An epidemic dynamics model with social classes different in the preventive behavior

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In this work, we consider a mathematical model for the epidemic dynamics with the heterogeneity of preventive behavior among individuals about a disease transmission, focusing on the relation of the distribution of preventive behavior to the final epidemic consequence in a community. The preventive behavior varies according to the level of caution to the disease transmission. We assume that people could be categorized into n classes based on their caution level about a spreading disease. The caution level affects the preventive behavior of not only susceptible but also infected individuals. Our first consideration is for the following SIR type of model that incorporates such a social structure with n classes of caution level:

$$\begin{aligned}
\frac{dS_i}{dt} &= -\varepsilon_i\beta\sum_{k=1}^{n} c_k I_k S_i;\\
\frac{dI_i}{dt} &= \varepsilon_i\beta\sum_{k=1}^{n} c_k I_k S_i - \rho I_i;\\
\frac{dR_i}{dt} &= \rho I_i.
\end{aligned}$$

Variables S_i, I_i, and R_i denote the sizes of susceptible, infective, and recovered subpopulation of caution level i respectively. Any demographic change due to birth, death or migration is assumed to be negligible in the epidemic season. The total population size is given by a positive constant N, and the size of subpopulation of caution level i is given by $N_i := p_i N$ with a given constant $p_i \in (0,1)$, where $\sum_{i=1}^{n} p_i = 1$. Thus we have $S_i(t) + I_i(t) + R_i(t) = p_i N$ for any $t \geq 0$. For the initial condition, we assume that $R_i(0) = 0$ and $S_i(0) + I_i(0) = p_i N$ for all i. The infection coefficient for susceptible individuals of caution level i is given by $\varepsilon_i\beta$ with positive constants ε_i and β, where $\varepsilon_i \in (0,1)$ represents the efficiency of preventive behavior. Susceptible individuals of low caution level are more likely to get infected than those of high caution level. Without loss of generality, we number the n classes as satisfying that $\varepsilon_1 > \varepsilon_2 > ... > \varepsilon_n$, where individuals of caution level n are regarded as those have the highest caution level. The parameter $c_k \in (0,1)$ introduces the contribution of the infected individuals of caution level k to the disease transmission. We assume that the individuals of low caution level serve the disease transmission more than those of high caution level, because the caution level determines the quality of behavior regarding the epidemics, even at the infectious state after the infection. We assume that $c_1 > c_2 > ... > c_n$, corresponding to the order of ε_i. Note that the parameter ε_i characterizes the behavior of susceptibles of caution level i, which c_i does that of infectives of the same caution level. The former is to avoid the infection, and the latter is to transmit the disease to the others. The parameter ρ denotes the recovery rate of an infected individual.

In this presentation, we are going to provide some theoretical results on the contribution of the heterogeneity in social behavior to the epidemic dynamics and try to find theoretical insights for public health in a community.