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Impact of negative information diffusion on green behavior adoption

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ABSTRACT

Apart from the technical improvements, inducing the green citizen behavior is also a key way to reduce carbon emissions. Various studies have tried to identify the determinants of green behavior. Hitherto, there lacks a quantitative analysis directed to the effects of some factor on the outbreak of green behavior and the final adopted fraction. To fill this gap, this paper propose a Heterogeneous Green Behavior Spreading (HGBS) model to explore the impacts of negative information diffusion (about the green behavior) that effects on the spreading of green behavior. Simulations are performed on top of the two-layer multiplex networks, in which individuals are involved in two processes, the information diffusion in information layer and the green behavior spreading in physical contact layer. Based on the Microscopic Markov Chain Approach (MMCA) and the Monte Carlo (MC) simulations, we find the slight impact of information layer would make the green behavior harder to break out and reduce the adopted fraction. Moreover, the diversity of information diffusion ways makes it worse. It suggests that the control of negative information diffusion would be helpful in contributing to low-carbon city. Another effective way is to encourage individuals having more neighbours in real world to behave pro-environmentally since the adopted fraction is increased for small degree of the individuals in physical contact layer. It is essential to consider the heterogeneity in spreading activity if one wants to model the green behavior spreading.

1. Introduction

Recently, with the increasing concern about global warming, researchers have concentrated efforts on identifying factors that affect green citizen behaviors (Ding et al., 2018; Matsumoto et al., 2018) and firms' environmental behaviors (Long et al., 2017a,b). Different from firms' environmental behaviors which mainly take place in production processes, green citizen behaviors are regular activities that happen in daily life and contribute to reducing carbon emissions, such as the purchasing choice of energy-saving products, the travelling choice of sustainable transportation, application of green energy and other behaviors which are helpful for low-carbon city.

Many factors were considered to have impacts on green behaviors (see Ding et al., 2018; De Medeiros et al., 2014 for a review). Wang et al. (2018) found the availability and clarity of green information and the presence of green certification has keen effect on consumers' propensity to make a decision in purchasing the remanufactured products. Varela-Candamio et al. (2018) considered the environmental education such as awareness of global warming is a powerful tool to generate green behavior among citizens. Other factors like gender (Belaïd and Garcia, 2016; Vicente-Molina et al., 2018), income (Ramos et al., 2016; Lu et al., 2017) and green beliefs (Kahn and Morris, 2009) were also proved to affect people's decisions to adopt green behaviors. However, most of the above studies paid more attention to the identification of the influencing factors, ignoring the quantitative analysis directed to the impacts of factors that can have on the outbreak of green behavior and the final adopted fraction. In the present study, we don't focus on elaborating factors behind a special green behaviors. Hitherto, to our knowledge, present study is the first attempt to investigate quantitative effects of a special factor that can effect on the green behavior spreading.

Since social networking has permeated our daily life, when a green behavior spreads, negative information about the green behavior spreading through online social network or other sources may concomitantly depress people's propensity to adopt green behavior (Geng et al., 2017). Here, the negative information mainly refers to information that are adverse to the adoption of green behavior, such as the relative high costs of green power, the inconvenience and incivility of hanging laundry compared with drying.

Though researches have been done to understand the impacts of

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online social network on several human activities, including voting (Bond et al., 2012), health behavior (Centola, 2010), user offline real-world physical activity (Althoff et al., 2017) and epidemic spreading (Granell et al., 2014; Wang et al., 2014; Zang, 2018), sparse is known about how green behavior spreading is influenced. To fill this gap, this study tries to gain deep understanding into the effects of the negative information diffusion can have on the green behavior spreading with the help of two different multiplex networks (see Gao et al., 2011 or Boccaletti et al., 2014 or Kivelä et al., 2014 for the detail introduction on the multiplex networks). In fact, as a natural way to describe the interrelated complex connections among people (Granell et al., 2013), multiplex networks have been widely used in recent studies (Granell et al., 2013, 2014; Wu et al., 2017; Pan and Yan, 2018). For example, based on a two-layer multiplex network, in which individuals participate in two processes, a trust dynamics in one layer and an information spreading in the other, Wu et al. (2017) quantified the effects of a rational individual's decision making in the propagation of information. Granell et al. (2013) explored the interplay between information diffusion and epidemic spreading on top of a two-layer multiplex network. Results revealed that there exists a meta-critical point of information transmission rate over which the epidemic threshold is affected by awareness spreading.

Notice that when individuals are making decisions, they always exhibit distinct behaviors according to their own experiences and attributes (Borge-Holthoefer et al., 2013; Zhang et al., 2014; Geng et al., 2016). Different levels of trust in acquaintances do play an important role in human behavioral responses (Sherchan et al., 2013; Wu et al., 2017). If an individual occasionally reads a negative message about the green behavior on Facebook or other social networks, he may not transmit it further. Yet if the message is from authority or his friends, he may believe it and inform others (Perra et al., 2012). Therefore, we consider the individual heterogeneity in the green behavior spreading process, and propose a Heterogeneous Green Behavior Spreading (HGBS) model, in which the heterogeneous activity levels of diffusing information and the heterogeneous attitudes towards the green behavior are both considered. Specifically, the attitudes towards the green behavior depend on the number of the neighbors who have received the negative information. We finally find that the heterogeneity in activity levels do have influence on the green behavior outbreak or prevalence. In addition, this study helps to gain insight on the promotion of green behavior spreading. Suggestions include controlling the negative information diffusion about the green behavior and encouraging individuals who has more neighbours in real world to follow the green behavior.

The remainder of this paper is organized as follows. Section 2 describes in detail the construction of the HGBS model. Section 3 presents the theoretical analysis about the green behavior threshold. Section 4 gives the simulated results. Finally, Section 5 concludes the paper.

2. Model

The Heterogeneous Green Behavior Spreading (HGBS) model works on a two-layer multiplex network, see Fig. 1. Each layer has different connectivity while the nodes in each layer are same. Each node represents an individual and two nodes are linked by an edge if the two individuals having a relationship. In the information layer individuals transmit (or receive) negative messages about the green behavior to (or from) people they share information with. Apart from the face-to-face contacts, links to whom they only contact in online social network are also included in this layer. The physical contact layer is the place where the dynamics of green behavior evolves. Individuals follow the green behavior in this bottom layer and its links corresponds face-to-face contacts ranging from the relations with family members, neighbors to co-workers.

In the information layer where nodes spread the negative messages about the green behavior, an unaware–aware–unaware (UAU) model is

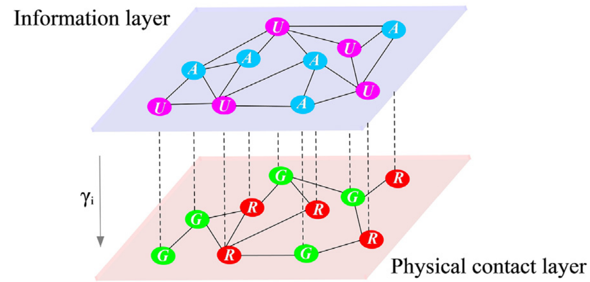

Fig. 1. Two-layer multiplex network. Diffusion takes place in information layer while green behavior evolves on physical contact layer. Nodes in the information layer can be in one of the two states: unaware (U) or aware (A). In the physical contact layer, their state can be: red (R) or green (G). (For interpretation of the references to color in text/this figure legend, the reader is referred to the web version of the article.)

applied to represent the diffusing process. Each node is assigned in one of the two states: aware (A) and unaware (U). Aware nodes are able to transmit the negative information about the green behavior (such as inconvenience, discomfort) to unaware nodes in the same layer and can forget the information with the probability δ. Unaware nodes have not received any information, but can get it with the probability λ by communicating with aware nodes. Considering that aware individuals are not always active to spread the information and the activity levels are partly determined by their own experiences and attributes, hence, a value a_i is assigned to each aware node i to account for the heterogeneity of activity levels. In particular, we propose three models, including a uniform model $a_i = c$, $c \in [0, 1]$, an exponential model and a degree correlation model, for the assignment of spreading activity a_i to individual i:

1. Uniform model:
   In the uniform model, aware individuals are assigned with the same values of activity in the range [0, 1].

$$a_i = c$$

2. Exponential model:
   In the exponential model, aware individuals are assigned with different values of activity follow the exponential distribution $P(a) \sim exp(-\lambda a)$. Note that individuals with the same degree may have different activity.
3. Degree correlation model:
   Following the idea that more active individuals, usually, also have a central role in the topology of the network (Borge-Holthoefer et al., 2013), this model assumes that the spreading activity a_i of an aware individual i is positively correlated with its degree k_i in the physical contact layer, which implies that an individual with a larger degree has a higher spreading activity:

$$a_i = \frac{k_i - k_{\min}}{k_{\max} - k_{\min}},$$

   where k_{max} and k_{min} are the maximum and minimum degrees of individuals in the physical contact layer, respectively.

The spreading process of green behavior in the physical contact layer can be described by the red-green-red (RGR) model. Each node is allowed to be in one of the two states: red (R) or green (G). A red node can follow the green behavior with an adoption rate β and green node can recover to the red state (i.e., abandon the green behavior) with the recovery rate μ. For simplicity and for gaining insights into the effects of information diffusion on the spreading of green behavior rather than the opposing situation, we assume an individual would be aware of the