A review and socio-mathematical analysis of self-defense against infection: the impact of societal influences and awareness of danger

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Abstract:

Social influence and risk perception are important to drive the adoption of self-protective behaviors among people during an epidemic outbreak. It is interesting to know whether people should have more belief in social influence or in risk perception when they are faced with an asymptomatic infection. To explore the problem, we develop an extended epidemic model and apply it in a multilayered network topology. It is found that both social influence and risk perception can increase the density of self – protection and reduce the density of infections, but their impacts on the epidemic threshold are different. Specifically, risk perception unable to affect the epidemic threshold, while social influence can increase the epidemic threshold only if its strength is larger than its own threshold. However, when the epidemic infective is very high and the epidemic is ineradicable by self-protection, increasing belief in social influence may instead lead to more infections. The contrary results not only reveal the different mechanisms of social influence and risk perception in hindering an epidemic, but also provide practical implications on the belief distribution between them.

Literature reviewed and introduction:

- As the world gradually transitions into the post-pandemic era, the risk of infection persists, compounded by the virus's ongoing mutations. This situation has placed significant burdens on social and economic systems, leading many countries to ease their public health measures.
- In this context, individuals' self-initiated protective behaviors will become crucial in resisting the epidemic. From a social science perspective, behavioral intentions primarily stem from two sources: personal beliefs about the behavior and the influence of others—commonly referred to as social influence or imitation.
- This concept illustrates how the behavior of peers can shape an individual's beliefs and likelihood of adopting similar behaviors. Research has shown that self-protective actions, such as voluntary vaccination, social distancing, and mask-wearing, significantly mitigate the spread of epidemics.
- The dynamics of these self-protective behaviors and their impact on epidemic transmission have

been explored through coupled epidemic-behavior dynamic models and evolutionary game theory. Notably, both risk perception (individual awareness of risk) and social influence play critical roles in driving self-protective actions.

- Risk perception has been demonstrated to promote self-protective behaviors, thereby reducing infections and increasing the epidemic threshold. However, recent studies highlight its limitations, particularly in scenarios with asymptomatic infections, where the sources of infection may be undetectable, rendering risk perception less effective.
- Conversely, social influence has gained attention for its ability to encourage healthy behaviors and curb the spread of harmful ones during an outbreak. It is particularly influential in the adoption of self-protective measures, ultimately affecting the course of the epidemic.
- For example, research shows that when individuals imitate protective strategies from influential peers (hub nodes), the epidemic can be better contained. Unlike risk perception, social influence can enhance the overall resilience of a network, potentially compensating for the shortcomings of risk perception during periods of undetected infections.
- However, social influence also has its drawbacks; it tends to be less targeted than risk perception and can be more costly. When the costs associated with self-protective behaviors are high, imitation may actually decrease participation in these behaviors.
- Therefore, it is essential to consider both risk perception and social influence together, leveraging their respective strengths, especially in the context of asymptomatic infections. Prior research has looked at historical experiences and social influence but has not adequately integrated real-time risk perception.
- This study aims to explore the crucial question of whether individuals should prioritize social influence or risk perception to enhance self-protection during periods of asymptomatic infections. We introduce a coefficient to represent individuals' belief distribution between these two drivers of self-protection and incorporate this combined mechanism into a novel extended epidemic model.

The Basic Exponential Model:

The spread of a contagious disease depends on both the amount of contact between individuals and the chance that an infected person will transmit the disease to someone they meet. If the transmission risk of the disease is 100 per cent and each infectious person meets two other people before they recover, the disease will soon begin to spread very quickly. Assuming that recovery takes one day, this situation will result in the number of sick people doubling each day. We can model this situation by the following equation:

$$y = 2^{t-1} \quad (1)$$

where

y the total number of people infected

and

t the time, in days,

which has elapsed since the initial outbreak.

One can also describe the situation graphically as:

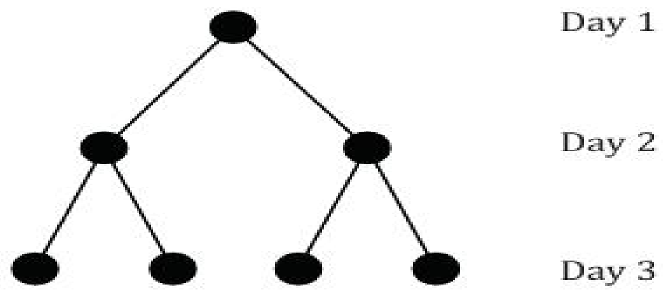

Figure (A): The spread of disease with an exponential growth of $y = 2^{t-1}$

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A scenario where the number of infections increases by a constant factor each day is known as exponential growth. This model can be a simplified representation of how an infection might spread through a population.

Theoretical analysis:

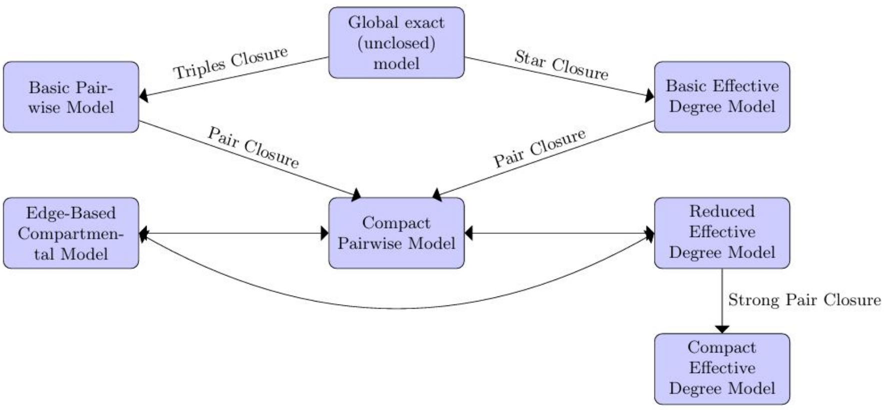

Figure (B) The hierarchy of models.

Labeled edges denote the additional assumptions required to find the mathematically simpler model. Unlabeled (bidirectional) edge simply that the two models are equivalent and each can be derived from the other. The un closed exact model will reduce to either the basic effective degree model of [22] or the basic pair wise model [7] depending on the closure used. Each of these then reduces to the compact pairwise model (as modified from [2]). The compact pairwise model, the reduced effective degree Model and the Edge-based Compartmental model [34] are all equivalent. Using the strong version of the pair closure, we can derive the compact effective degree model which also tracks information about infected individuals and their partners.

Model	Minimal number of Differential Equations	Analytic final size calc?	Early growth calc?
Basic pairwise model	$2K^2 + K + 1$	No	$\mathcal{O}(K^2 \times K^2)$ eigenvalue problem
Compact pairwise model	$K + 3$	No	Analytic calculation
Basic effective degree model	$(M + 1)^2 + 1$	No	$\mathcal{O}(M^2 \times M^2)$ eigenvalue problem
Compact effective degree model	$M + 3$	No	$\mathcal{O}(M \times M)$ eigenvalue problem.
Reduced effective degree model	$M + 3$	No	Analytic calculation.
Edge Based Compartmental model	2	Yes	Analytic calculation.

Table1. Comparison of the models.

In this research, the following aspects have been discussed:

Combine risk perception and social influence together and try to investigate an important problem: whether peoples would have more belief in social influence or in risk perception to increase their self-protection during an asymptomatic infection. Proposed a coefficient to denote people's belief distribution over the two types of self – protection drivers and apply the combined self-protection mechanism into a novel extended epidemic model. Model is then analyzed using the heterogeneous mean – field (HMF) method and verified with the numerical results. Find both theoretically and numerically that social influence and risk perception can help to reduce the number of infected people, while only social influence can increase the threshold of epidemic outbreak. Risk perception sometimes may be more effective than social influence to reduce the number of infected people when the epidemic infection is very high (i.e. the epidemic is impossible to remove with self – protection) because social influence is less targeted than risk perception. Fortunately, the deficiency of social influence will gradually disappear with the increase of social influence strength, namely the targeted deficiency of social influence can be remedied by extending its coverage. Besides, the threshold for social influence is also investigated. When the strength of social influence is lower than its own threshold (i. e. social influence is unable to promote self-protection alone), social influence will be unable to increase the epidemic threshold and people should have less (or even no) belief in it.

Conclusions and fruitful discussions:

Social influence and risk perception are both considerably important for people to adopt the self-protective behaviors in the social network during an epidemic outbreak. But there remain debates on whether people should have more belief in social influence or in risk perception. In this research, we develop an extended epidemic model which is incorporated into a multilayered network structure to investigate this problem during an asymptomatic infection.

Credit Authorship Contribution Statement:

Dr. Anand K. Acharya	Conceptualization, Methodology.
Dr. Haresh D. Chaudhari	Verification of the Existing Data.
Dr. Nayanesh A. Gadhavi	Sociological Justification and Reviewing.
Rakesh M. Patel	Writing of the article.

Declaration of Competing Interest

All the authors declare that they have no known / unknown competing financial interests or personal relationships that could have appeared to influence the work reported in this review article. If so all the authors agreed to cite references with due respect at their proper place/s.

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