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Parino, Francesco; Zino, Lorenzo; Porfiri, Maurizio; Rizzo, Alessandro

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Document Version
Early version, also known as pre-print

Publication date:
2021

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Parino, F., Zino, L., Porfiri, M., & Rizzo, A. (2021). *A metapopulation model to assess the effectiveness of social distancing and travel restrictions on COVID-19 spreading: The Italian case study*. Abstract from NETWORKS 2021.

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A metapopulation model to assess the effectiveness of social distancing and travel restrictions on COVID-19 spreading: the Italian case study*

Francesco Parino[1], Lorenzo Zino[2], Maurizio Porfiri[3], and Alessandro Rizzo[1,3]
[1]Politecnico di Torino, Italy [2]University of Groningen, Netherlands [3]New York University, USA

COVID-19 has led to the unprecedented scenarios of a global pandemic. In response, most countries enacted a wide range of non-pharmaceutical interventions (NPIs), which entail a reduction in social activity and mobility restrictions. Mathematical models have emerged as powerful tools to guide and assist public health authorities in their difficult decisions, by generating accurate predictions of the epidemic spreading and providing insights into the effectiveness of NPIs[1−3]. Quantifying the effect of NPIs, however, is a difficult task because of the many aspects that play a role in the spreading of infectious diseases. Two major aspects are the spatial spreading of the outbreak, mainly driven by the human mobility pattern; and the heterogeneous and time-varying nature of human interactions, which also account for the behavioral changes in response to the pandemic evolution.

We propose a mathematical model of COVID-19 transmission that encapsulates these two features by combining the advantages of granular spatial modeling of meta-population models[4] with an interaction pattern inspired by activity-driven networks, which is able to realistically describe the heterogeneous and time-varying nature of social contacts[5] (Fig 1a). The proposed model is calibrated on real-world data on the first wave of the Italian COVID-19 outbreak. Our findings reveal that the timing of interventions is essential for their effective implementations. The effects of mobility restrictions largely depend on the possibility to implement timely NPIs in the early phases of the outbreak, whereas activity reduction policies should be prioritized afterwards (Fig. 1b). Through data analysis techniques, we have used our model to study the effect of the timely implementation of mobility restrictions among the Italian provinces. Our results suggest that their impact is spatially heterogeneous: some provinces (typically located far from the initial outbreak) are positively affected by such restrictions (in green in Fig. 1c), whereas others remain unaffected (brown). Our modeling framework allows us to assess the effect of targeted intervention policies, such as implementing different levels of activity restrictions across age cohorts. Our findings suggest that the application of severe restrictions only to the most vulnerable age cohorts would not be sufficient to effectively reduce the deaths toll. More details an further scenarios (including relaxation of containment measures) can be found in our Ref. [6].

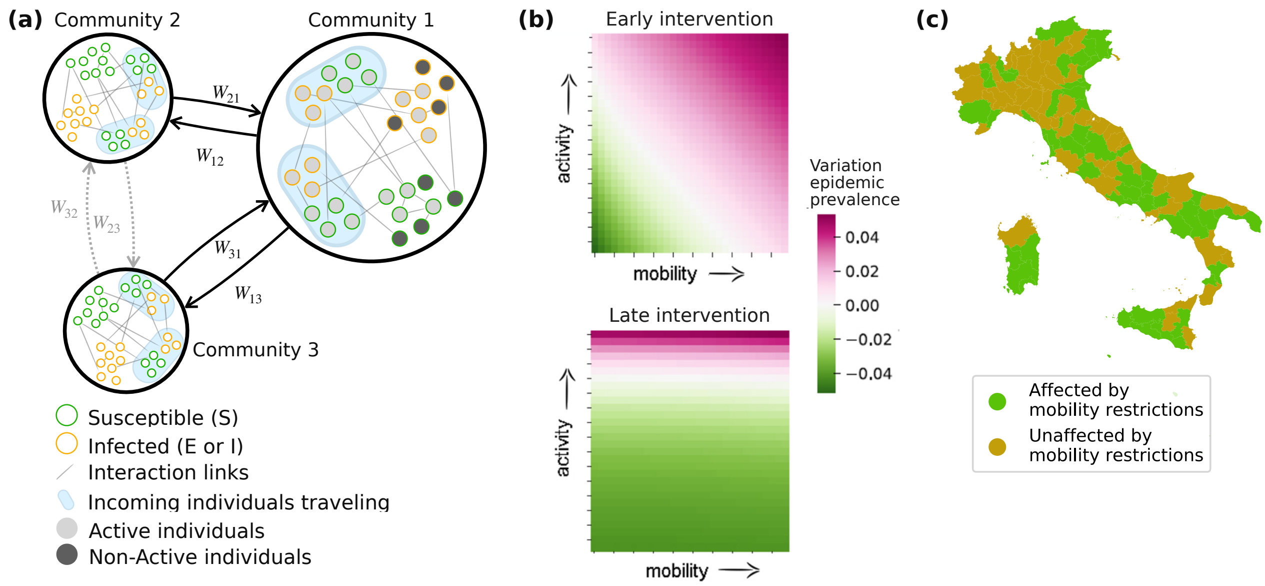

Figure 1: **(a)** Schematics of the meta-population model, illustrating the community structure and the role of mobility and activity in the interaction formation process. **(b)** Combined effect of activity reduction and mobility restrictions in the case of early interventions (above) and late interventions (below). While timely mobility restrictions seems effective to reduce the death toll, late mobility restrictions are ineffective. **(c)** Classification of Provinces in affected and unaffected by the timely implementation of mobility restrictions.

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* This work was partially supported by National Science Foundation (CMMI-1561134 and CMMI-2027990), Compagnia di San Paolo, MAECI ("Mac2Mic"), the European Research Council (ERC-CoG-771687), and the Netherlands Organisation for Scientific Research (NWO-vidi-14134).