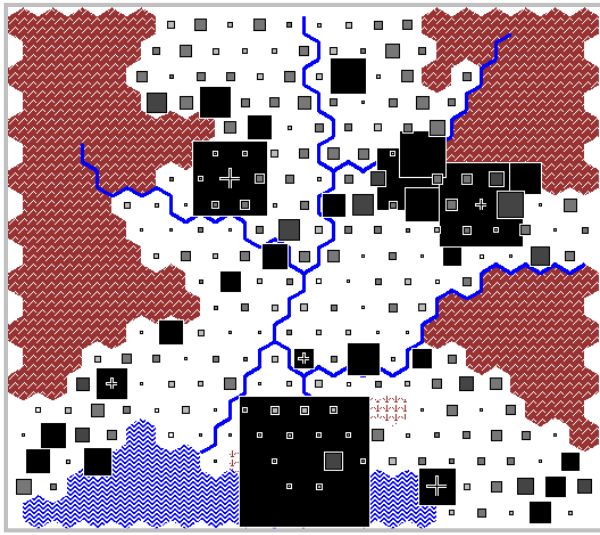
# The SIMPOP model: emergence of a polycentric system of cities

t=100



t=1700

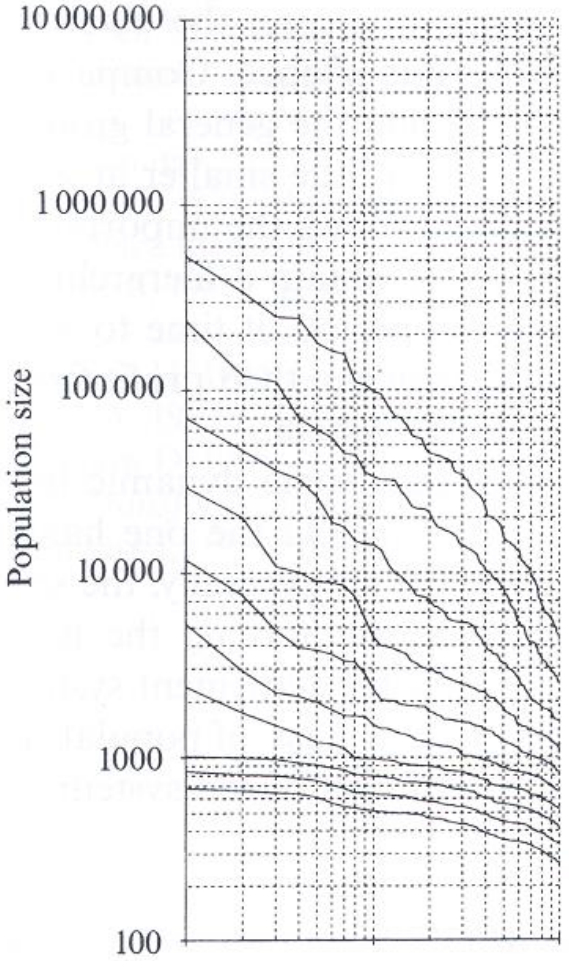
t=2000

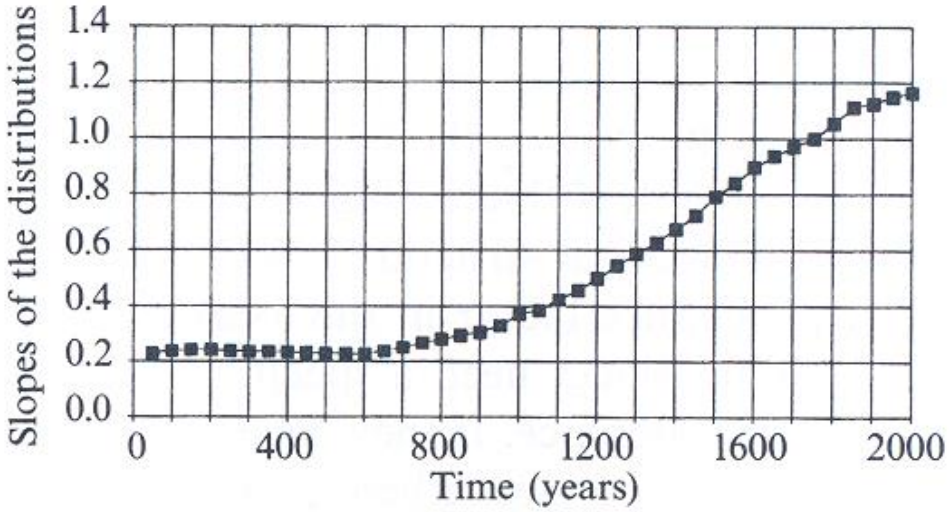


Starting from a rather regular distribution of settlements, a system of cities emerges, with a strong hierarchical and spatial organization

[Bura, Guérin-Pace, Mathian, Pumain, Sanders, 1996; Sanders et al.1997]

# Emerging hierarchical differentiation of the settlement system (rank-size distribution)




t = 2000

t = 1600

t = 0

*Source: SIMPOP model, Sanders et al.1997*

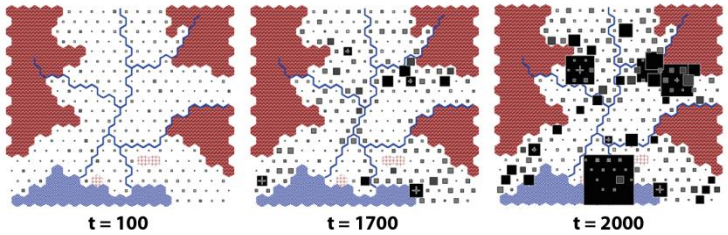
# Originality of SIMPOP Models

- Scale: national or continental integrated urban systems, long term
- Cities are agents : collective, immobile, heterogenous, evolving entities
- Main attributes: location, resources (labour force, capital), functions (10 types)
- Three levels: individual (firm or mayor, for scenarios), cities (local governance), national or multinational (global governance)
- Rules : stylised facts from comparative study of the observed evolution of integrated urban systems

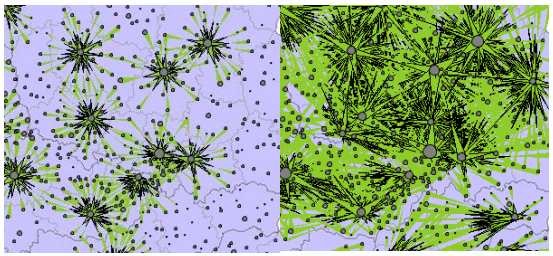
# The Simpop family of simulation models

## URBAN EVOLUTIONARY THEORY

**SIMPOP *(1996)***

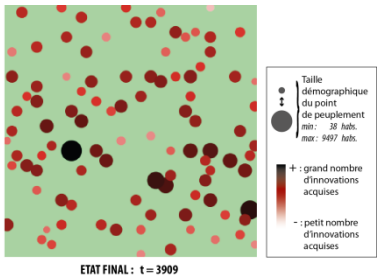



**SIMPOP 2 *(2006)***

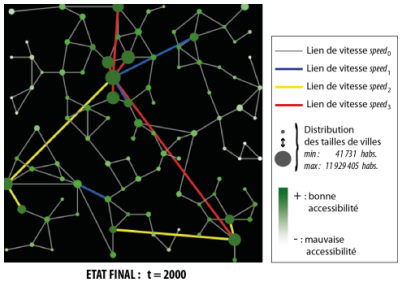


*First generation*

**SimpopLocal *(2012)***




**& SimpopNet *(2012)***




*Second generation*

**MARIUS *(2014)***

# Two types of modelling teams

- 1995-2010 : 3 PhD students in computing from 3 different labs Ferber, Drogoul, Giavitto/Hutzler help geographers ( S. Bura, B. Glisse, T. Louail)

➔ Three models each in a different langage (Smalltalk, Swarm, C++…), not reusable

Institutional event : ERC adv. grant GeoDiverCity

- 2010-2015: real daily team work between 4 computer scientists (Reuillon, Leclaire, Chapron, Cherel) and PhD in geography and geomatics (C. Schmitt, C. Cottineau, S. Rey-Coyrehourcq, E. Swerts, A. Ignazzi, S. Baffi, O. Finance)

➔ Models on systems of cities in Europe, USA, BRICS with OpenMOLE platform (evolutionary algorithms and distributed computing)

# Further advances in explanation

- No counter-urbanisation (≠ Berry, 1976), increasing hierarchisation / Gibrat' model prediction

(Bretagnolle, Pumain, Rozenblat, 1997, *Cybergeo*, 61, Bretagnolle, Mathian, Pumain, Rozenblat 2000, *Cybergeo* 131, Bretagnolle, Paulus, Pumain 2002, *Cybergeo*, 219)

➔« metropolisation » and « simplification from below of urban hierarchies (cf. « shrinking cities »)

- « Global cities since Middle Ages » (Bretagnolle, Pumain, 2010, *Urban Studies*)

# Urban trajectories to reconstruct

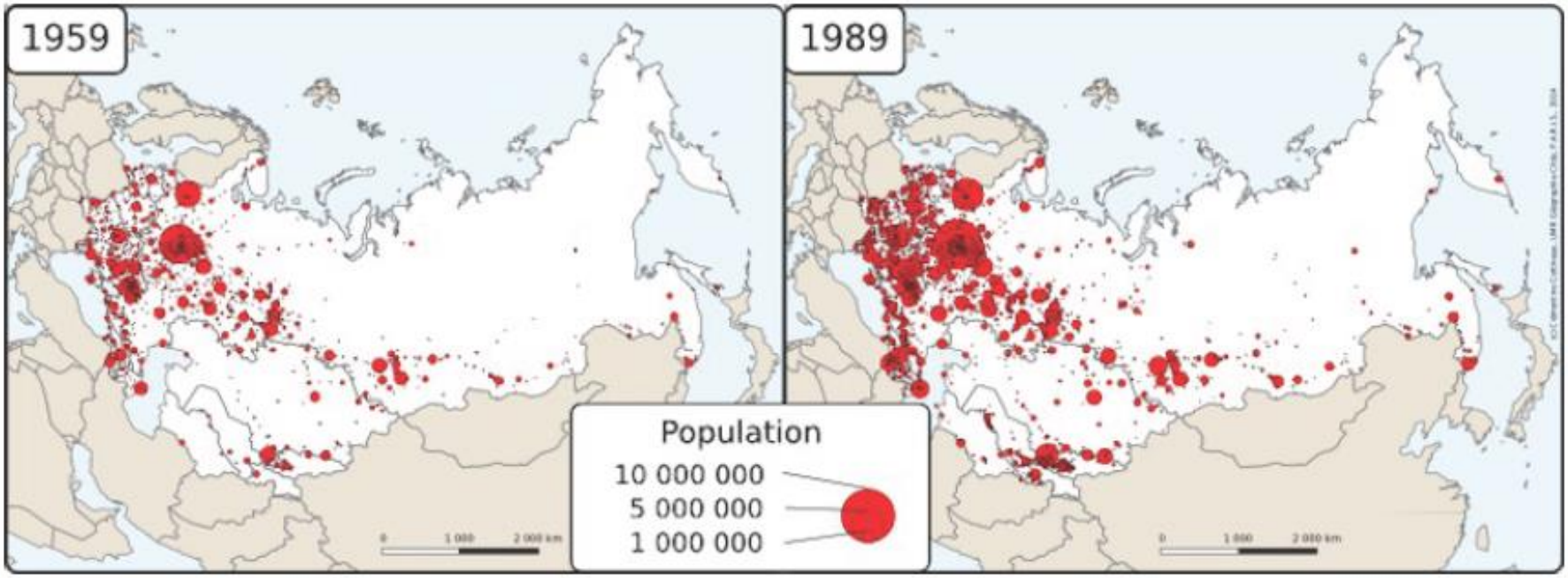
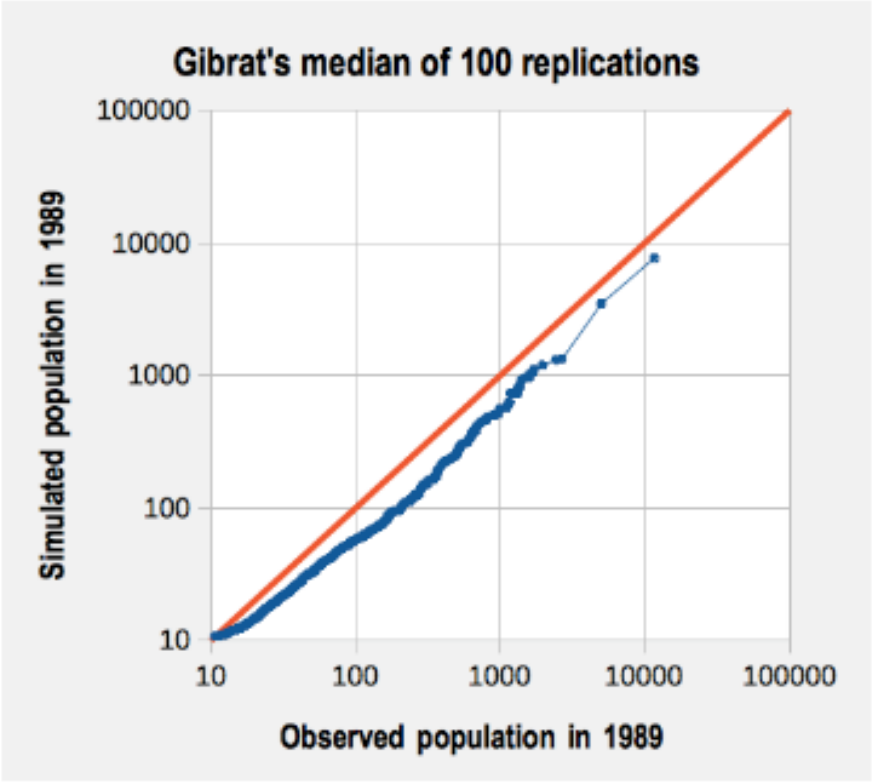



Figure 2. Empirical spatial and hierarchical distribution of cities in the post-Soviet space
source: DARIUS, 2014

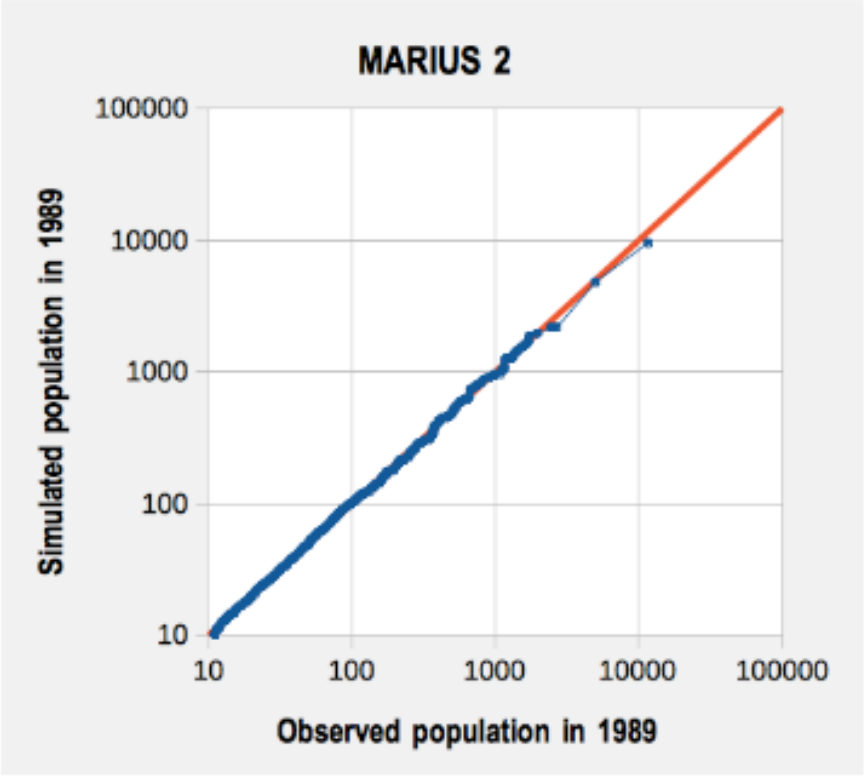
*Cottineau et al., 2015, JASS*

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

**Gibrat's model**

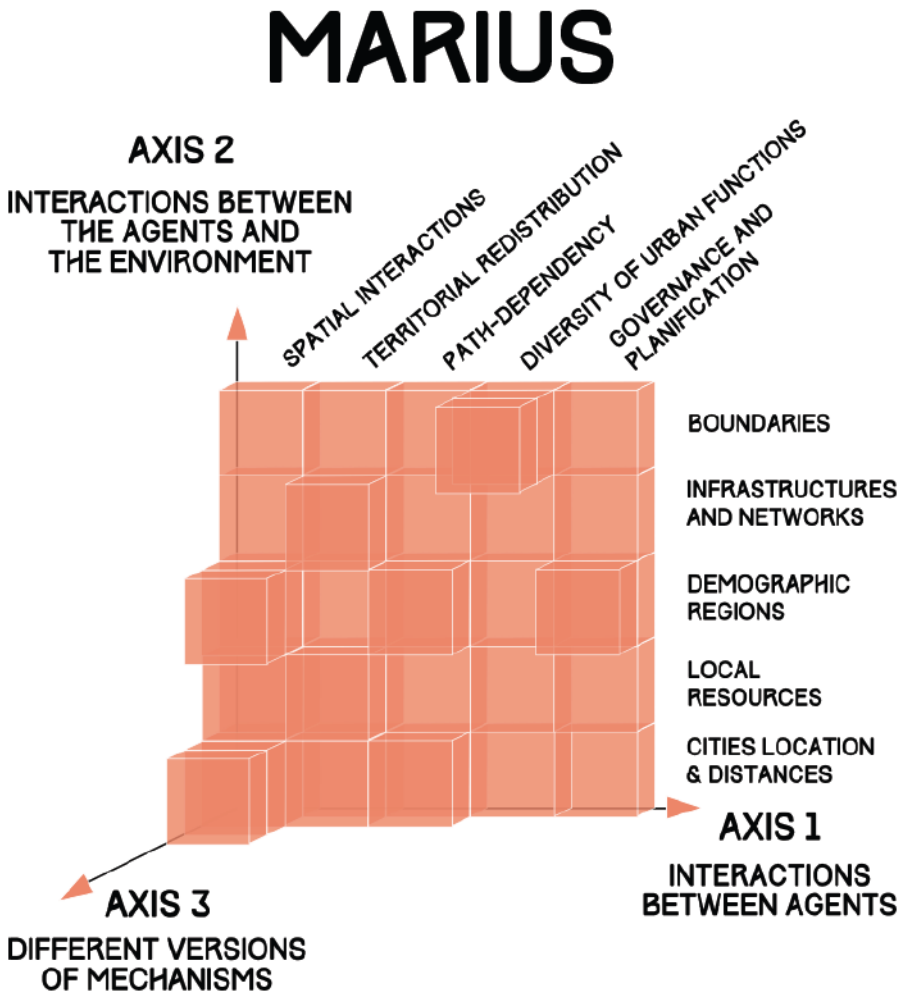



**model with interactions**




*Cottineau, 2014*

# New modelling method: building multi-models




*Cottineau, Chapron, 2015*

# Toward providing proofs in HSS

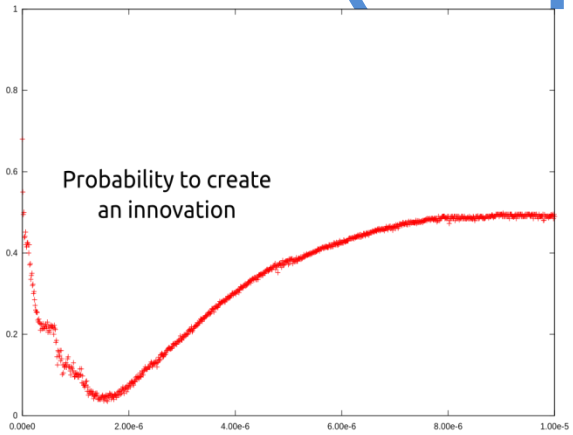
With SimpopLocal model (Clara Schmitt & Sébastien Rey-Coyrehourcq) and simulation platform OpenMole (Romain Reuillon, Mathieu Leclaire)

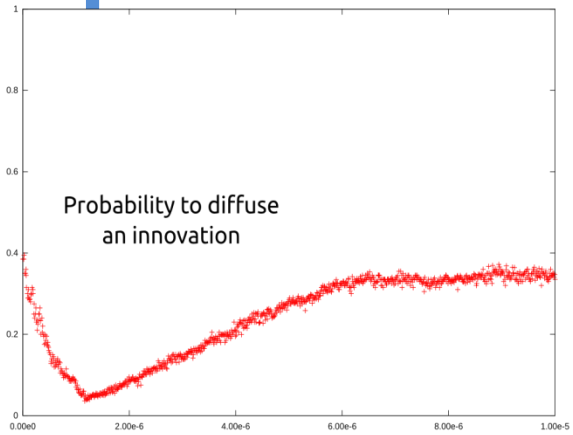
➔ Proof: hypotheses are sufficient…and necessary!

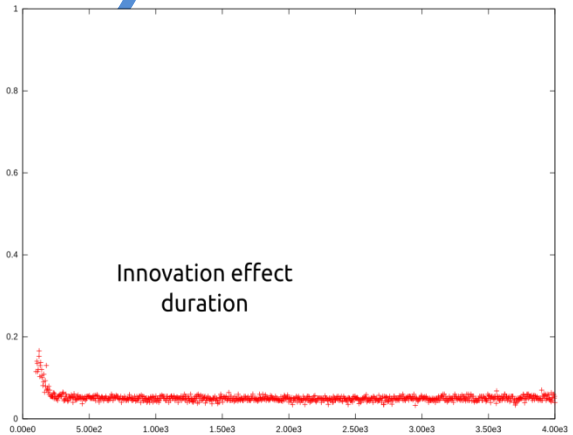
➔ Schmitt C., Rey-Coyrehourcq S., Reuillon R., Pumain D., 2015, Half a billion simulations, Evolutionary algorithms and distributed computing for calibrating the SimpopLocal geographical model, *Environment and Planning B, 42, 2,300-315.*

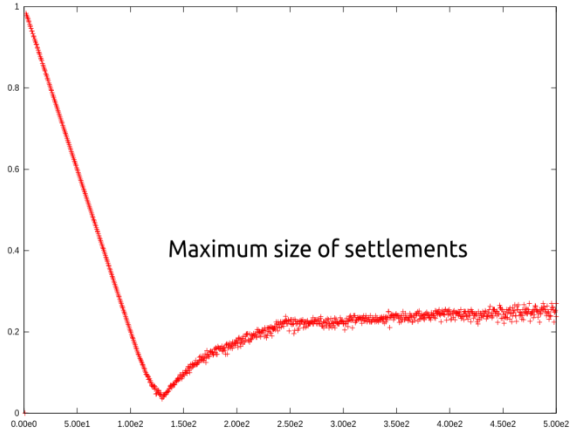
- Calibration profile: Romain Reuillon

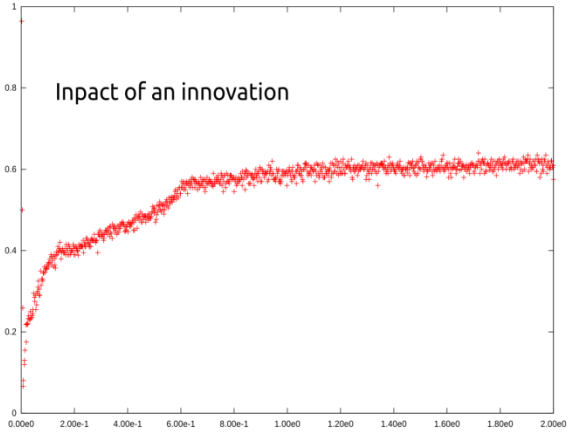
# Best solutions in parameter space (SimpopLocal model)

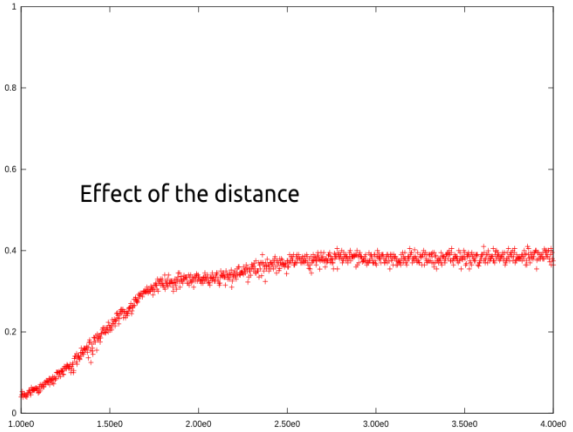


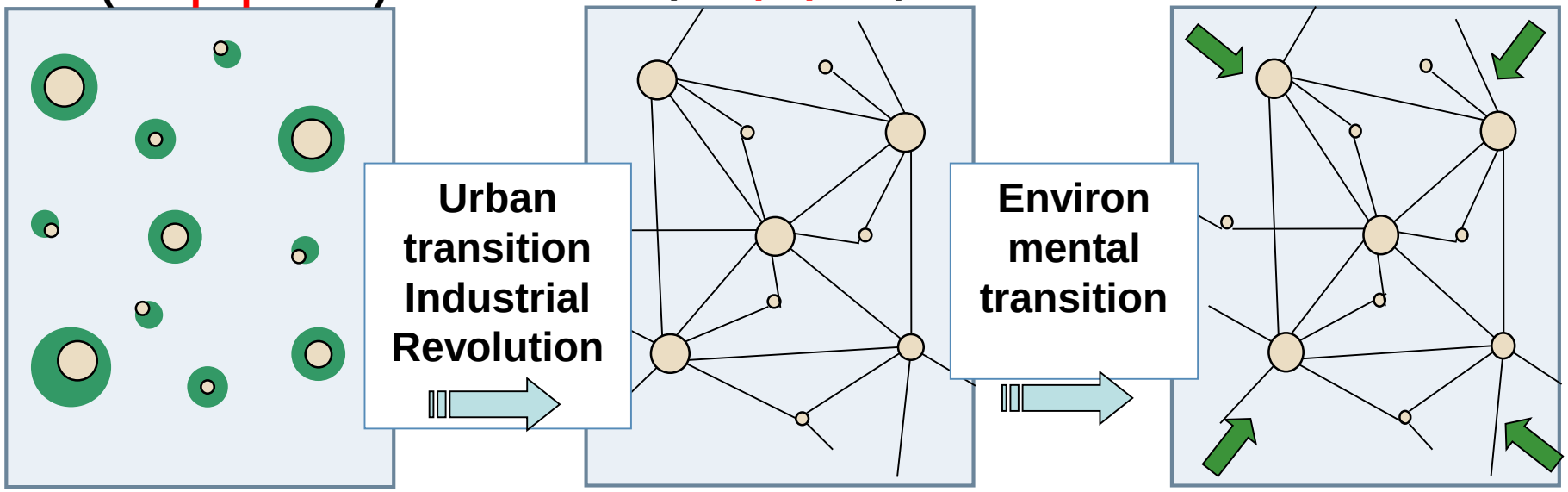

***Schmitt, Reuillon, 2014: Calibration profile method***

# Three stages in the evolution of urban systems (consolidated evolutionary theory)

**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 )*

# Discussion

Thanks to OpenMole, a step forward assessing the level of generality of urban theories vs identifying regional variations:

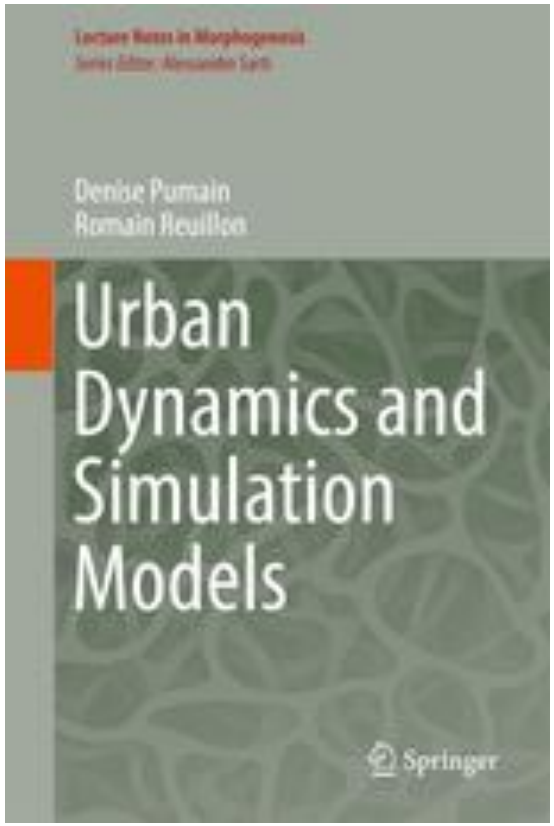
- Multimodelling (incremental modelling with generic computing and distributed computing tool) produces a population of optimal solutions and compares their contribution to model fit = the explanatory power of different mechanisms at reconstructing urban trajectories
- For non-compatible models: comparing respective performances of bi-objective Pareto fronts

**Open questions**

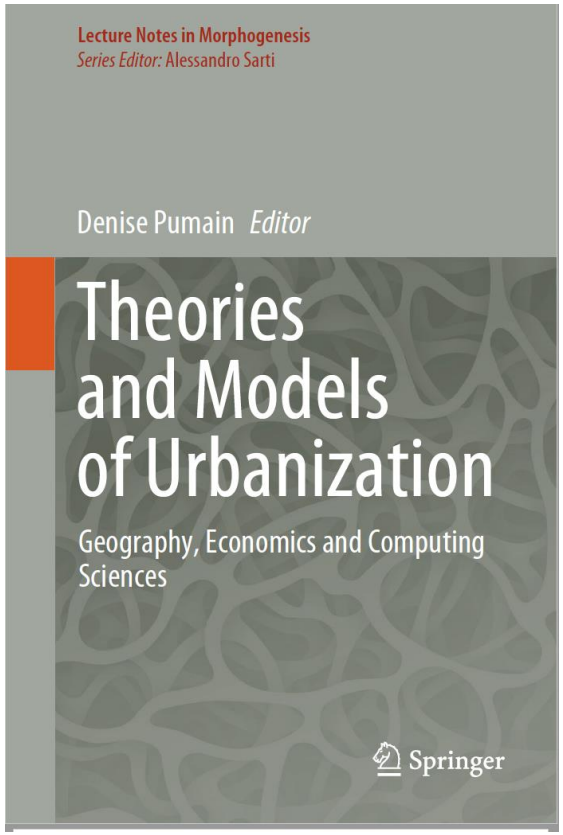
- How to compare the explanatory power of models with different structures?
- Observations or synthetic data for simulations?

# Thank you for your attention!

**http://geodiversity.parisgeo.cnrs.fr**




2017




2020