Modeling adaptive forward-looking behavior in epidemics on networks

Keywords: epidemic modeling, epi-economics, forward-looking behavior, complex networks

Extended Abstract

The course of an epidemic can be drastically altered by changes in human behavior [1]. Incorporating the dynamics of individual decision-making during an outbreak represents a key challenge of epidemiology, faced by several modeling approaches siloed by different disciplines [2,3]. Here, we propose an epi-economic model [4,5,6] including adaptive, forward-looking behavioral response on a heterogeneous networked substrate, where individuals tune their social activity based on future health expectations.
Our model includes a feedback loop between the social activity of individuals and the spreading of the epidemic.
To this aim, we consider a SIR model in which individuals change their behavior, reducing or increasing their social activity, depending on the prevalence of the disease, see Fig. 1(a).
Susceptible individuals tune their social activity with a forward-looking approach, i.e., they balance the risk of being infected in the future while maintaining the highest possible social activity, see Fig. 1(b).
Individuals choose their social activity to maximize their future expected utility, by balancing the risk of being infected in the future while maintaining the highest possible social activity.
We rely on two simplifying yet realistic assumptions: i) homogeneous behavior across all health states and ii) individuals believing current epidemic conditions will remain unchanged. These assumptions allow us to describe the optimal behavior by an analytical expression depending on the epidemic conditions (prevalence and disease parameters) and the behavior of the population itself.

Under basic assumptions, we show that it is possible to derive an analytical expression of the optimal value of the social activity that matches the traditional assumptions of classic epidemic models.
We provide a simple interpretation of the infection cost in terms of an equivalent social activity, defined as the acceptable social activity equivalent to the risk of infection.
Such equivalence allows us to distinguish regimes of weak and strong behavioral responses.
Crucially, we go beyond the homogeneous mixing hypothesis usually assumed in epi-economic models and test different degrees of heterogeneity in the population.
We explicitly contrast the cases of global awareness, in which individuals have a bird-eye view of the epidemic unfolding on the whole population (see Fig. 1(c)), with a local awareness setting, where individuals only know which of their contacts are infected (see Fig. 1(d)).
The latter case triggers a highly heterogeneous behavioral response.
Through numerical simulations, we show that behavior change can flatten the epidemic curve by lowering the peak prevalence, thus potentially reducing the load on the health system at the epidemic peak.
By quantifying the effect of behavior change on the final attack rate of the disease in the strong behavioral response regime, we show that local awareness allows for a stronger outbreak reduction than global awareness.

Our study is aimed at bridging classical epidemic modelling, in which the transmission rate is modulated by some nonlinear function of the prevalence, and epi-economic models, characterized by a forward-looking approach.
Our findings shed light on the effects of heterogeneous behavioral responses on the epidemic outbreak, indicating that local awareness is much more effective in curbing early the disease with respect to global awareness.

References

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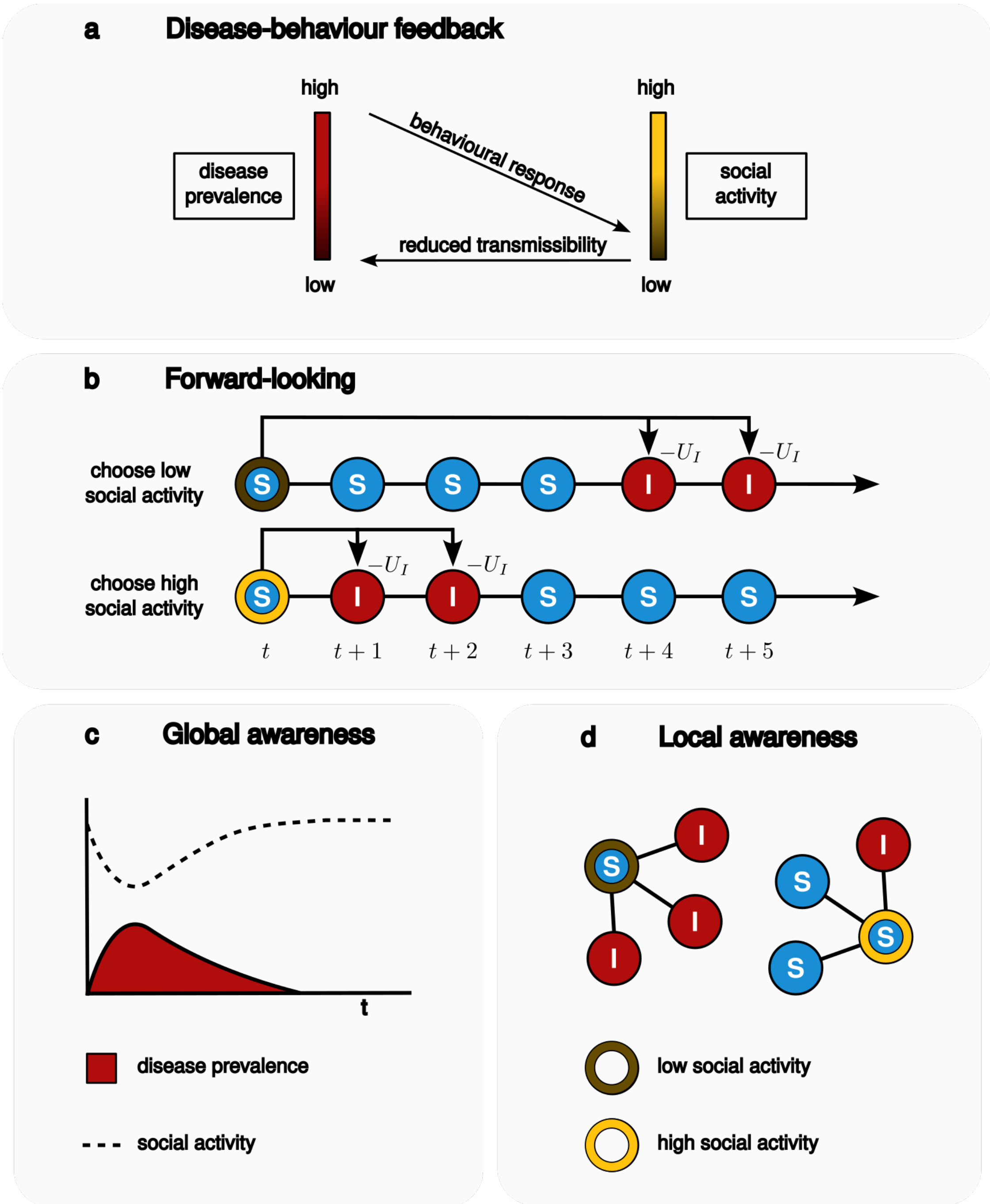

Figure 1. Schematic illustration of the model. (a) Feedback loop involving epidemic spreading and *social activity*. If the prevalence is high, individuals can decrease their social activity, which in turn reduces the transmissibility of the disease, decreasing prevalence. With low prevalence, individuals can choose high levels of social activity, increasing the prevalence. (b) Individuals choose their social activity to maximize their future expected utility. They can choose a low value of social activity to delay the expected infection (and the expected penalty U_I), or benefit from high social activity at a higher infection risk. Awareness and behavioral response can be of two kinds. *Global awareness* (c): individuals know the prevalence of the disease in the population but do not know who is infected, so social activity is homogeneous across the population. *Local awareness* (d): individuals know which of their contacts are infected, resulting in different values of social activity for each individual.