

## Urban dynamics and innovation

- Cities are central for innovation in social systems [3] and future sustainability [2]
- Urban innovation systems now span from local clusters to global networks
- Innovation dynamics in systems of cities follow complex patterns across scales

## Towards multi-scalar models

- Multi-scalar models necessary to design sustainable territorial policies [9]
- “Artificial cities” [4] and urban simulation approaches focus on a single scale  
→ a new **simulation model** coupling innovation diffusion dynamics **between cities** (macro) [5] with research cluster dynamics **within urban areas** (meso) [6]

## Simulation model

Synthetic **system of cities** with populations following a Zipf law and random positions in the geographical space; within each city an **innovation cluster** is composed of firms, themselves composed by employees (ideas as real-valued genome), which aim at optimising a fixed random fitness (Rastrigin function).

**Iterated steps**, for  $t_f$  macro time steps:

1. **Meso cycle**: in each cluster 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

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. **Macro step**: innovation are diffused between cities; population migration and growth follow spatial interactions based on attractivity; new innovations are added to cities' genomes.

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.

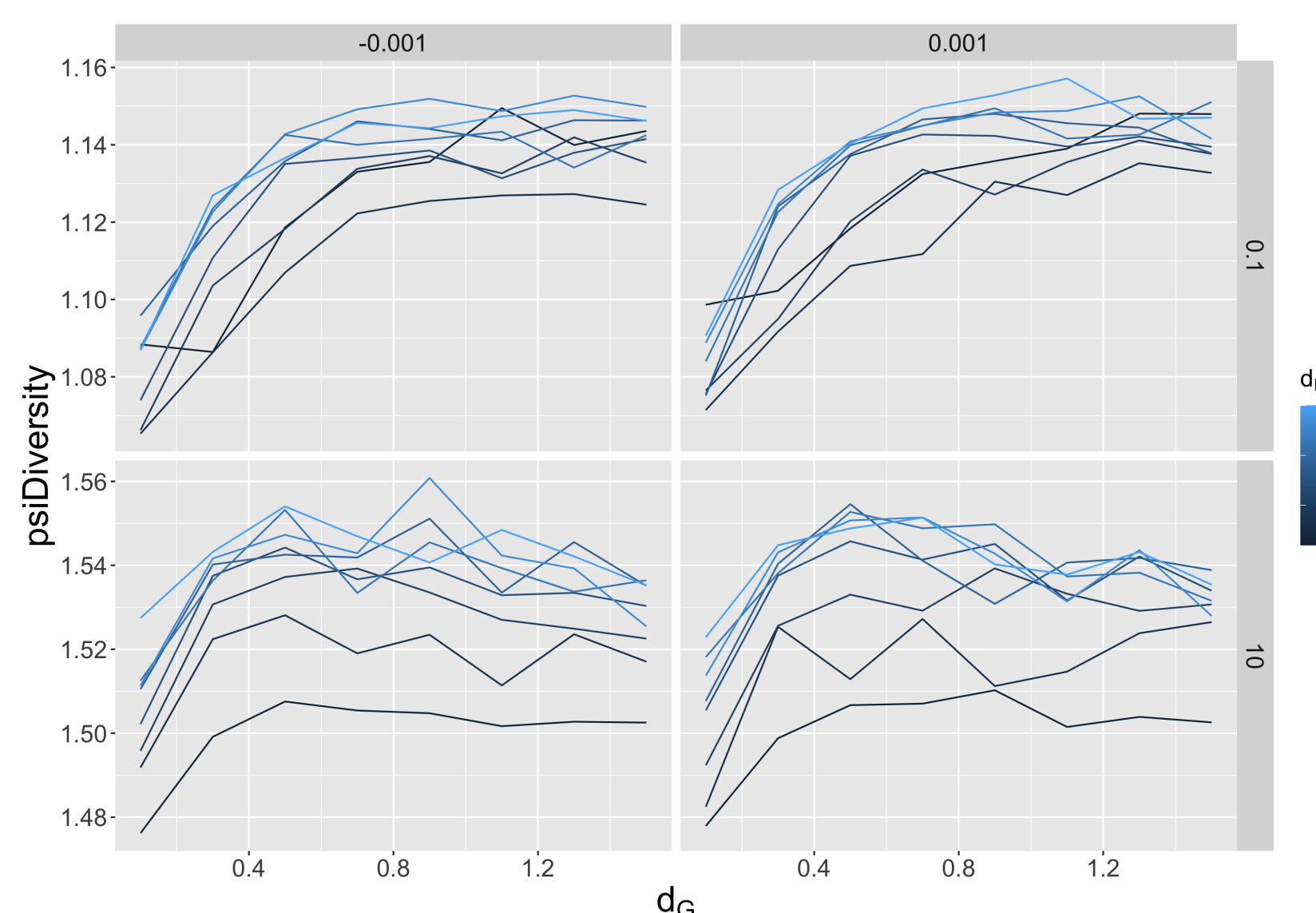
**Indicators**:

- Macro observables: utility and diversity of innovations
- Meso observables: best fitness and diversity of ideas
- Indicators for downward causation from [8] ( $\Delta$ ,  $\Psi$ ,  $\Gamma$ ) on these observables to quantify the strength of emergence

**Implementation**:

- Model implemented in scala: <https://github.com/JusteRaimbault/InnovationMultiscale-model>
- Integrated into the OpenMOLE platform for model exploration and validation [7]

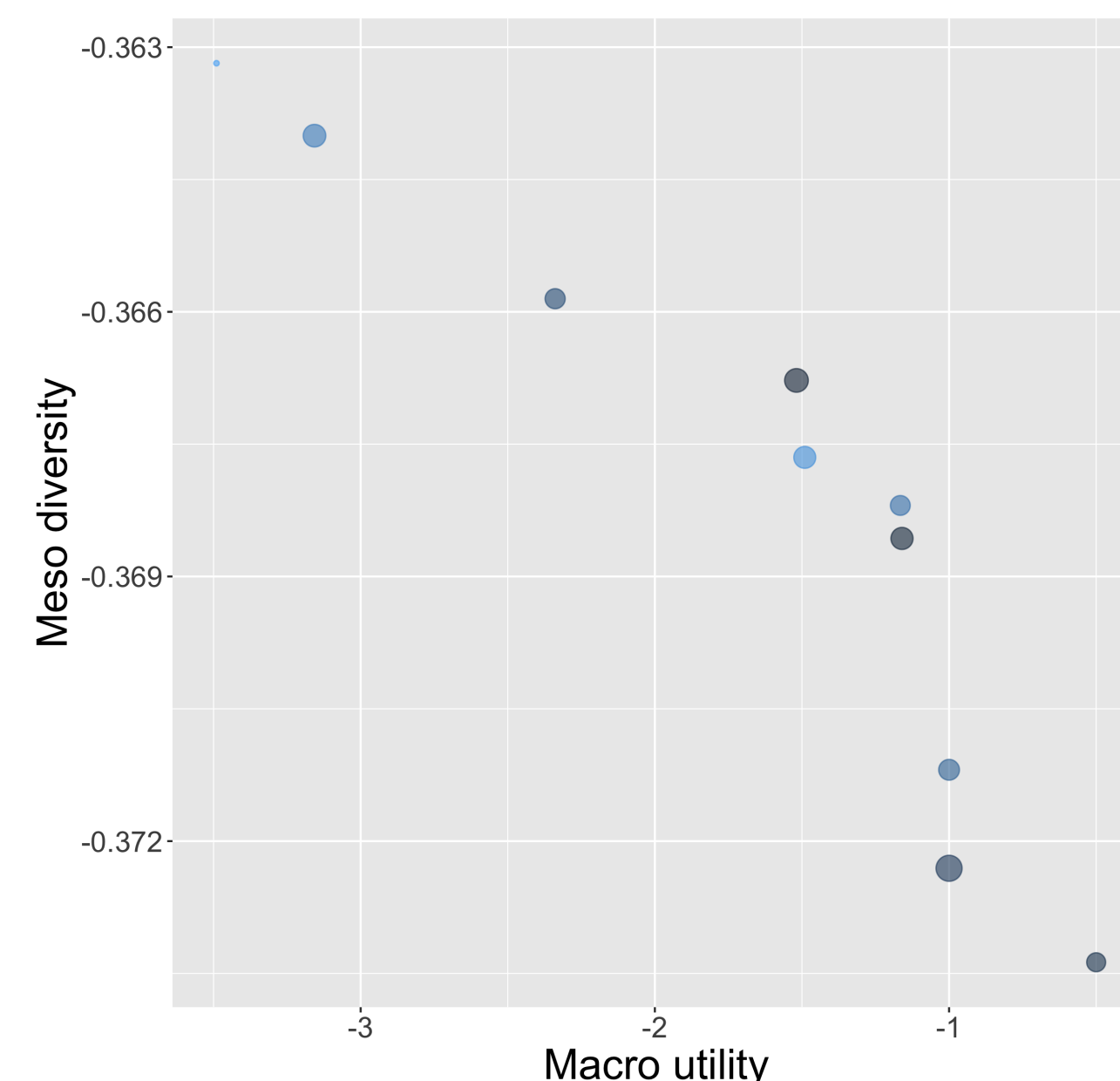
## Model exploration



**Grid exploration** of the parameter space, to explore main dynamics of the model; 10,000 replications for each parameter point; variety of indicator behaviours.

*Left plot*: increasing then plateauing strength of emergence  $\Psi$  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.

## Optimisation

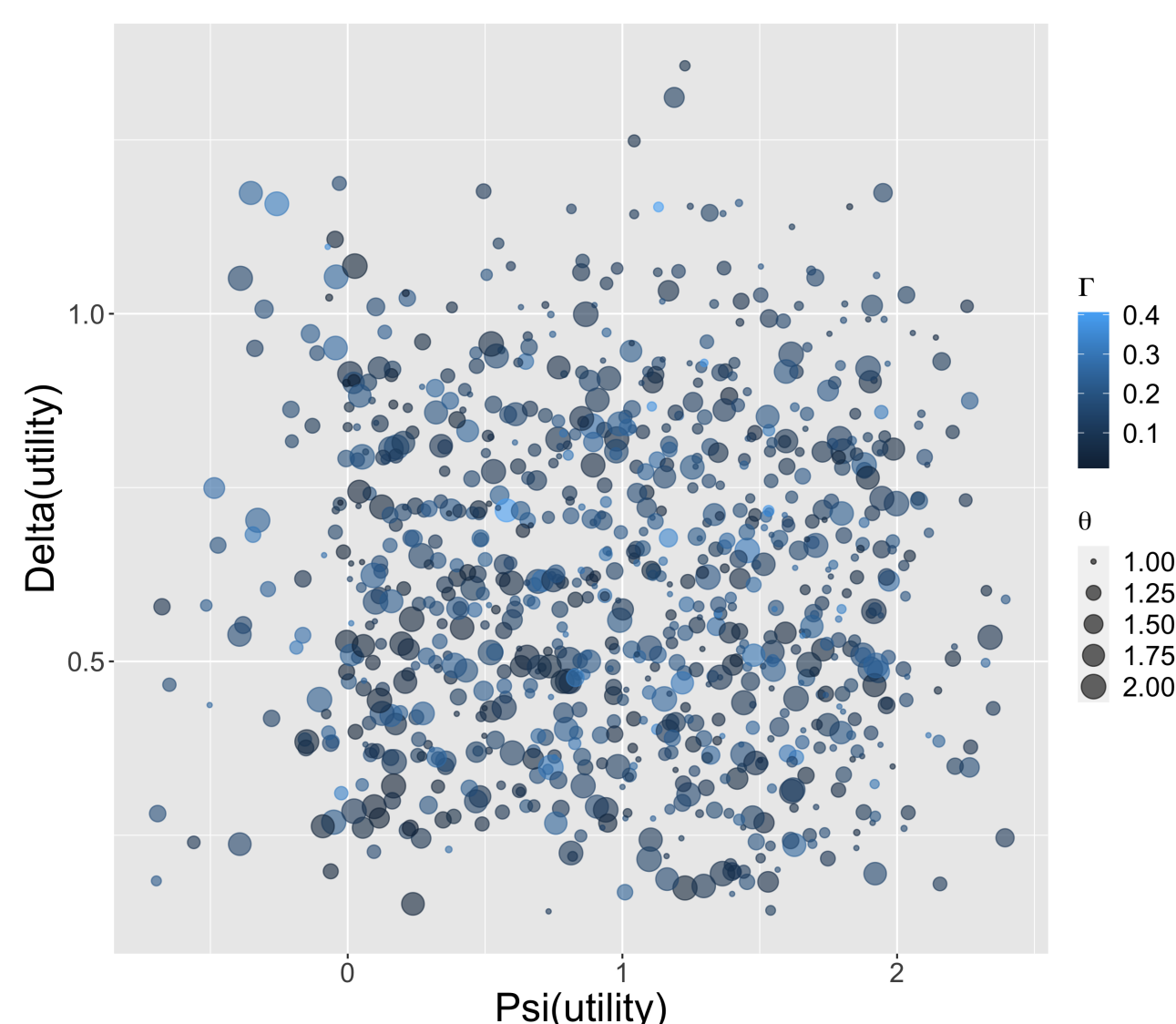


**Bi-objective optimisation** of indicators at both scales: aggregated utility at the macro scale and diversity of innovations within urban areas; achieved using a **NSGA2 algorithm** with a population of 200 and for 10,000 generations.

→ low number of points on the Pareto front, corresponding to diverse geographical regimes (value of  $d_G$  capturing spatial interactions)

→ such optimisations can in practice be used to reconcile conflicting stakeholders at different scales

## Diversity search



Application of the **PSE diversity search algorithm** [1] 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 ( $\Gamma \sim 0$ )

→ scale coupling is confirmed useful as strong emergence is captured

## Discussion

• 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 and refinements include more detailed economic processes: 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

## References

[1] Guillaume Chérel, Clémentine Cottineau, and Romain Reuillon. Beyond corroboration: Strengthening model validation by looking for unexpected patterns. *PLoS one*, 10(9):e0138212, 2015.

[2] Michael Keith et al. A new urban narrative for sustainable development. *Nature Sustainability*, pages 1–3, 2022.

[3] Denise Pumain. *Theories and models of urbanization*. Springer, 2020.

[4] Juste Raimbault. Cities as they could be: Artificial life and urban systems. *arXiv preprint arXiv:2002.12926*, 2020.

[5] Juste Raimbault. A model of urban evolution based on innovation diffusion. *ALIFE 2020*, 2020.

[6] Juste Raimbault. Innovation and informal knowledge exchanges between firms. 2022.

[7] Romain Reuillon, Mathieu Leclaire, and Sebastien Rey-Coyrehourcq. Openmole, a workflow engine specifically tailored for the distributed exploration of simulation models. *Future Generation Computer Systems*, 29(8):1981–1990, 2013.

[8] Fernando E Rosas et al. Reconciling emergences: An information-theoretic approach to identify causal emergence in multivariate data. *PLoS computational biology*, 16(12):e1008289, 2020.

[9] Celine Rozenblat and Denise Pumain. Conclusion: Toward a methodology for multi-scalar urban system policies. *International and Transnational Perspectives on Urban Systems*, 385, 2018.