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Knowledge transmission model with consideration of self-learning mechanism in complex networks

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A B S T R A C T

Based on the fact that one can attain knowledge by oneself, which is different from epidemic spreading, we analyze the knowledge transmission in complex networks. In this paper, we propose a knowledge transmission model by considering the self-learning mechanism and derive the mean-field equations that describe the dynamics of the knowledge transmission process. Furthermore, we obtain the transmission threshold R_0, which is closely related with the transmission rate and self-learning rate. Moreover, we investigate the global stability of the knowledge free equilibrium E_0 and the endemic equilibrium E^* of the model. That is, when $R_0 < 1$, the knowledge free equilibrium point E_0 is globally asymptotically stable and the knowledge becomes completely extinct eventually; when $R_0 > 1$, a unique endemic equilibrium point E^* is globally stable, and the knowledge can be transmitted. Finally, numerical simulations are given to illustrate the theoretical results. The simulation results indicate that the self-learning factor has an obvious promoting effect on the knowledge transmission, both in scale-free and homogeneous networks. Besides, the simulation results illustrate that the scale-free network is more efficient to knowledge transmission.

1. Introduction

In the era of the knowledge economy, information and knowledge are considered as the main driving force for economic development. In 1993, Drucker explicitly maintained that the most valuable assets of enterprises are their knowledge and knowledge workers. Knowledge has become a crucial factor for economic growth. Knowledge, as the dominant resource, can create competitive advantages for firms [1,2]. Further, the value of knowledge is closely related with efficient propagation process. Knowledge transmission, as a critical factor, is necessary to the changes, innovation, and competitive success of firms [2–4]. Knowledge transmission is important both within a firm and between different firms [4]. The success of many companies are based on their ability to transfer the knowledge, to share experience between internal companies and others, as well as to improve their capabilities by assimilating new knowledge [5,6].

With the development of information and the internet, knowledge dissemination has not only occurred in physical space, but also in the "logic space" [7]. A new transmission route of knowledge, i.e., information networks, which differs from the traditional face-to-face or physical contact, has emerged and gradually become dominant in the recent decades [32]. Commonly used social networks, such as Facebook, Twitter, or Google+, have become popular internet platforms, in which

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worldwide people can simultaneously share information, opinions, and knowledge with a large number of peers [8]. The development of social networks plays an essential role for knowledge transmission in today's Internet world [9]. Complex networks are widely applied to describe the features of real-world networks [10], and knowledge transmission in complex networks has been studied extensively. Cowan et al. [11,12] analyzed the relationship between network structures and the performance of knowledge diffusion and demonstrated that the maximum performance in terms of knowledge transmission is achieved in small-world networks. Kim and Park [16] measured the knowledge diffusion in regular, random, and small-world networks and drew a similar conclusion to that of Cowan and Jonard's. Morone and Taylor [13] proposed a general model for knowledge diffusion based on a face-to-face network, considering knowledge diffusion under the influence of interactive learning. Tang et al. [14,15] constructed two types of networks, i.e. hierarchy and scale-free networks, to investigate knowledge transfer and gotten that the scale-free structure was more effective for knowledge transfer. Further, Lin and Li [17] studied how the growth and diffusion of knowledge are affected by the network structure. They considered the knowledge innovation and diffusion process in four representative network models, i.e., regular networks, random networks, small-world networks, and scale-free networks, and the results indicated that optimal knowledge transfer performance is obtained in scale-free networks [17].

In terms of transmission dynamics, the epidemic spreading theory has been studied extensively, in which SIS (susceptible-infected-susceptible) and SIR (susceptible-infected-removed) are the most important and fundamental epidemic models. With the introduction of scale-free networks and small-world networks, the spread of epidemic diseases in complex networks has been studied by many researchers [18–24,41]. Pastor-Satorras and Vespignani [18–20] studied the SIS model and figured out the existence of an epidemic threshold in finite scale-free networks. That is, if the effective spreading rate exceeds this threshold, the infection can produce an epidemic outbreak; otherwise, the disease will disappear gradually. What is more, the SIR model in complex networks was studied in [21], which indicated that the large connectivity fluctuations of networks considerably strengthen the incidence of infection. In addition, researchers have established a number of compartmental models to investigate the dynamics of infectious diseases. For instance, the SIS epidemic model with nonlinear infectivity was established and analyzed in Ref. [22]. Zhang et al. [23] presented an SIS epidemic model with feedback mechanism on networks and figured out that feedback mechanism can weaken the spreading of diseases and reduce the endemic level. In Ref. [24], the authors reviewed the developmental of theoretical epidemiology with emphasis on vaccination.

Based on the similarity of knowledge transmission and epidemic spreading [25], many researchers have used the epidemic spreading theory in different fields, including information spreading [26–28], scientific interaction [29–31], and knowledge transmission [32–33]. In Refs. [26–28], information spreading was formulated as an optimal control problem by using the epidemic spreading model. Bettencourt et al. [29,30] viewed published papers or publishing authors as a proxy for the diffusion of ideas and introduced epidemic models to quantify the spreading of ideas in both theoretical and experimental physics. They observed a good fit between suitably adapted epidemic models and data for the dissemination of a specific research topic. By using individual-based models from mathematical epidemiology, Kiss et al. [31] developed an individual-based directed and weighted network model to determine how a research topic spreads over an existing network of disciplines, which was obtained from citations between ISI subject categories (SCs). Zhu et al. [32] extended the SIS epidemic model to study tacit knowledge transmission through the two routes, online social networks and face-to-face physical contact. Cao et al. [33] considered the knowledge forgetfulness and established a general SIS knowledge transmission model in which the level of forgetfulness depended mainly on the number of neighboring individuals who possess knowledge.

In the knowledge explosion era, the flow of knowledge is particularly important. Lifelong learning philosophies [34] pointed out that any worker maintains an ongoing, voluntary, and self-motivated pursuit of knowledge. In Ref. [35], this behavior was described as a self-learning process. Różewski and Jankowski [35] considered the self-learning factor and established the knowledge diffusion model by using the agent simulation approach to illustrate the different aspects of the proposed model from the methodical point of view. Furthermore, knowledge transmission has been studied extensively, especially regarding scientific citations. In Ref. [36], Kuhn et al. proposed a simple formalization of scientific memes in the scientific literature and revealed that scientific memes are governed by a surprisingly simple relationship between frequency of occurrence and the degree to which they propagate along the citation graph. Perc [37] analyzed the titles and abstracts of over half a million publications of the Physical Review that were published between July 1893 and October 2012 and indicated that both the rise and fall of scientific paradigms are subject to the principles of self-organization. In Ref. [38], the author reviewed self-organization across the social and natural sciences and determined that the Matthew effect affects the pattern of scientific collaboration and the propagation of citations.

Based on the previous research, we extend the SIS epidemic model to analyze knowledge transmission in complex networks by considering the self-learning mechanism. The rest of the paper is organized in the following way. Section 2 introduces the knowledge transmission model and the mean-field equations. In Section 3, we prove the global stability of the equilibrium points. In Section 4, we provide some numerical simulations to support the theoretical analysis. Finally, this paper ends with a brief conclusion.

2. Modeling and analysis

Suppose that knowledge is transmitted in a closed and mixed population with N individuals (denoted as vertices) without any losses during the transmission process. Based on the previous study on knowledge transmission, we assume that all of