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EXTENDED ABSTRACT:

Sustainable Development Goals are intrinsically competing, but their embedding into urban systems furthermore emphasises such compromises, due to spatial complexity, the non-optimal nature of such systems, and multi-objective aspects of their agents, among other reasons. The concept of urban optima, in the sense of optimising certain dimensions of urban systems, has been considered from diverse perspectives. It is often conceived within the economic paradigm of equilibrium (Glaeser, 2008). In most cases, there does not seem to be clear patterns, neither empirical nor theoretical, of possible simple optimisations of single objectives by urban systems.Sustainable Development Goals (SDGs) are characterised in a similar way by compromises between different dimensions. Urban sustainability, in the sense of the urban aspect of environmental issues (Finco and Nijkamp, 2001), has thus to be understood as trade-offs between multiple objectives (Viguie and Hallegatte, 2012).

A good knowledge of the dynamics of the systems of cities is useful to prepare possible interventions in urban systems because of their complexity (Reggiani et al., 2021). It implies a very important collection of information on the processes of urban dynamics at all geographical scales. The variables to be considered are considerably more numerous and the knowledge of their interactions is much less easy to build than those, already fantastically colossal, which were necessary to ascertain the evolutionary direction of the climate. Alongside the many localised investigations, we believe that abstract modelling, which distances itself from the diversity of cities, their cultures and subjective sensitivities, can help

to discern some of the possible ways of managing urban dynamics (Pumain and Reuillon, 2017).

We propose in this paper to study trade-offs between different SDGs in systems of cities. We consider systems of cities at the macroscopic scale, and more particularly the dynamics of innovation diffusion and population growth. Using a stylised model for such urban dynamics, we apply a bi-objective optimisation genetic algorithm, to explore how trade-offs can occur in such systems.

We work with a stylised model for the dynamics of urban systems at the macroscopic scale (i.e. a country or a continent or any integrated region of the world). This model is based on innovation diffusion dynamics and their impact on population growth. It was first formulated by (Favaro and Pumain, 2011), within the context of an evolutionary urban theory (Pumain, 1997). A similar agent-based model was used to explore assumptions on the emergence of systems of cities themselves (Schimtt et al., 2015). A modified version was described by (Raimbault, 2020) as an urban evolution model, including an urban genome shared and mutated across cities. As this particular version can furthermore be setup on stylised systems of cities, we use it in our multi-objective optimisation approach. The simulated urban system is composed by cities, characterised at each time step by (i) their population; (ii) their location in the geographical space; (iii) adoption rates by their populations for different innovations (urban genome). We work on synthetic systems of cities, which are randomly generated given some fixed macro characteristics. This approach allows controlling for example for the role of space, and disentangling intrinsic model dynamics from geographical contingencies (Raimbault et al., 2019). In our case, as emission indicator is linked to inter-city flows, strongly dependent on the geography, averaging over several synthetic systems of cities will thus provide robust results. We consider the ``innovation'' SDG (goal 9) and the ``climate'' SDG (goal 14) as conflicting objectives. We can expect that a higher economic activity linked to more intensive innovative activities will increase endogenous emissions, but also transport emissions between urban areas, generated by economic and transport flows.

We investigate trade-offs between total innovation utility and emissions, by optimising the model using a bi-objective heuristic with free parameters and indicators detailed above. We use a NSGA2 optimisation algorithm, provided by the OpenMOLE software (Reuillon et al., 2013), with a population of 100 individuals, for 10,000 generations. We find a broad Pareto front, confirming the existence of a trade-off in such urban dynamics driven by innovation diffusion. We then investigate how trade-offs change in different hypothetical systems of cities, ranging from highly hierarchical (Zipf exponent of 1.5) to a more balanced system (exponent of 0.5). We expect to obtain different Pareto fronts, for different values of a hierarchy index, which corresponds to the slope of the initial Zipf law. We find that the higher the hierarchical inequalities, the less flat the front. Furthermore, the size of the front is the smallest with the less unequal hierarchy, meaning that this system is indeed closer to some global optimum. A similar conditional optimisation is also run by changing the fixed value of innovation hierarchy. This corresponds in terms of policies, to either letting innovation aggregate into larger metropolises (scaling with a high exponent value (Pumain et al., 2006)), or regulating and providing incentives to enhance innovation into smaller and medium-sized cities. We also find that balanced policies provides a more optimal front.

We show in this work, with a stylised model of urban population and innovation dynamics, that trade-offs between transport emissions and total innovation utility emerge from model dynamics. This has theoretical implications, confirming the general non-optimising nature of urban systems and the predominance of trade-offs across different urban dimensions. Our results from conditional optimisation suggest that less hierarchical systems, both regarding initial population hierarchy and innovation hierarchy, provide more optimal Pareto fronts. This could have implications for policies such as innovation incentives, to avoid a too strong concentration into larger cities. More empirical investigations remain however needed.

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