Robustness of behaviourally-induced oscillations in epidemic models under a low rate of imported cases

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This paper is concerned with the robustness of the sustained oscillations predicted by an epidemic ODE model defined on contact networks. The model incorporates the spread of awareness among individuals and, moreover, a small inflow of imported cases. These cases prevent stochastic extinctions when we simulate the epidemics and, hence, they allow to check whether the average dynamics for the fraction of infected individuals are accurately predicted by the ODE model. Stochastic simulations confirm the existence of sustained oscillations for different types of random networks, with a sharp transition from a non-oscillatory asymptotic regime to a periodic one as the alerting rate of susceptible individuals increases from very small values. This abrupt transition to periodic epidemics of high amplitude is quite accurately predicted by the Hopf-bifurcation curve computed from the ODE model using the alerting rate and the infection transmission rate for aware individuals as tuning parameters.

Keywords: epidemic models, awareness, oscillations, stochastic simulations.

I. INTRODUCTION

The importance of the interplay between epidemic spreading and preventive behavioural responses in a globalized world has long been recognized and was specially highlighted after the SARS outbreak of 2003 [1, 2]. The rise of the incidence rate of sexually transmitted diseases (STDs) [3] and the current resurgence of measles [4] are also examples of such an interplay. For STDs, increasing high risk sexual behaviour and novel sexual networks are among factors responsible for their re-emergence, whereas vaccine hesitance and distrust in public health intervention programs are among behavioural factors responsible for the rise of diseases like measles.

Risk perception is an important determinant of self-initiated, voluntary protective behaviour [5]. It constitutes the basic ingredient in many epidemic models to encapsulate human behaviour in their formulation [2]. For instance, some extensions of classic deterministic compartmental models include the impact of behaviour on disease transmission by assuming more general incidence rates than the standard one (bilinear). The latter is proportional to the product of the number of susceptible (S) and infectious individuals (I), βSI, whereas its generalizations assume a saturation with respect to the number of infectives in order to model a reduction of the contact rate in the presence of a high disease prevalence [6–9].

Other model extensions take into account awareness transmission among individuals. For example, one of them [10, 11] divides each epidemic compartment (S, I and R (recovered/immune)) into two subcompartments of aware and unaware individuals, respectively, and introduces the corresponding transition rates between subcompartments. Other models assume one or more additional compartments consisting of aware (A) individuals [12–15]. Some of these works consider several awareness levels resulting from the assumption of a degradation in the quality of the information as it is passed from one individual to another [16, 17]. In all these examples, the effect of preventive behaviour is to modify the values of the epidemic parameters like the probability of infection or the recovery rate.

When the contact network structure of a population is explicitly considered, the effect of behavioural responses can also affect the contact structure itself when modelling social avoidance behaviours. This reduction of the exposure to disease has been modelled by means of preventive disconnection from infectious neighbours [18–25] or, also, by replacing some infected nodes by healthy ones [26] leading, in both cases, to dynamical networks. Here the assessment of disease prevalence is based on the individual neighbourhood (local contacts), in contrast to homogeneous compartmental models where information about the prevalence is assumed to be globally available [2].

Under the previous modelling approaches, protective behavioural responses are triggered by the disease prevalence. As long as these responses are based on the global prevalence, one expects the likelihood of epidemic oscillations to be high. Moreover, the linear dependence of the standard incidence rates on the number of infected individuals implies that, when these oscillatory solutions occur, they should pass through low prevalence levels due to the lack of an abrupt switching behaviour. A low prevalence, in turn, will drive the number of aware individuals down as a consequence of a lower perception of the contagion risk, and the cycle repeats again with a new rise in the number of infectives. In fact, several ODE epidemic models with transmission of awareness [17, 27] or assuming self-initiated, voluntary vaccination [28] exhibit such periodic solutions under some values of the parameters.

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