A systematic comparison of interaction models for systems of cities

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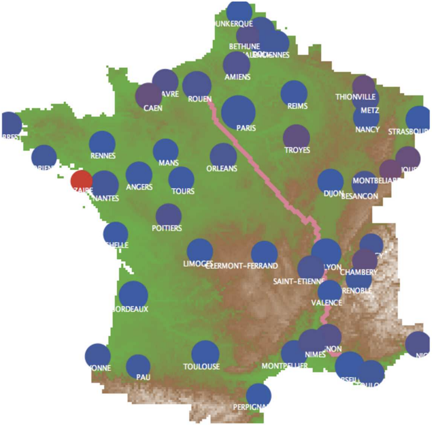
The long time memory of urban systems

Source: Wikipedia

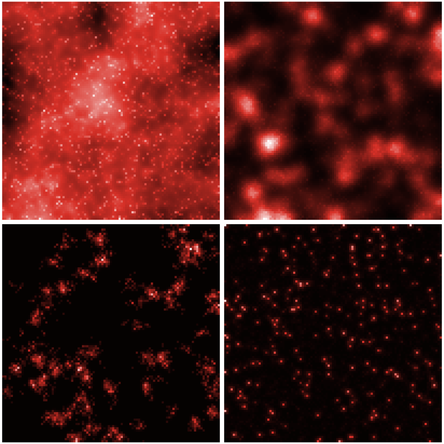
Modeling urban growth

Macroscopic urban system



Raimbault, J. (2018). Indirect evidence of network effects in a system of cities. *Environment and Planning B: Urban Analytics and City Science*, 2399808318774335.

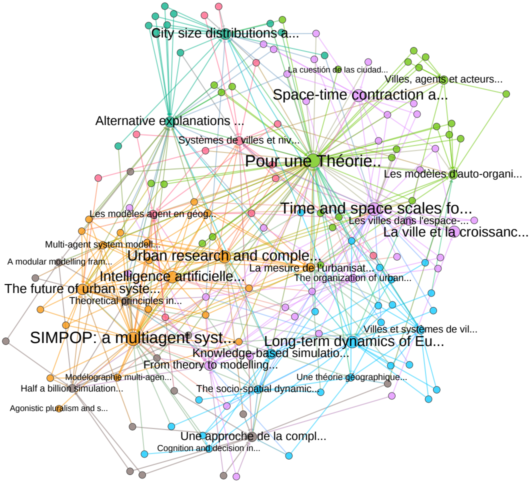
Mesoscopic territorial systems



Raimbault, J. (2018). Calibration of a density-based model of urban morphogenesis. PloS one, 13(9), e0203516.

An evolutionary urban theory

From [Pumain, 1997] to [Pumain, 2018]: systems of cities as co-evolutive systems in which interactions are crucial



[Raimbault, 2017] Citation network analysis of core publications in the evolutionary urban theory

Towards a systematic model comparison

$\rightarrow$ several models in this context have been introduced, but never compared (e.g. in terms of explanative power)

$\rightarrow$ multidimensionality of urban systems and the potential complementarity between very different processes

Research objective : *Benchmark interaction models for systems of cities developed in the frame of the evolutionary urban theory, on several comparable systems of cities.*

Urban systems interaction models

Comparison of three approaches based on the evolutionary urban theory [Pumain, 1997] capturing different dimensions of urban systems:

- The Favaro-Pumain model for the diffusion of innovation [Favaro and Pumain, 2011]
- The Marius model family based on economic exchanges [Cottineau, 2014]
- An interaction model including physical transportation networks [Raimbault, 2018b]

Description of models

Network interaction model

- Endogenous growth
- Interactions inducing growth through gravity potential
- Static physical network taken into account (geographical shortest path with topography)

Favaro-Pumain model

- Endogenous growth
- Innovation emerge and diffuse in cities
- Growth rates adapted according to utility of innovation and level of adaptation

Marius model

- Cities produce economic goods
- Economic exchanges are estimated according to gravity flows
- Populations grow depending on final economic balances

Datasets

Dataset

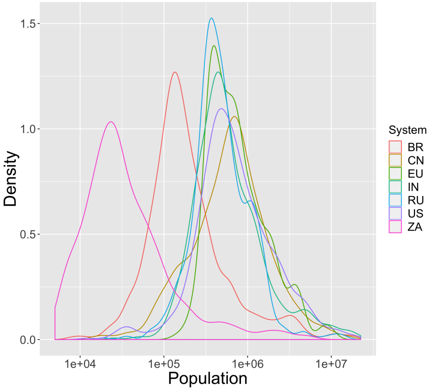
Harmonized dataset, explored in particular by [Pumain et al., 2015] (built in the context of Geodivercity ERC)

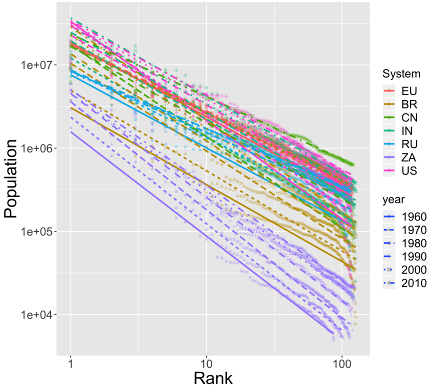
Data preprocessing

- Remove small cities and medium-sized cities ([Adam, 2006] for definition of medium-sized) for scalability of simulations
- Shortest paths matrices (direct and taking into account topography, using the EEA world DEM) computed a priori and cached (*no evolution of the network*)

Stylized facts

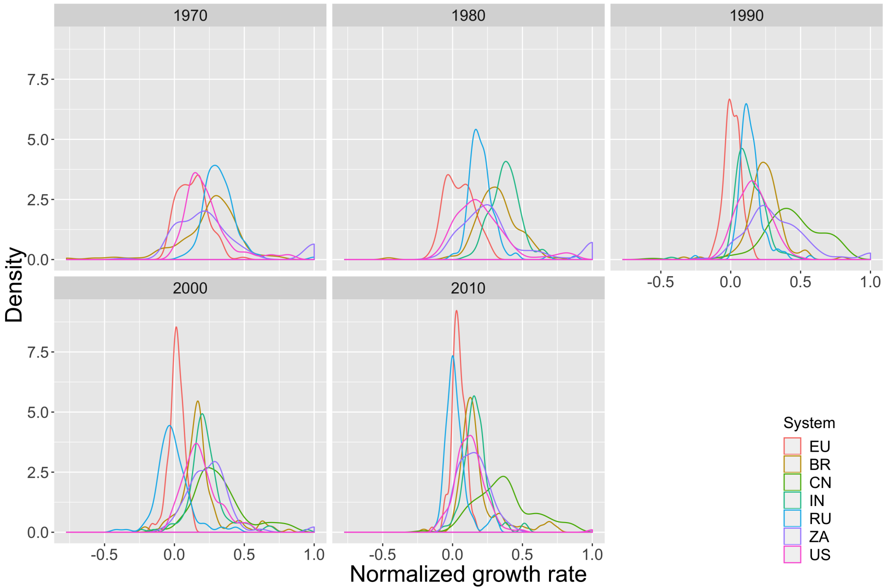
Population distributions mainly log-normal (75% with KS-test, all with AIC); consistent hierarchies in time.





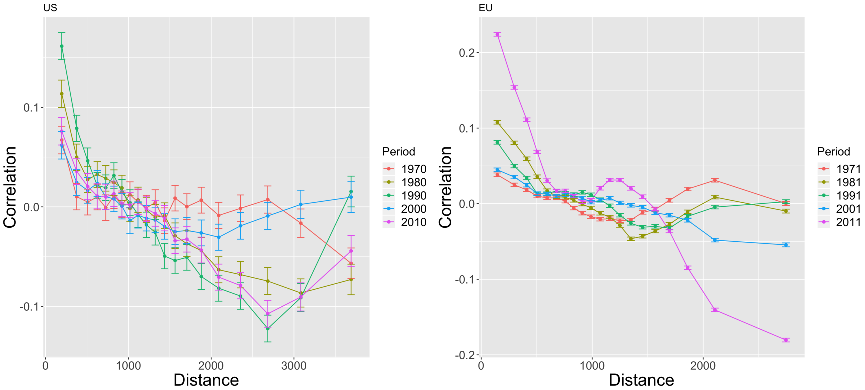
Stylized facts

Growth rates distributions evolve considerably in time



Stylized facts

Correlation as a function of distance: long-range correlations in several systems



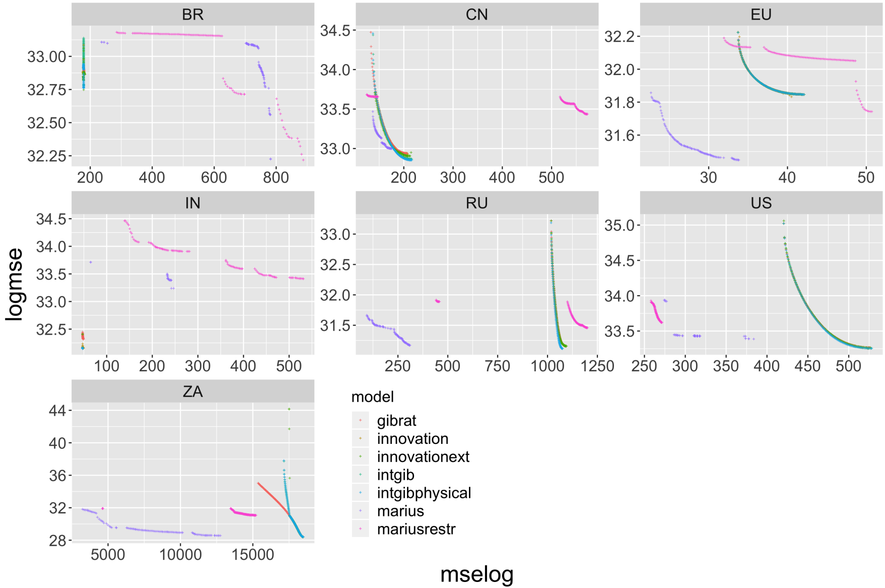
Model calibration

Bi-objective calibration of 7 models for 7 city systems → use of genetic algorithms on grid, made smooth with the OpenMOLE software `https://next.openmole.org/`

OpenMOLE: (i) embed any model as a black box; (ii) transparent access to main High Performance Computing environments; (iii) model exploration and calibration methods.

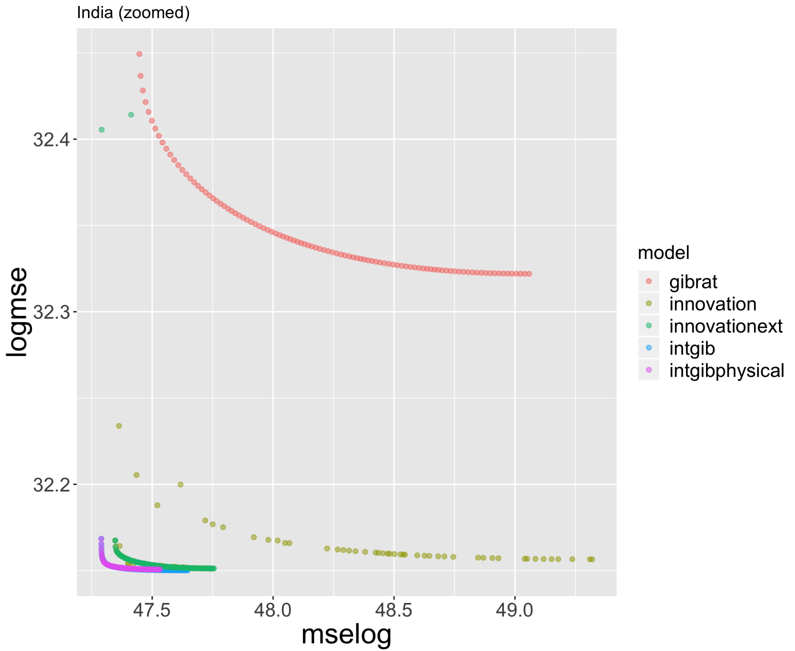
Come to the Satellite on Wednesday, and apply to the summer school ! (`https://exmodelo.org/`)

Comparison of models on all systems

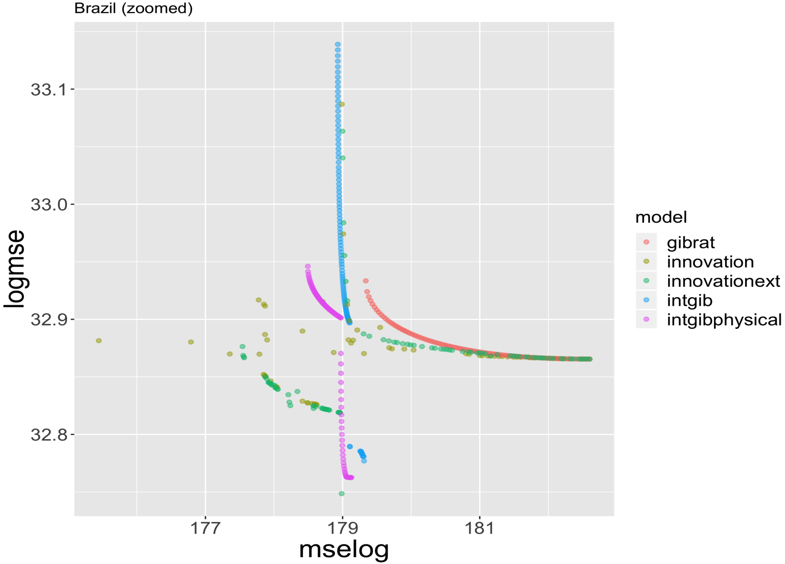


Systems driven by economic exchanges: EU, US, RU, ZA

Indian urban system: direct interactions

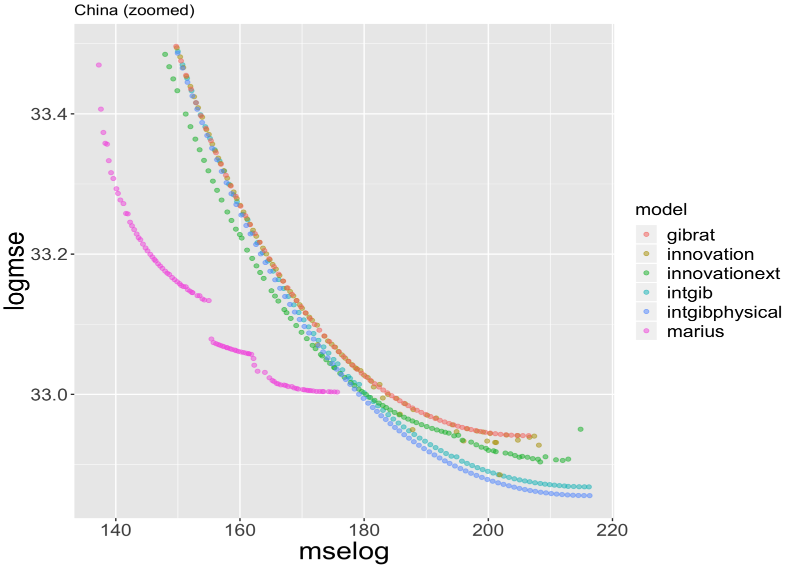


Brazilian urban system: multiple factors



Importance of topography; innovation processes mostly.

China: a tight competition



No clear best model: other processes in play ? (strong top-down planning)

Results: empirical AIC

Comparing Gibrat and Network model by correcting for the number of parameters [Raimbault, 2018b]: additional parameters actually improve the fit (but not always)

System	ΔAIC (log)	ΔBIC (log)	ΔAIC (mse)	ΔBIC (mse)
ZA	33.82658	29.40496	-838.07184	-842.49347
CN	20.67713	16.78273	13.40767	9.51327
BR	-263.27003	-267.71575	-407.55220	-411.99792
IN	-85.01949	-89.24206	-188.16703	-192.38960
RU	50.60535	46.24233	104.94806	100.58503

Discussion

Implications

→ Complementarity of economic, innovation and direct interaction processes

→ High dimensionality of urban systems

Developments

→ Still points on robustness to be investigated: influence of stochasticity, convergence of GA, saturation of parameters, number of cities.

→ Towards integrated models coupling these different components ?

→ Compare on synthetic systems of cities with appropriate indicators [Raimbault, 2018c].

→ Calibrate at the second order (correlations), non-stationary in time.

→ More elaborated method to compare models in a "fair" way (correcting for additional parameters, open question for models of simulation): model reduction ?

Conclusion

→ First step towards systematic benchmarks and multi-modeling. **Need for more systematic model exploration.**

→ Model integration and multi-scalarity ? **Need for more integrated models.**

→ Multiple perspectives on urban systems ? **Need for more interdisciplinarity.**

Related works

Raimbault, J. (2018). Indirect evidence of network effects in a system of cities. Environment and Planning B: Urban Analytics and City Science, 2399808318774335. `https://halshs.archives-ouvertes.fr/halshs-01788559`

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Raimbault, J. (2018). Caractérisation et modélisation de la co-évolution des réseaux de transport et des territoires (Doctoral dissertation, Université Paris 7 Denis Diderot). `https://halshs.archives-ouvertes.fr/tel-01857741`

Open repository at `https://github.com/JusteRaimbault/UrbanGrowth`

Acknowledgments: thanks to the *EGI* for access to the infrastructure.

Reserve Slides

Model calibration

Genetic algorithm NSGA2:

- Around 40000 generations (4e6 model runs)
- Population $\mu = 100$
- Convergence tested with hypervolume relative variation

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