An agent-based model for city networks based on interactions between firms

J. Raimbault[1,2,3*] N. Zdanowska[1,3]

*j.raimbault@ucl.ac.uk

[1]CASA, UCL
[2]UPS CNRS 3611 Complex Systems Institute Paris
[3]UMR CNRS 8504 Géographie-cités

CCS 2019
Satellite Simulation models
October 2nd 2019

Urban firm networks

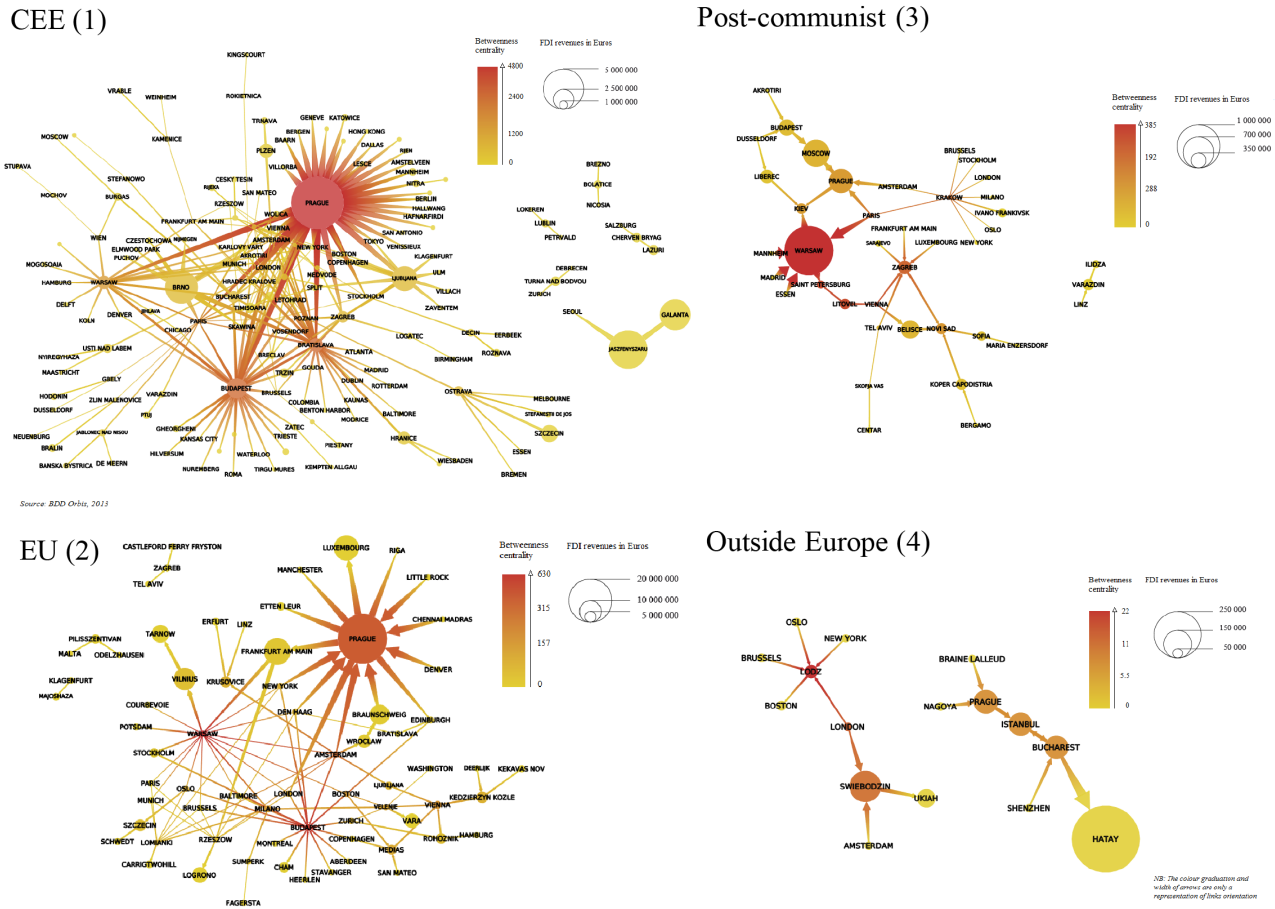
General framework:

- Cities as cross-overs of socio-economic interactions
- Network economies [Sassen, 1991] [Castells, 1996]
- World city network driven by interactions between firms [Taylor, 2001] [Martinus and Sigler, 2018]
- Asymmetrical spatial interactions – different relative position of cities

An evolutionary approach to Urban Systems

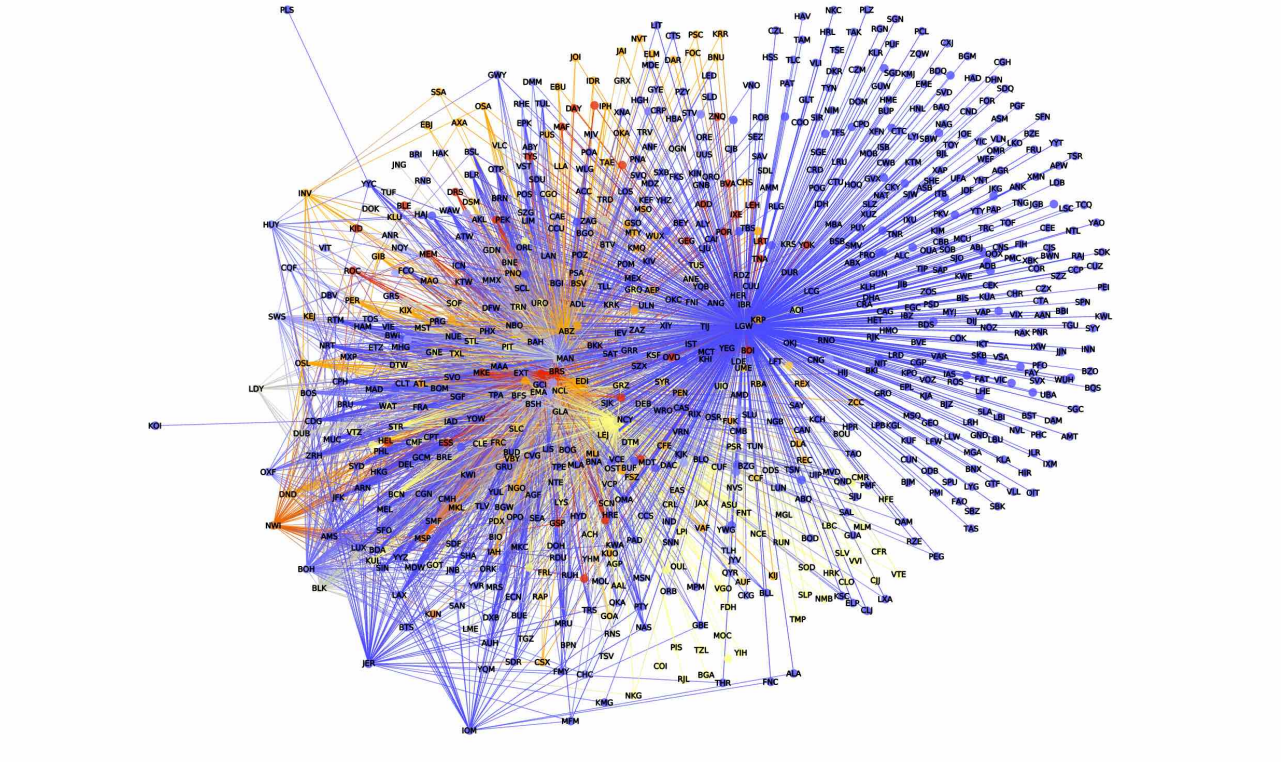
- Evolutionary Theory of Urban Systems [Pumain, 1997] [Pumain, 2006]
- Adaptive cycles and diffusion on innovation [Hagerstrand, 1968]
- Path dependence [Martin and Sunley, 2006] [Pumain, 2012]
- Selection and emerging structures of systems
- Evolutionary models for urban systems dynamics: [Favaro and Pumain, 2011] [Cottineau et al., 2015] [Schmitt et al., 2015] [Raimbault, 2018b] [Raimbault, 2018a]

Firm linkages structuring urban systems



Central and Eastern European cities within ownership links of firms in 2013

Firm linkages structuring urban systems



UK cities within transnational ownership links of firms in 2016

Urban firm linkages and geo-economic processes

Assumptions

- Metropolisation vs. regionalisation effects
- Relationship local/global of multinational firm linkages
- Specialisation-driven factors and drivers of innovation
- Macroeconomic exogenous chocs and resilience of urban systems

$\rightarrow$ *How can we capture geographical and economic processes within urban networks of firms with a generative model?*

- Indirect inference on processes
- Includes path-dependency

Model rationale

$\rightarrow$ Cities are defined by their GDP and their profile regarding the proportion of firms in the different sectors. Links between cities are created in an iterative way, taking into account:

- geographical proximity (distance or effective accessibility)
- geopolitical proximity (belonging to the same country or single market $\rightarrow$ application to Brexit)
- city size (economic size as GDP)
- economic similarity (e.g. cosine distance between sector proximity as done in [Cottineau and Arcaute, 2019]
- previous linkages

Formalization

Cities characterized by economic size E_i (GDP) and economic structure S_{ik} (probability distribution of firms within K sectors)

Starting from an initial network, at each time step:

1. Evolve city sizes $E_i\left(t+1\right) = f\left(E_j\left(t\right)\right)$ with an interaction model ([Raimbault, 2018b] or [Cottineau et al., 2015])
2. Add a fixed number of links randomly, following a probability function of sizes, sector proximity, and geographical and socio-cultural proximity

Formalization

Probability for a new link follows a generalized Cobb-Douglas function

$$p_{ij} \propto \left(\frac{E_i}{E}\right)^{\gamma_F} \cdot \left(\frac{E_j}{E}\right)^{\gamma_T} \cdot \left(\frac{w_{ij}}{W}\right)^{\gamma_W} \cdot s\left(S_{ik}, S_{jk}\right)^{\gamma_S} \cdot \exp\left(-\gamma_G \cdot d_{ij}\right) \cdot \exp\left(-\gamma_D \cdot g_{ij}\right)$$

where $E = \sum_k E_k$, $W = \sum_{i,j} w_{ij}$, s is a proximity measure given by cosine similarity, d_{ij} euclidian distance, and g_{ij} a socio-cultural distance

Model parameters: $\gamma_F, \gamma_T, \gamma_W, \gamma_S, \gamma_D = \frac{1}{d_G}, \gamma_G = \frac{1}{d_G}$

Model indicators

Geographical indicators:

- Internationalisation (modularity of countries in the network)
- Metropolisation (correlation between weighted degree and city size)
- Regionalisation (correlation between length and flow of links, stratified by size of extremities)
- Specialisation (correlation between sector proximity and flow of links, stratified by size of extremities)

Network and flows indicators:

- Louvain modularity, community sizes
- Degree and flows distribution (average, hierarchy, entropy)
- Correlations (degree-size, flow-distance)

Simulation on synthetic systems of cities

Following [Raimbault et al., 2018], geosimulation models must be studied within synthetic controllable urban contexts in order to (i) understand intrinsic behavior of the model and robust qualitative stylized facts; (ii) study the sensitivity to the spatial configuration

Generation of a continent-scale urban system with stylized order of magnitude corresponding to Europe:

1. Generate $N = 700$ cities with size following a power law $E_i = E_0 \cdot i^{-\alpha}$ with $E_0 = 10^{11}$ and $\alpha = 1.1$ (computed on Europe for GDP with cities larger than 50.000 inhabitants)
2. Distribute them randomly in space ([Simini and James, 2019] vs [Banos et al., 2011])
3. Create countries with k-means clustering ($C = 30$)
4. Distribute sectors such that (i) smaller cities are more specialized and (ii) larger cities are more knowledge-based, with a one dimensional axis to position sectors $1/K \dots 1$ where the density $f\left(k\right)$ follows a log-normal with $\left(\mu, \sigma\right)$ such that $\sqrt{\text{Var}\, f} = K/2$ for the largest, $\sqrt{\text{Var}\, f} = 1/K$ for the smallest

Implementation and experiments

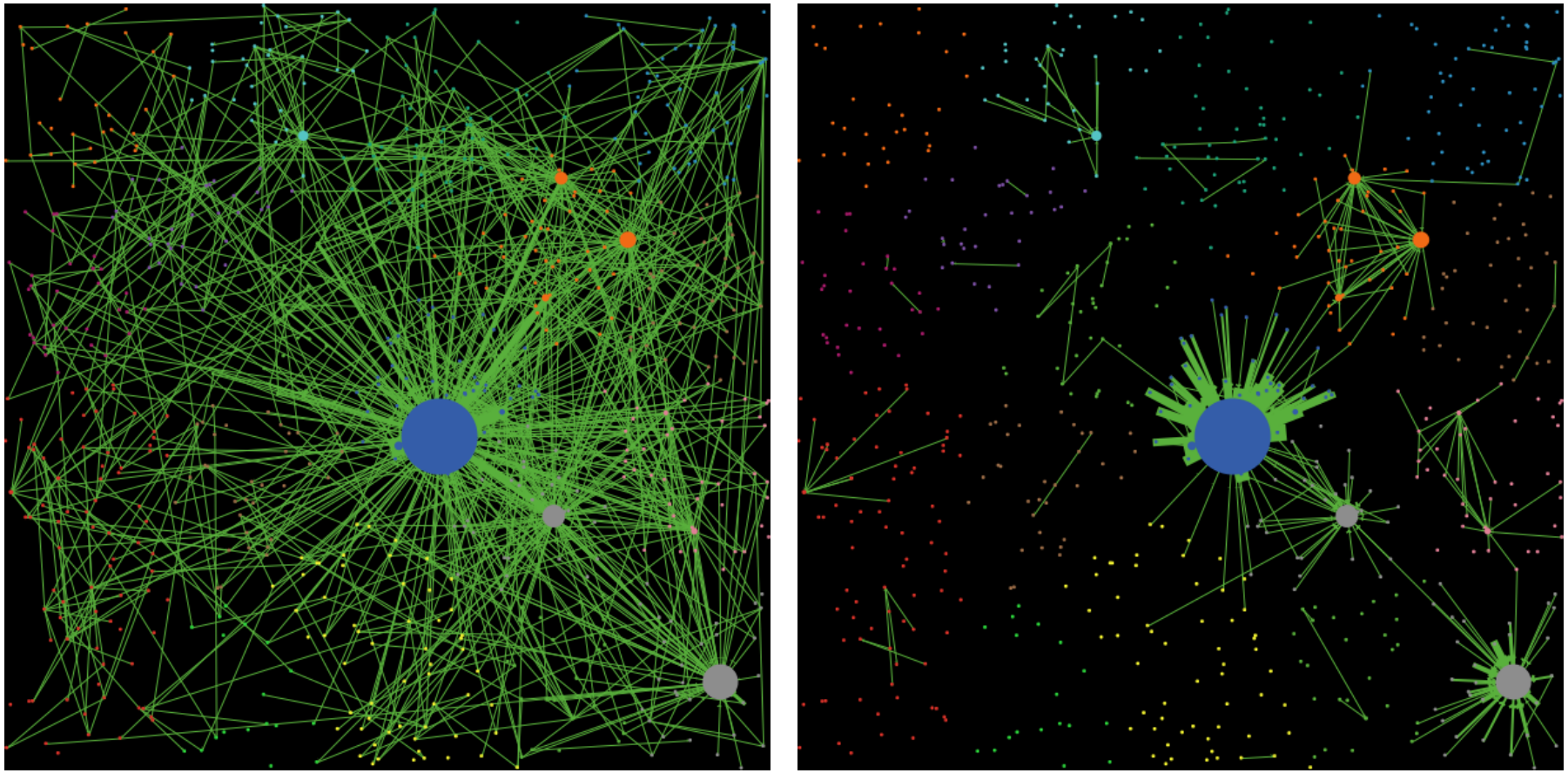
Implementation

- Model implemented in NetLogo (good compromise interactivity / ergonomy), with fast data structures (matrix/table extensions)
- Integrated seamlessly into OpenMOLE [Reuillon et al., 2013] for model exploration (NetLogoTask)

Experiments

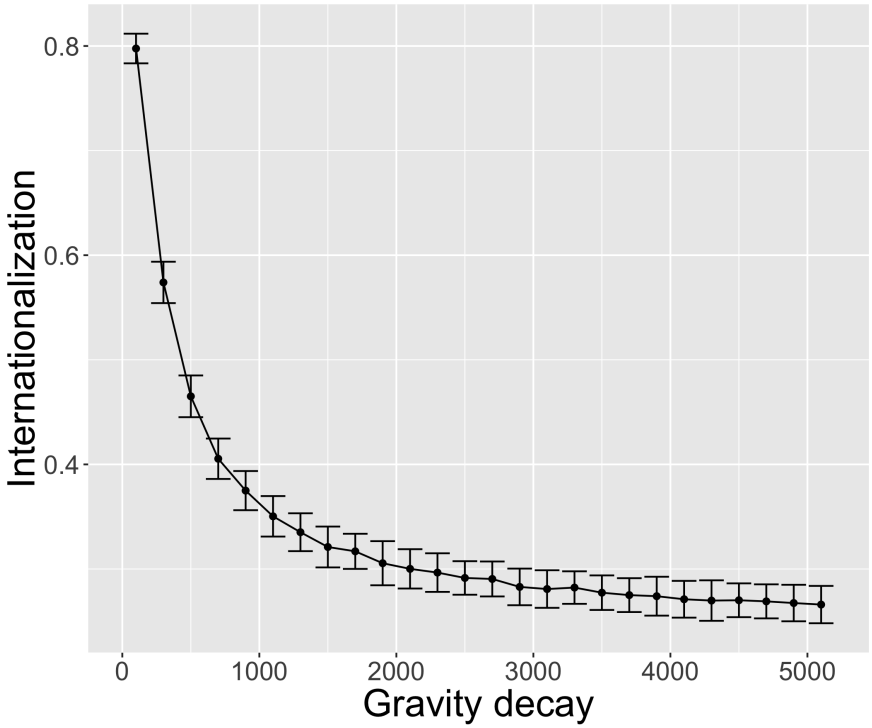
- Current experiment: only network dynamics (short time scale)
- One-factor sampling with 100 repetitions to assess statistical properties (good convergence, average sharpe ratios for indicators all larger than 5)
- Grid sampling with 20 repetitions for model behavior

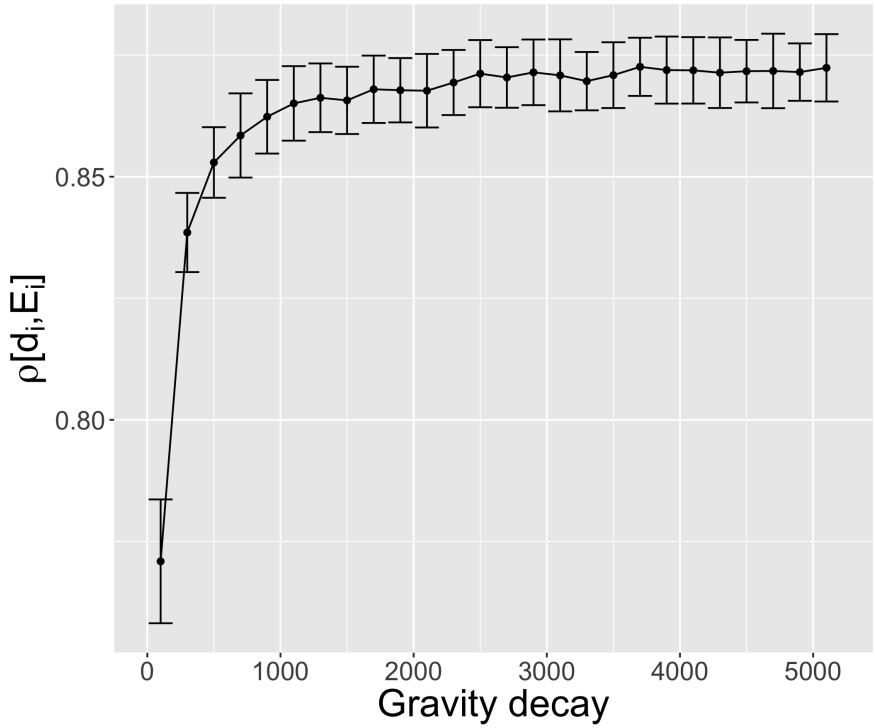
Simulation of urban networks



Networks at t = 1500*, for default parameters values and high gravity (left) and low gravity (right)*

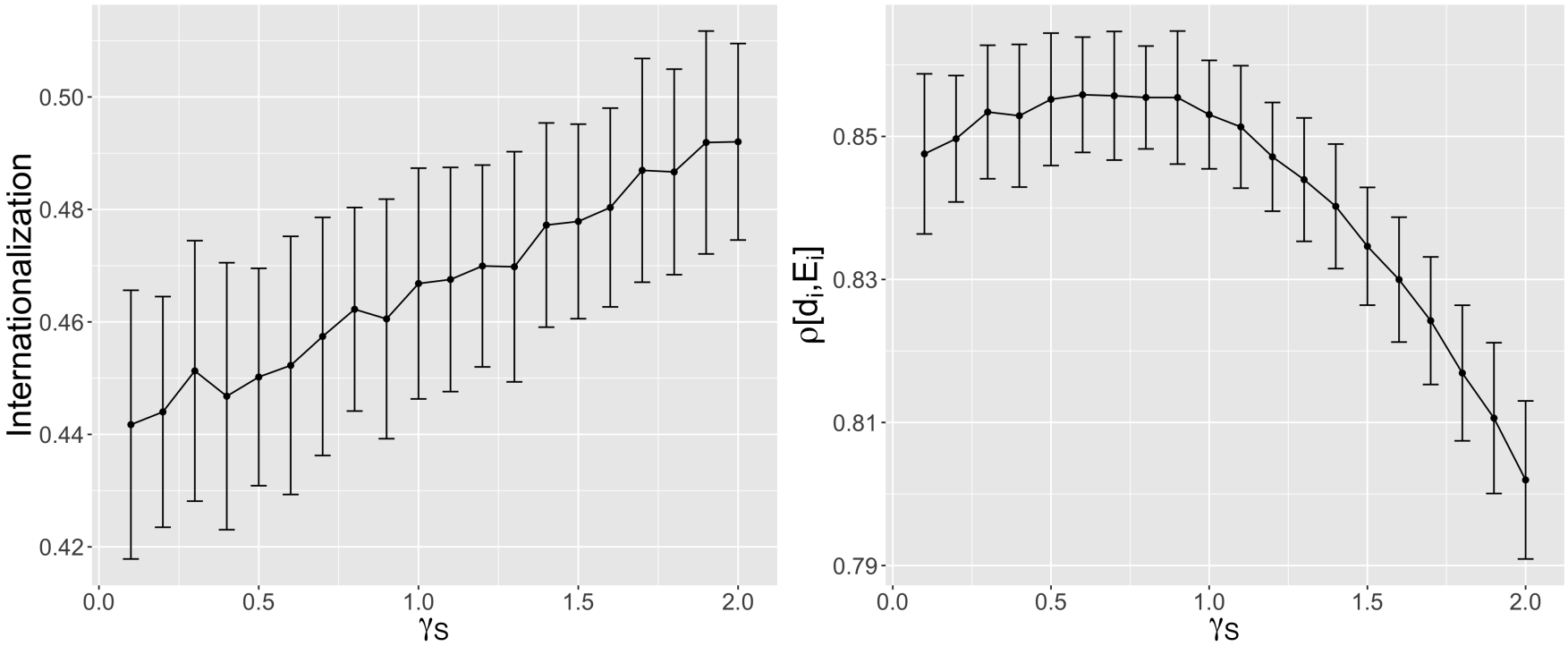
Effect of interaction decay





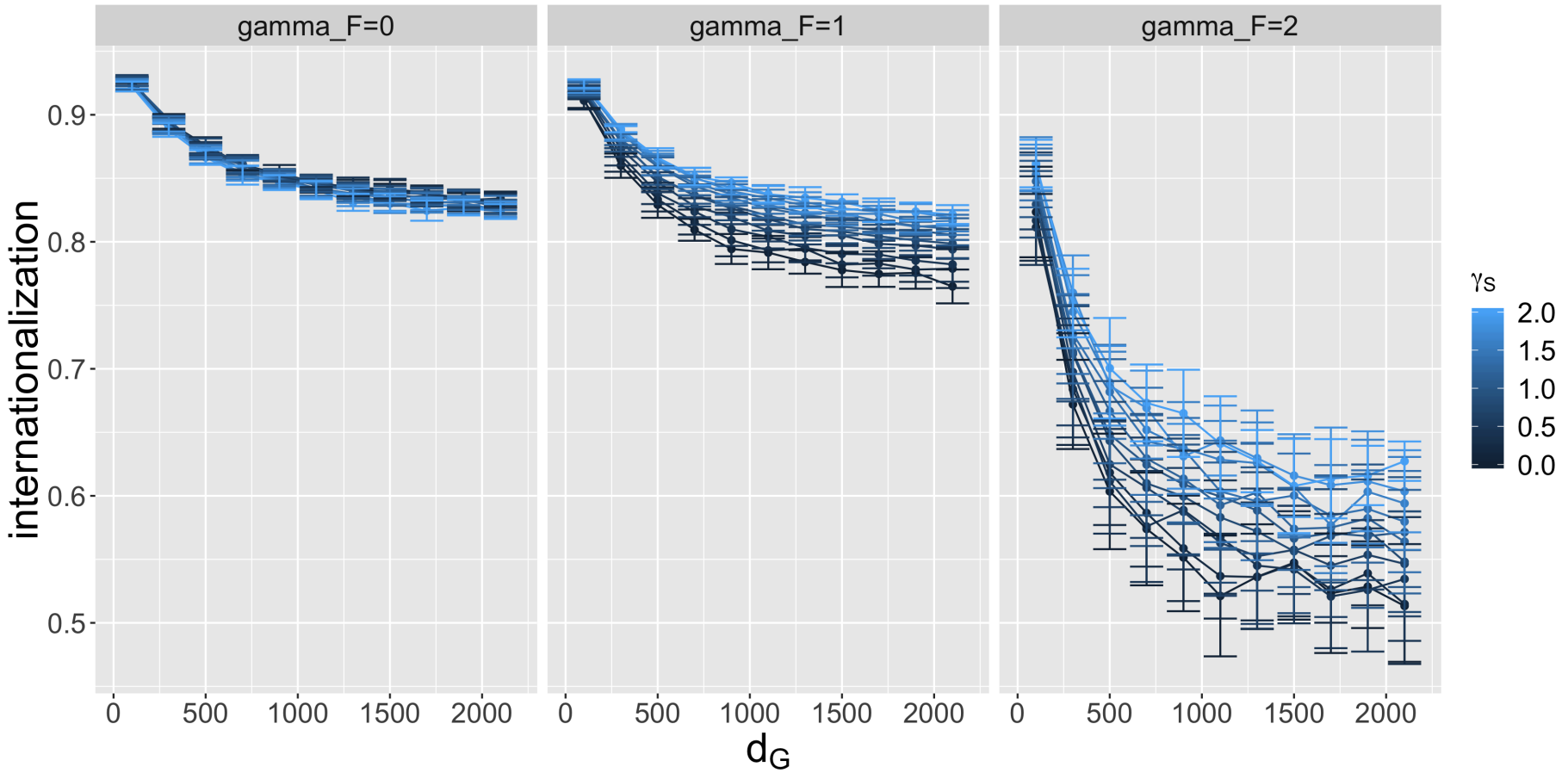
(Left) Internationalization index decreases exponentially with gravity decay; (Right) Correlation between city weighted degree and size. Both plots show a transition from a local to a global regime.

Effect of sector proximity



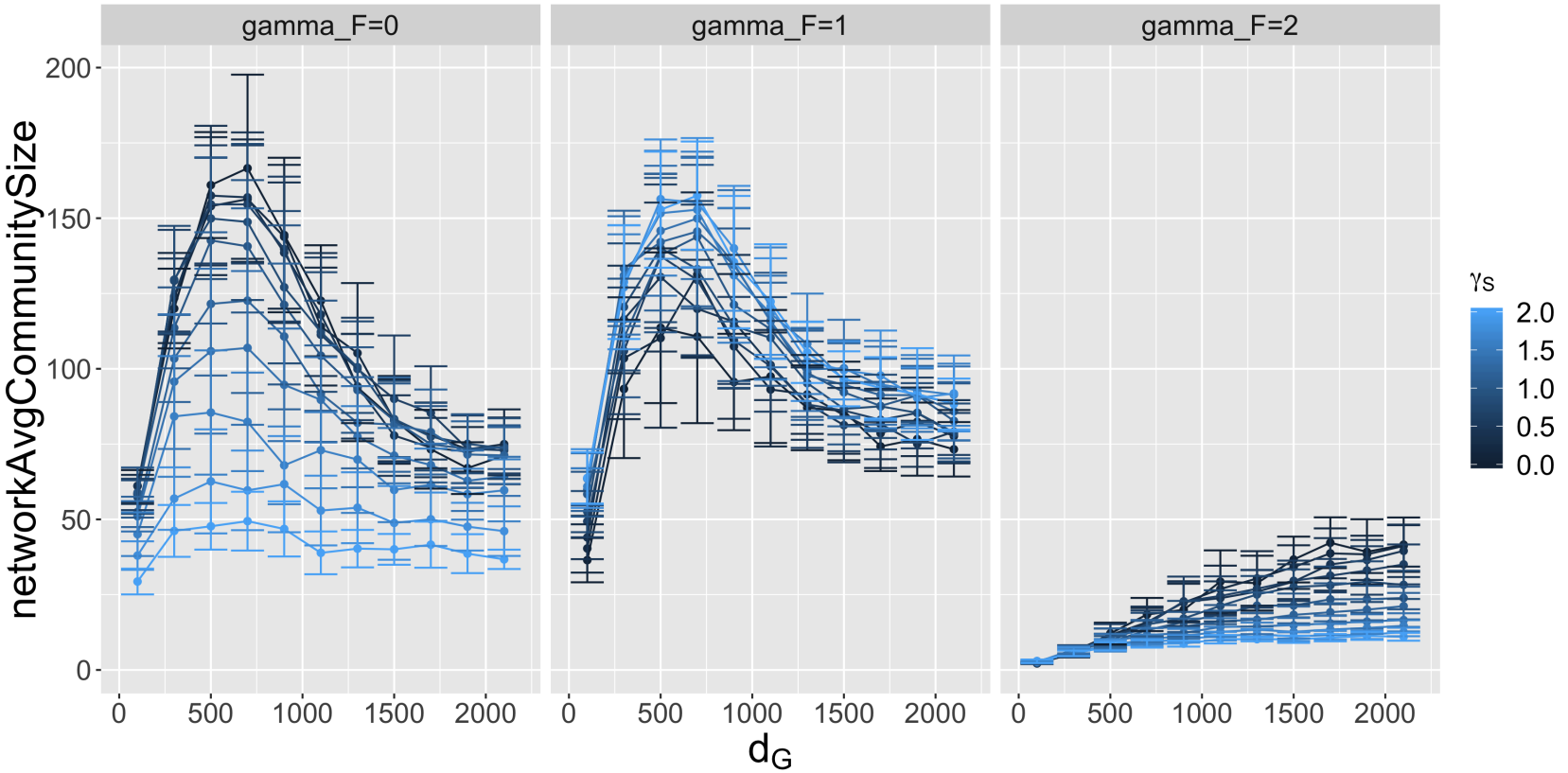
(Left) Internationalization varies linearly with sector proximity γ_S; (Right) Correlation between degree and size exhibits a maximum, witnessing an intermediate regime where size is the most important

Grid exploration: internationalization



The transition as a function of interaction range depends on the influence of origin size γ_F; sector proximity γ_S plays a role only for a large influence of the origin.

Grid exploration: community size



- Maximal integration in term of community size is achieved at an intermediate value of d_G: emergence of a regional regime
- Maximal size depends on the role of sectors γ_S, in a decreasing way when origin size is deactivated, and increasing way when γ_F 1
- This regime disappear when origin size influence is too large

Discussion

Practical application

→ effect of exogenous shocks in the socio-economic structure (“subsystem-xit”)

Developments

→ evolution of city sizes (co-evolution model)
→ parametrization/calibration on real data
→ role of path-dependency
→ towards a model with firm agents? (multi-scale ABM)

On the role of model exploration

→ even with such a “simple” model (close to directly tractable stationary state), behavior is highly non-linear in many dimensions
→ model exploration allows to overcome hidden parameters (deactivated mechanisms or default parameter values)
→ exploration of intrinsic dynamics on synthetic data is a crucial step before an application on real data (disentangle effects of geography from model dynamics)

Conclusion

$\rightarrow$ A generative model to understand processes of economic network emergence

$\rightarrow$ Crucial role of model exploration to validate and extract knowledge from such a simulation model

Open repository for model and results at
`https://github.com/JusteRaimbault/ABMCitiesFirms`

Simulation data at `https://doi.org/10.7910/DVN/UPX23S`

Acknowledgments: thanks to the *European Grid Infrastructure* for access to the infrastructure.

References I

- Banos, A., Moreno, D., Pivano, C., and Taillandier, P. (2011). Christaller, toujours vivant! *Cybergeo: European Journal of Geography*.
- Castells, M. (1996). The information age: Economy, society and culture (3 volumes). *Blackwell, Oxford*, 1997:1998.
- Cottineau, C. and Arcaute, E. (2019). The nested structure of urban business clusters. *arXiv e-prints*, page arXiv:1905.05106.

References II


Cottineau, C., Chapron, P., and Reuillon, R. (2015).
Growing models from the bottom up. an evaluation-based incremental modelling method (ebimm) applied to the simulation of systems of cities.
Journal of Artificial Societies and Social Simulation, 18(4):9.


Favaro, J.-M. and Pumain, D. (2011).
Gibrat revisited: An urban growth model incorporating spatial interaction and innovation cycles.
Geographical Analysis, 43(3):261–286.


Hagerstrand, T. (1968).
Innovation diffusion as a spatial process.
Chicago, University of Chicago Press, page 334.

References III

Martin, R. and Sunley, P. (2006).
Path dependence and regional economic evolution.
Journal of Economic Geography, 6–4:395–473.

Martinus, K. and Sigler, T. J. (2018).
Global city clusters: theorizing spatial and non-spatial proximity in inter-urban firm networks.
Regional studies, 52(8):1041–1052.

Pumain, D. (1997).
Pour une théorie évolutive des villes.
L'Espace géographique, pages 119–134.

Pumain, D. (2006).
Villes et systèmes de villes dans l'économie.
Revue d'économie financière, pages 29–46.

References IV


Pumain, D. (2012).
Urban systems dynamics, urban growth and scaling laws: The question of ergodicity.
In *Complexity theories of cities have come of age*, pages 91–103. Springer.


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


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

References V

- Raimbault, J., Cottineau, C., Texier, M. L., Néchet, F. L., and Reuillon, R. (2018).
  Space matters: extending sensitivity analysis to initial spatial conditions in geosimulation models.
  arXiv preprint arXiv:1812.06008.
- Reuillon, R., Leclaire, M., and Rey-Coyrehourcq, S. (2013).
  Openmole, a workflow engine specifically tailored for the distributed exploration of simulation models.
  Future Generation Computer Systems, 29(8):1981–1990.
- Sassen, S. (1991).
  The global city.
  New York.

References VI

Schmitt, C., Rey-Coyrehourcq, S., Reuillon, R., and Pumain, D. (2015).
Half a billion simulations: Evolutionary algorithms and distributed computing for calibrating the simpoplocal geographical model.
Environment and Planning B: Planning and Design, 42(2):300–315.

Simini, F. and James, C. (2019).
Testing heaps' law for cities using administrative and gridded population data sets.
EPJ Data Science, 8(1):1–13.

Taylor, P. J. (2001).
Specification of the world city network.
Geographical analysis, 33(2):181–194.