

Innovation dynamics in multi-scalar systems of cities

J. Raimbault^{1,2,3,4,*} and D. Pumain⁴

* `juste.raimbault@ign.fr`

¹ LASTIG, IGN-ENSG

²CASA, UCL

³UPS CNRS 3611 ISC-PIF

⁴UMR CNRS 8504 Géographie-cités

ALife 2023 - ALife and Society

July 28th 2023

Urban dynamics and innovation

- Cities are central for innovation in social systems [Pumain, 2020] and future sustainability [Keith et al., 2022]
- Urban innovation systems now span from local clusters to global networks [Binz and Truffer, 2017]
- Innovation dynamics in systems of cities follow complex patterns across scales [Bauer and Fuenfschilling, 2019]

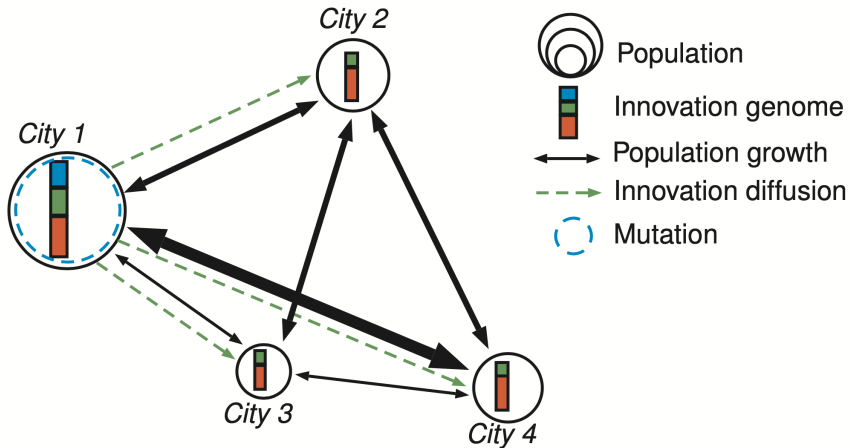
Towards multi-scalar models

→ Multi-scalar models necessary to design sustainable territorial policies [Rozenblat and Pumain, 2018]

→ “Artificial cities” [Raimbault, 2020a] and urban simulation approaches focus on a single scale

Contribution: a new **simulation model** coupling innovation diffusion dynamics **between cities** (macro) [Raimbault, 2020b] with research cluster dynamics **within urban areas** (meso) [Raimbault, 2022a]

Macroscopic dynamics



Mesosopic dynamics from [Raimbault, 2022b]: **Innovation clusters** composed of firms, sets of employees (real-valued genome representing ideas); aim at optimising a fixed random fitness (Rastrigin function).

Meso cycle: in each innovation cluster (city) for t_m meso time steps:

- employee exchange ideas within firms (genome crossovers)
- idea with best fitness is chosen by each company
- ideas are informally exchanged between firms

Iterated steps, for t_f macro time steps:

- 1 Mesoscopic cycle
- 2 **Bottom-up feedback:** if relative fitness gain of the best firm exceeds a parameter ($\delta f_i > \theta$), the corresponding city will innovate at the macro scale.
- 3 Macroscopic step: innovation diffusion; population migration and growth; new innovations.
- 4 **Top-down feedback:** firm strategy is updated by changing crossover probability and mutation probability, and the urban environment in terms of informal exchanges, both depending on relative population growth.

- Macro observables: utility and diversity of innovations
- Meso observables: best fitness and diversity of ideas
- Indicators for downward causation from [Rosas et al., 2020] on these observables to quantify the strength of emergence: (Δ, Ψ, Γ)

Model setup on synthetic systems of cities resembling real systems
[Raimbault et al., 2019]

Model implementation

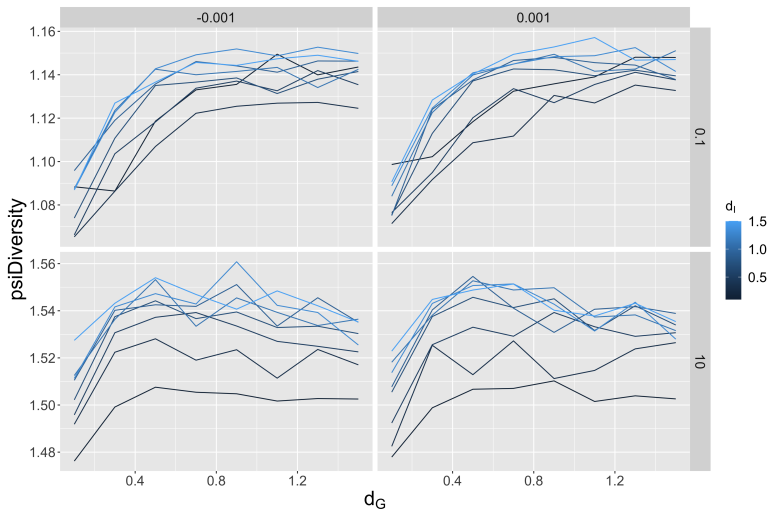
Model implemented in scala: <https://github.com/JusteRaimbault/InnovationMultiscale-model>

`https://github.com/JusteRaimbault/InnovationMultiscale-model`

Integrated into the OpenMOLE platform for **model exploration and validation** [Reuillon et al., 2013]

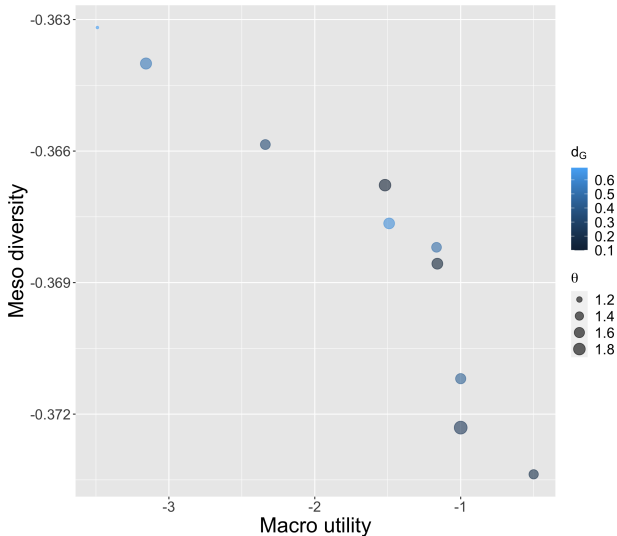


Model exploration



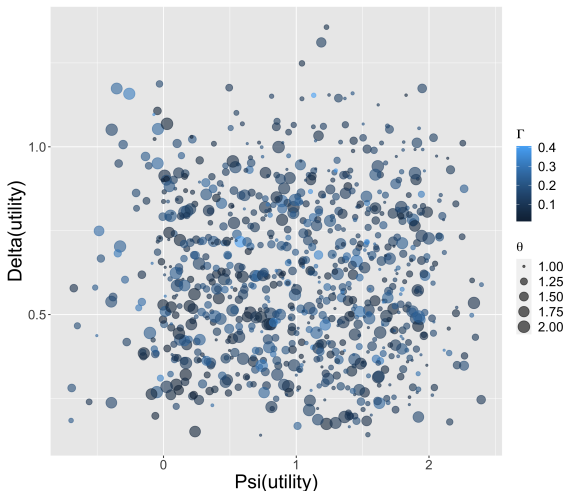
Increasing then plateauing strength of emergence Ψ for macro diversity, as a function of spatial interaction range d_G and innovation diffusion range d_I , for varying top-down (columns) and bottom-up (rows) feedbacks.

Model optimisation



Bi-objective optimisation of indicators at both scales: aggregated utility at the macro scale and diversity of innovations within urban areas

Diversity search



Application of the **PSE diversity search algorithm** [Chérel et al., 2015] to obtain the feasible space of emergence regimes: downward causation always occurs ($\Delta > 0$), many regimes with causal emergence ($\Psi > 0$) and with autonomy between scales ($\Gamma \sim 0$).

→ **Main results:** proof-of-concept for a **bi-objective optimisation across scales**, towards policy applications; **diversity of emergence regimes** produced by the model.

→ Possible extensions: higher dimension of the innovation space, economic structure for companies, coupling with economic agent-based models, migration of ideas (employees) between urban areas, bottom-up feedback through a change of macro parameters.

→ Future application on real urban systems requires innovation data across scales: adaptation of the model to fit specific data, patent data only a proxy of innovation, firm data not open.

Conclusion: a first step towards **multi-scalar integrated models** for sustainable urban and territorial policies.

References I



Bauer, F. and Fuenfschilling, L. (2019).

Local initiatives and global regimes—multi-scalar transition dynamics in the chemical industry.

Journal of Cleaner Production, 216:172–183.



Binz, C. and Truffer, B. (2017).

Global innovation systems—a conceptual framework for innovation dynamics in transnational contexts.

Research policy, 46(7):1284–1298.



Chérel, G., Cottineau, C., and Reuillon, R. (2015).

Beyond corroboration: Strengthening model validation by looking for unexpected patterns.

PloS one, 10(9):e0138212.








Keith, M. et al. (2022).

A new urban narrative for sustainable development.

Nature Sustainability, pages 1–3.

References II

-  Pumain, D. (2020).
Theories and models of urbanization.
Springer.
-  Raimbault, J. (2020a).
Cities as they could be: Artificial life and urban systems.
arXiv preprint arXiv:2002.12926.
-  Raimbault, J. (2020b).
A model of urban evolution based on innovation diffusion.
ALIFE 2020.
-  Raimbault, J. (2022a).
Innovation and informal knowledge exchanges between firms.
-  Raimbault, J. (2022b).
Innovation and informal knowledge exchanges between firms.
In ALIFE 2022: The 2022 Conference on Artificial Life. MIT Press.



Raimbault, J., Cottineau, C., Le Texier, M., Le Nechet, F., and Reuillon, R. (2019).

Space matters: Extending sensitivity analysis to initial spatial conditions in geosimulation models.

Journal of Artificial Societies and Social Simulation, 22(4).



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.



Rosas, F. E. et al. (2020).

Reconciling emergences: An information-theoretic approach to identify causal emergence in multivariate data.

PLoS computational biology, 16(12):e1008289.



Rozenblat, C. and Pumain, D. (2018).

Conclusion: Toward a methodology for multi-scalar urban system policies.

International and Transnational Perspectives on Urban Systems, 385.