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ABSTRACT

Purpose

–The purpose of this paper is to extend prior supply chain research by describing the process of innovation knowledge increase in supply chain network. More specifically, this study investigates the role of network density, and views the knowledge increase as the process of knowledge diffusion and knowledge innovation.

Design/methodology/approach

–A Multi-agent model, which demonstrates the process of knowledge increase in supply chain network, was established， and simulated by using NetLogo simulation platform.

Findings

–The results indicate that the network density will promote the knowledge increase of the supply chain when it is high or low. In the meantime, these results show that the inhibition of knowledge diffusion and knowledge innovation, will appear when network density is moderate.

Originality/value

–Although previous research has identified the importance of knowledge increase in promoting sustainable development of supply chain, far less attention was given to the study of the effect of network structure on the knowledge increase in supply chain. This study thus fulfills the research gap by providing an description of the process of knowledge increase with the consideration of network density. The conclusion is of great significance for the choice of network density for sustainable development of supply chain.

Keywords: network density; innovation knowledge increase; supply chain network; Agent-Based Model and Simulation

0. Introduction

The existing research considers the supply chain as a knowledge alliance, and believes that the knowledge increase in the supply chain is important for its sustainable development (Wowak, 2013; Ikem, 2013; Sambasivan, 2009). Driven by increased market competition and rapid technological changes, the supply chain needs to continuously increase innovative knowledge to strengthen its core competitiveness (Liang, 2015; Min, 2015). In order to promote the growth of knowledge, the structure of supply chain also gradually changes from the original chain structure into a network structure, that is, the close innovation cooperation also exists between suppliers and users in addition to the cooperation between the enterprise and its upstream and downstream (Shi,2012; Tseng2013;Zhao, 2016; Zhou,2013). With the help of modern information technology, this complex network structure can meet the innovation demand quickly in the market (Xu,2015; Liao,2016; Katja, 2011). Some scholars believe that such network structure is beneficial to the acquisition of heterogeneity knowledge, and reduces the transmission costs caused by redundant connections, so as to ensure the sustainable increase of innovation knowledge in supply chain (Chen, 2015; Chih, 2011; Scott, 2012; Burt, 1993).

However, few studies have analyzed the innovation knowledge increase of supply chain with this network structure, and have not proved that the network structure is beneficial to the innovation knowledge increase in supply chain. Several studies, based on social network theory, have analyzed the characteristics of the supply chain network structure, and proposed the factors which affect the formation of the network structure (Gnyawali, 2001; Zhou, 2016; Yi, 2016). A part of studies have found the influence of knowledge integration and flow in obtaining the core competitive advantage of supply chain; however, few have analyzed the innovation knowledge increase process of supply chain with different network structures. Indeed, the influence of network structure on the innovation knowledge increase has been studied in the existing innovation literature (Katja, 2011;Kieron,2004), and network density is regarded as an important factor that affect innovation knowledge increase based on the complex network theory (Katja, 2011; Wang, 2016; Long, 2016; Kühne, 2013). Nevertheless, some studies suggest that network density has a positive influence on the innovative knowledge increase (Wang et al., 2010; Xiong et al., 2011), others suggest that network density has a negative influence on the innovative knowledge increase (Zhang, 2011; Ma, 2017).

Nonaka’s (2000) argument on Socialization-Externalization-Combination-Internalization (SECI) model helps to explain the inconsistent results of prior research. According to Nonaka (2000), knowledge increase is viewed as the process of knowledge diffusion and knowledge innovation. However, the innovation knowledge increase in the supply chain network is equivalent to the knowledge diffusion or knowledge innovation in the existing researches, without considering the two as a continuous process (Cao et al., 2016; Wang, 2016). When the network density becomes greater, the social relations and the goals of the enterprises in the supply chain are more and more unified through long-term cooperation and communication, thus conducive to the knowledge diffusion. But the deepening of interconnection can also lead to the homogeneity of knowledge, which is adverse to knowledge innovation (Xu, 2015; Liao, 2016).

Based on the research of Nonaka (2000), the process of innovation knowledge increase in the supply chain network can be understood accurately only through the analysis of the knowledge diffusion and knowledge innovation as a whole process (Tse, etc., 2016). We argue that, in the supply chain network, enterprises acquire the outside knowledge through knowledge diffusion in the network (Love, 2009; Chen, 2015), and make an innovation based on the existing knowledge, to increase their own knowledge. When the knowledge quantity of an enterprise exceeds that of others, it will trigger a new round of knowledge diffusion and knowledge innovation, and ultimately lead to the entire network knowledge increase (Tse, etc., 2016). As a continuous, interconnecting and constant process, knowledge innovation and knowledge diffusion push each other and jointly facilitate the innovation knowledge increase of supply chain network (Argote et al., 2016; Battistella et al., 2016) .

Using the analysis of knowledge diffusion and knowledge innovation of the supply chain with different network density structures, in this study we describe the process of innovation knowledge increase based on the innovation theory, complex network theory and SECI model in knowledge creation theory. In the application of methods, it is difficult to carry out the follow-up research on network density structure and innovation knowledge increase of supply chain for a long time in different periods by adopting case study method. In addition, if econometric model or other empirical research methods which need to collect the large sample data are adopted, it is hard to meet manpower and material resources required for investigation and accurate measurement of network density of a large amount of supply chain network. Nevertheless, agent-based model and simulation can control the influence of other variables well and measure the network density accurately (Oliveira, 2016;Long, 2016;Luis et al. ,2012, Labarthe et al.,2007 , Bahroun et al. ,2010, Li et al. ,2010, and Long et al. ,2011), and describe the innovation knowledge increase process of the supply chain vividly (Bahroun, 2010). Therefore, agent-based model and simulation are adopted in this paper to analyze the innovation knowledge increase process of the supply chain under different network density structures.

The rest of the paper is organized as follows. First, we present literature review. Second, multi-agent models of supply chain networks are proposed. Third, we discuss the process of simulation. Finally, we discuss the implications of our research and identify limitations and directions for future research.

1. Literature review

1.1 Network density and knowledge increase

The network density of supply chain reflects the density of inner connections. In a supply chain network with low density, network sanctions have low effectiveness and a high risk of opportunism arising from asymmetric information (Flynn et al., 2010; Cao, 2011). It will reduce the trust among members of the network, and inhibit the exchange and integration of the knowledge in the supply chain network (Schilling, 2007). At the same time, low network density indicates fewer connections among the members and a lack of close connections for the understanding of each others' knowledge. A lack of channels also prevents tacit knowledge transfer within the network (Giovanna, 2008). In addition, a network density that is too small will counter the appearance of the advantage of structural holes and impede the growth of the knowledge of a supply chain network (Liu, 2011). With the gradual growth in density of a supply chain network, the connection quantity and interactive frequency among members within the network increases. And the effect of sanctions experienced by members for their irregularities is exacerbated, thus producing forced and deterrent trust (Gulati, 2008). As a result, the sharing standards and common behavior modes among the network members will be formed (Gnyawali, 2001). Meanwhile, the levels of collaboration and knowledge sharing among network members are improved (Dyer, 1998). In addition, the increase in the interaction frequency within a supply chain network allows members to communicate which will reduce the risk resulting from asymmetric information (Gulati et al, 2000) and the opportunism within the network, thus promoting the transfer of knowledge (Dyer, 2000; Kogut, 2000). Moreover, frequent exchanges can facilitate the building of efficient mechanism of knowledge transfer, thereby improving the transmission, absorption, and integration among network members, and promoting the quality of transferring knowledge .

However, high network density of supply chain network is not always favorable. A network that is dense also has adverse effect on the growth of knowledge, and too many links among network members inevitably lead to the repetition of knowledge, thus increasing the cost of duplicate management. Excessive external information enhances the difficulty of filtering valuable information, impeding quick decision-making and the spread of new knowledge. The rapid information flow among network members easily leads to high homogenization of knowledge which prohibits network members from obtaining heterogeneous knowledge and innovating knowledge. Furthermore, the development of high cohesion and sharing standards of a dense network results in a high pressure to display consistent behavior rather than encouraging distinct behaviors (Kraatz,1998) and prevents new members from joining. On the one hand, a standard environment facilitated by intensive network causes network members to prefer cooperating with intimate partners, producing a lock-in effect that excludes other members (Hipkinand, 2006) . On the other hand, maintaining the cost of existing abundant links (including the links that have lost their advantages to network members) may diminish the power of network members to cultivate new prospective links (Gargiulo, 2000). Eventually, the whole supply chain network becomes a closed network, and the knowledge innovation of network members is inhibited. As a result, knowledge diffusion can be likened to water without a source, preventing the increase in knowledge of the supply chain network. By contrast, a relatively loose network structure established by the network members constantly opening up new links and eliminating redundant links is superior in promoting the increase in knowledge of the supply chain network. On the one hand, new connections established by network members are conducive to the establishment of their own structural holes to control the information transmission of other members. On the other hand, if the redundant links are removed, network members can invest limited resource into the most valuable contacts and reduce the cost of duplicate management. Furthermore, non-redundant contacts can narrow the gap between enterprises. Through exposure to a wider range of knowledge resources, the range that network comprises is expanded, and the breadth of knowledge diffusion is also expanded (Schilling, 2007). Therefore, when the network density of a supply chain network is high, density hinders the knowledge diffusion and innovation of the supply chain network. Nevertheless, with the help of Internet, the network density can increase easily. Through the access to external knowledge, trust and loyalty formed by the high network density structure will promote the rapid flow of knowledge, which is conducive to the occurrence of innovation (Christensen, 1997).

To sum up, when the network density is low, the increase of the network density promotes the growth of knowledge. However, when the network density is developed to the degree that the beneficial effects correspond to the adverse effects, further increase of network density inhibits the growth of knowledge. As the network density continues to rise, the innovative knowledge will increase again. Hence, we propose that: **the network density and the increase in the knowledge of a supply chain network have a cubic relationship.**

1.2 Complex network model and knowledge management in supply chain

Cowan and Jonard (2004) put forward the knowledge diffusion model in the complex networks, and proposed that the network structure which has the short average path length and high clustering coefficient is conducive to knowledge diffusion. Liu, et al.(2005) emphatically analyzed the knowledge propagation behavior in the network, and summarized the application of complex network in the social and economic system. Li (2006) proposed a knowledge dissemination model based on the complex network theory. The results show that, under the same conditions, when the randomization of the network is greater, the knowledge diffusion in the network is faster. Li et al. (2007) respectively established an innovative evolutionary model based on stochastic network and scale-free network, and then discussed the dynamical property of innovation diffusion. Hu (2008) adopted the scale-free network to simulate the realistic organizational model, and studied the propagation and evolution of knowledge in the model. Wang et al. (2008) introduced the complex network theory into the innovation network of small and medium-sized enterprises, and discussed the connection mechanism of the innovation network. Chang (2008), based on complex network theory, especially the scale-free characteristic of network, established an inter-enterprise market trading network and analyzed the development of small-sized enterprises. In the study of complex network, scholars also paid attention to the study of small-world network, that is, a certain weight is assigned to the connection of network nodes, thus quantifying the intensity of the link between enterprises. The rapid transmission capability of small-world networks is adopted to study the dissemination of knowledge. Many economic management scholars applied the statistical features of the small-world network to the evaluation of the knowledge diffusion. For example, Latora and Marchiori(2003) put forward a new theory of small-world network based on efficiency and cost in the undirected weighted network. In addition, they introduced a concept of low cost and efficient small-world network. Deng (2006) introduced the weight of connection side into knowledge sharing network, and put forward an idea of measuring the effect of knowledge sharing with global efficiency, local efficiency and cost in the weighted small-world network model, thus providing the quantitative analysis basis for knowledge sharing network in the global and local scope.

2. Multi-agent Models

The efficient diffusion and innovation of knowledge in supply chain system play an important role in improving the competitiveness of the supply chain. At present, the knowledge increase efficiency of the regular network, the small-world network (Xi et al., 2006; Cowan and Jonard, 2004; Li et al., 2010), the stochastic network (Lazer et al., 2007) and the scale-free network (Lin et al., 2012) is comparatively studied. Most of the researches show that the complex network structure has an impact on the knowledge increase. For example, Cowan and Jonard (2004) analyzed the relationship between network structure and diffusion performance, and believed that the average knowledge level of the small-world network model is the highest in the all kinds of network structures. Lin et al. (2012) found that the diffusion time of knowledge has a linear relation with the network scale, and the scale-free network has the faster speed of knowledge diffusion and better knowledge transfer performance than other networks. For regular complex network structure, such as supply chain, the relationship between its network structure and knowledge increase efficiency needs to be further studied (Ma, 2017). Based on complex network theory (Deng,2006), we built the model of innovation knowledge increase in the supply chain, and through the computer simulation method, to analyze the law of innovation knowledge increase in supply chain network.

Agent-based model and simulation is a type of bottom-up method for modeling and simulation. It can organically integrate individual micro-behaviors in complex systems with the whole properties of the systems. Specifically, a large number of interactions between agents are studied to elucidate the macroscopic phenomena that emerge in the interactions. The simulation entities in complex systems are modeled by using agents to describe the behaviors of complex systems through the behaviors as well as the interactions and social portrayals between them. This method focuses on the evolutionary process of the systems over time and how decisions affect the evolutionary results of the systems and explain the emergence in complex adaptive systems (Rosanna, 2005; Kieron, 2004).

According to the definition of complex network model (Watts，1998), the nodes of network represent manufacturers, suppliers, users, and other related innovative subjects (agents). The lines connecting the nodes represent the cooperative relationships among agents. Variable L represent the number of the existing connecting lines in the networks, $netD$ indicates the network density of the supply chain network, N is the number of members, then $netD = \frac{L}{C_N^2} = \frac{2L}{N(N-1)}$. The relationship among enterprises is stable in the supply chain network(Zhang et al., 2015); in addition, the connection strength is different, and so that the efficiency of knowledge diffusion is various (Sun, etc., 2011). We propose the following assumptions according to the situations described above:.

Assumption 1: The members of the networks and no subjects join the networks, extinct and break away from the networks.

Assumption 2: If two subjects have a direct link, namely first-level neighborhood, their link strength $Link$ is 1, otherwise, 0.

The level of knowledge is an attribute of a subject. It is a variable that increases with the growth of time, determining the behavior patterns and states of subjects' interactions in the following period. The purpose of the interactions of the subjects in the supply chain network is to achieve complementary advantages and different types of knowledge through knowledge sharing under the principle of mutual benefit. It will ultimately improve their own knowledge stocks and innovative ability. $(k_i^1(t), k_i^2(t), k_i^3(t)...k_i^m(t))$ represents the knowledge level of subject i in m fields at t.

2.1 Search rules

The subject search in a supply chain network is local search. Local search refers to searching in the local world which means the sets of neighbors who have historical contacts and deep connections to the subject, namely the set of first-level neighbors (Sandra, 2008; Li, et al., 2007).

Innovation subjects are intelligent and purposeful. Therefore, they search diffusion objects according to certain criteria. In our models, knowledge acceptors determine their own needs of knowledge first, in other words, the weakest domain of their own knowledge; then they search in accordance with the link strength to identify appropriate knowledge sources in this area. The knowledge sources have to meet the following criteria: (1) can provide receptors with the knowledge they need; (2) the knowledge difference between sources and receptors is small enough that the receptors can absorb the knowledge; and (3) be willing to diffuse knowledge to receptors. We propose the following assumption as follows.

Assumption 3: When the knowledge difference between the receptors and sources is more than $k_{\min}$ in a certain field, the receptors meet the conditions for absorbing knowledge. However, when the difference on stock of knowledge between receptors and sources exceeds 0.95 (Zhao, 2010), the knowledge diffusion in this field will be ceased by sources for protection of their own core knowledge.

2.2 Diffusion rules

According to the model of Cowan and Jonard (2004), $\alpha_{i,j}$ indicates the diffusion willingness of knowledge source i to knowledge receptor j, and $\beta_{j,i}$ shows the capacity that knowledge receptor *j* absorb the knowledge diffused by knowledge source i, then, after the knowledge is diffused, the knowledge levels of knowledge source i and knowledge receptor j are $\begin{cases} k_i^s(t+1) = k_i^s(t) \\ k_j^s(t+1) = k_j^s(t) + \alpha_{i,j}\beta_{j,i}[k_i^s(t) - k_j^s(t)] \end{cases}$, where both $\alpha_{i,j}$ and $\beta_{j,i}$ are directly proportional to the link strength $Link_{i,j}$ between knowledge source i and knowledge receptor j, without loss of generality. Suppose $\alpha_{i,j}\beta_{i,j} = k_1 Link_{i,j}$ (k_1 is a constant greater than zero), after substituting it for the equation shown above, then $\begin{cases} k_i^s(t+1) = k_i^s(t) \\ k_j^s(t+1) = k_j^s(t) + k_1 \times Link_{i,j} \times [k_i^s(t) - k_j^s(t)] \end{cases}$.

2.3 Innovation rules

Assumption 4: When the knowledge stock of subjects and the obtained external knowledge exceeds two critical values λ_1 and λ_2, respectively, knowledge innovation occurs. The critical value which is set in this way reflects the innovation as a discrete process (Kieron et al., 2004; Olav et al. 2006).. The increase of the innovative knowledge that arises from innovation depends on its own knowledge stock and the introduced knowledge diffusion. Without loss of generality, let the knowledge stock in the item m of innovation subject i be k_i^m. It triggers knowledge innovation after the knowledge diffusion with the item m of innovation subject j. The change in the knowledge stock of innovation subjects is $\overset{*}{k}{}_i^m(t) = \pi_2 k_i^m(t) * e^{[k_j^m(t) - k_i^m(t)]}$.

After the knowledge innovation is developed by the innovation subject, a certain difference of stock of knowledge exists between the innovation subject and its neighbors. This difference opens the prelude of a new round of knowledge diffusion. Thus, knowledge innovation and knowledge diffusion are mutually supportive in boosting the growth of network knowledge.

3. Simulation analysis

3.1 Simulation procedure of models

The density simulation test is conducted ten times under the conditions of each density. The mean value of the ten tests is the final result of the network density (Wang et al., 2012). The simulation procedure is shown in Fig. 1.

(1) Set the network density and knowledge distribution of the supply chain network.

(2) Each subject determines its own weakest knowledge field and searches for the knowledge sources among the first-level neighbors that satisfy the condition.

(3) Determine knowledge sources and diffuse knowledge according to the rules of diffusion; then innovate knowledge based on the requirement of meeting the innovation conditions.

(4) Repeat (2) and (3) until knowledge stock of subjects in the network does not change any longer, then record the value of each index.

(5) Repeat the experiment after changing the density of the supply chain network.

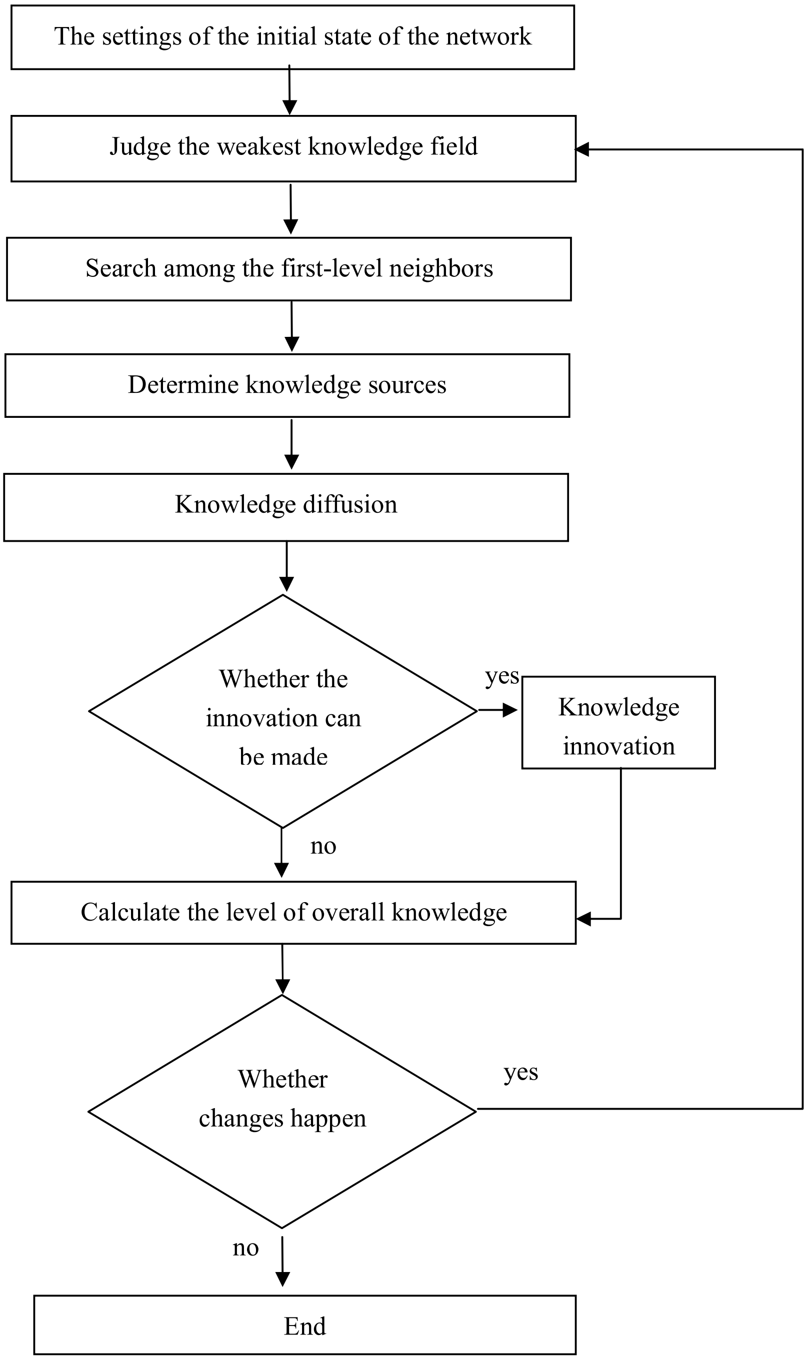

Fig.1 The process of model simulating

3.2 Parameter setting of models

According to the studies of Zhang et al. (2010), Meng et al. (2003), Li et al. (2007); Lin et al. (2012), and Shen et al. (2014), the settings of relevant parameters defined in the models are presented in Tab. 1.

Tab. 1 Parameter setting in models

Name of parameters	Symbol	Set values and descriptions
Number of subjects in the innovation network	N	40
Network density	$netD$	$L/780$, L=25,35,45,…,775
Number of knowledge categories owned by subjects	m	5
Maximum times of the global diffusion of subjects	N_{time}	5
Spillover coefficient	π_1	0.01
Link strength among first-level neighbors	$Link$	1
Minimum knowledge difference meeting absorption conditions	$k_{\min}$	0.7
Proportionality coefficient of the product of diffusion willingness and absorption capacity and link strength	k_1	1
Minimum knowledge stocks required by knowledge innovation	λ_1	0.7
Minimum knowledge diffusion required by knowledge innovation	λ_2	0.2
Innovation coefficient	π_2	1

3.3 Analysis of results

Although the data in each group of experiments varied, most of the data was close to the average value of 10 (see Fig. 2). The Fig. 2 shows that network density and innovation knowledge increments present the cubic relationship; that is, with the increase of network density, innovation knowledge increment firstly increased, then decreased, and finally increased. In order to further specify the relationship between the two variables, the regression analysis method is used. The linear model, quadratic model and cubic model of knowledge increment and network density are respectively built. Model estimation results are shown in Tab. 2. The significance levels of three models are 0.000, so three models pass the test. However, from the view of explanatory power of the models, the value of R Square continues to increase (i.e., 0.302, 0.615., 0.777), so the explanatory power of cubic model of network density is the strongest. The coefficients of constant term, linear term, quadratic term and cubic term of the regression equations are shown in the Parameter Estimates in the Tab.2. The regression curves corresponding to the three regression models are shown in Fig. 3. It is shown that the knowledge increment of the whole network is relatively low when the network density is extremely low. The increase of network density in a certain range can promote the growth of knowledge level. However, if the network density exceeds a certain threshold (the result of the group test is 0.2), the knowledge increment of the supply chain network decreases with the increase of network density. As the network density continues to increase to a certain value (the value is about 0.6), the knowledge increment of the supply chain network continues to increase with the increase of network density. The above analysis indicates that network density and knowledge increment in the supply chain network present the cubic relationship.

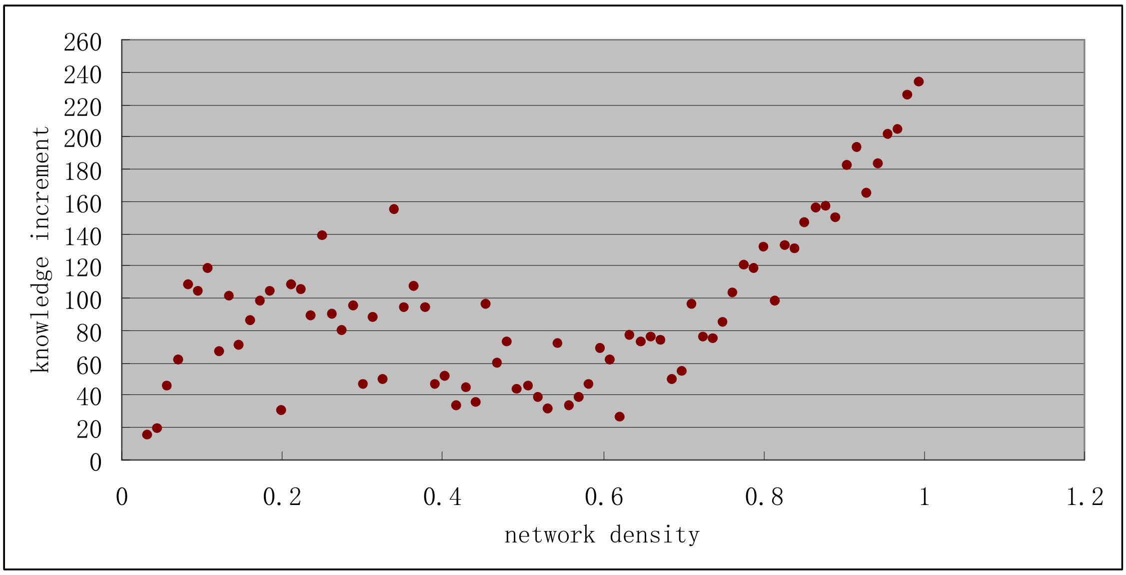

Fig.2 The distribution of knowledge increment at different level of network density

Tab. 2 Model summary and parameter estimates of relationship between network density and knowledge increment

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.302	32.030	1	74	.000	42.969	98.030		
Quadratic	.615	58.207	2	73	.000	115.873	-308.601	396.465	
Cubic	.777	83.754	3	72	.000	44.188	440.647	-1386.212	1158.740

Note: Dependent Variable: knowledge_increment

The independent variable is network_density.

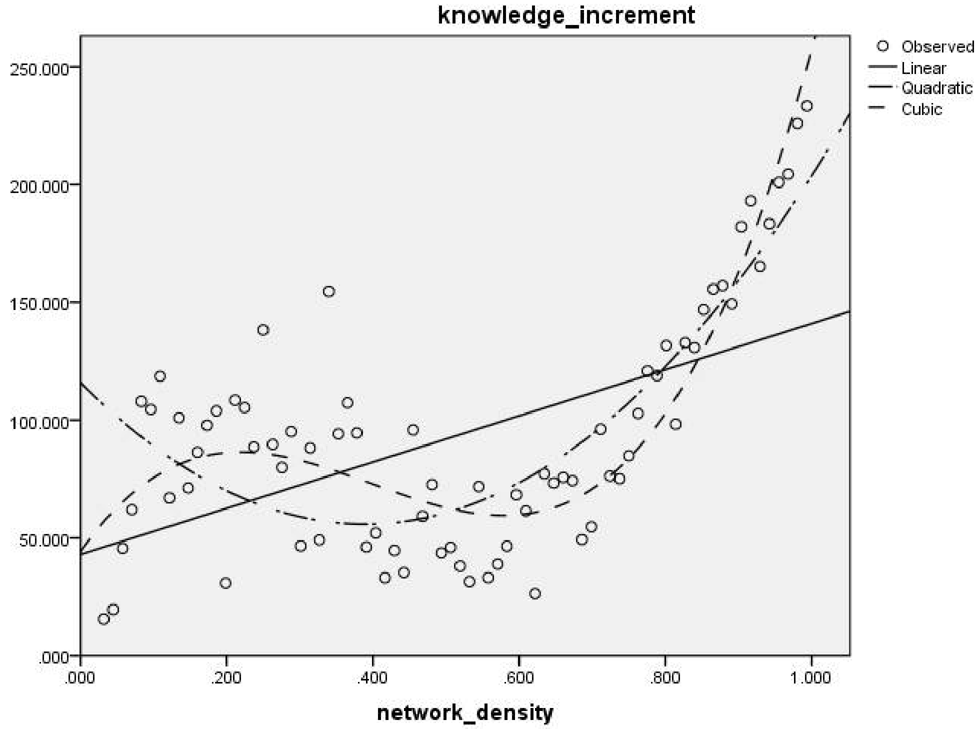

Fig.3 The regression curve of knowledge increment and network density

To further analyze the influence of network density of supply chain network on knowledge innovation, the mean value of each experiment is adopted to draw the graph of relationship between the number of knowledge innovation and network density (as shown in Fig. 4). It can be seen from Fig. 4 that with the increase of the network density, the number of knowledge innovation in the supply chain firstly increased, then decreased, and finally increased. In order to further specify the accuracy of this trend, the regression analysis method is used to test the regression equation between the two variables. The linear model, quadratic model and cubic model are respectively built and the results of model estimation are shown in Tab. 3. The significance levels of three models are 0.000, so three models pass the test. However, from the view of explanatory power of the models, the value of R Square continues to increase (i.e., 0.703, 0.855., 0.915), so the explanatory power of cubic model of network density is the strongest and the value of R Square is 0.915. The coefficients of constant term, linear term, quadratic term and cubic term of the regression equations are shown in the Parameter Estimates in the Tab. 3. The regression curves corresponding to the three regression models are presented in Fig. 5. The results in Fig. 3 indicate that a network density that is high or low has a strong positive effect on the subject of network innovation, which promotes the occurrence of knowledge innovation. Comparing the network density at the maximum times of knowledge innovation in Fig. 5 and maximum knowledge increment in Fig.3 , it shows that they are almost the same. When the density is greater than 0.2, the number of innovations significantly decreases. Because the homogeneity of knowledge becomes increasingly intense, each innovation subject is unwilling to diffuse its knowledge further. Therefore, it hinders knowledge increase. However, when the network density is greater than a certain threshold (e.g., 0.5), knowledge increase is also further enhanced, while the times of knowledge innovation in the network gradually increase. It is because when the network density exceeds 0.5, the link strength of network becomes greater. Under the introduction of the new knowledge of the outside, supply chain network is more likely to produce innovation.

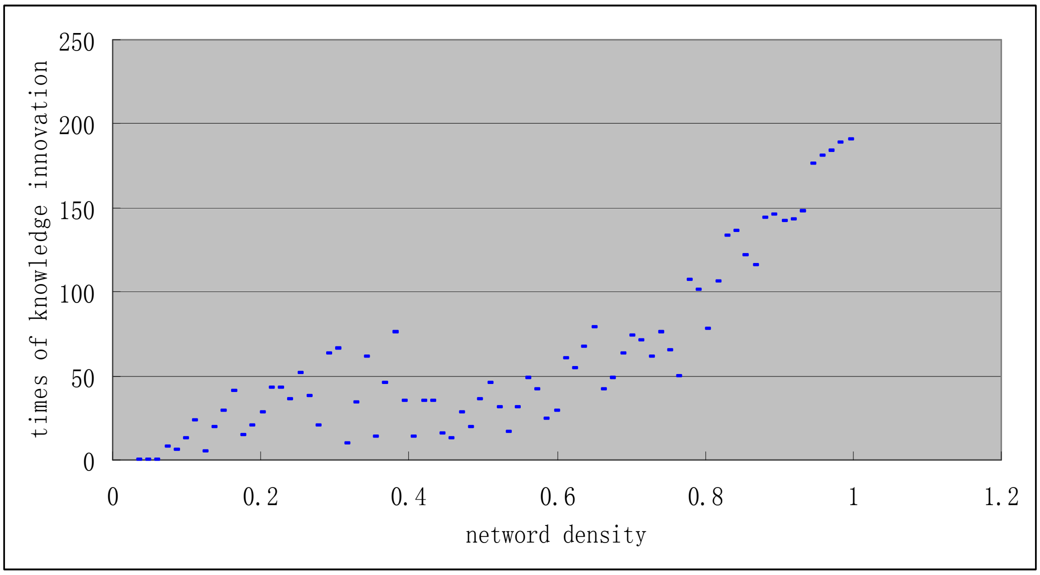

Fig.4 The distribution of times of knowledge innovation at different level of network density

Tab. 3 Model summary and parameter estimates of relationship between network density and times of knowledge innovation

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.703	174.760	1	74	.000	-16.369	151.563		
Quadratic	.855	214.560	2	73	.000	35.193	-136.036	280.409	
Cubic	.915	259.713	3	72	.000	-9.236	328.332	-824.456	718.162

Note: Dependent Variable: times_knowledge_innovation

The independent variable is network_density.

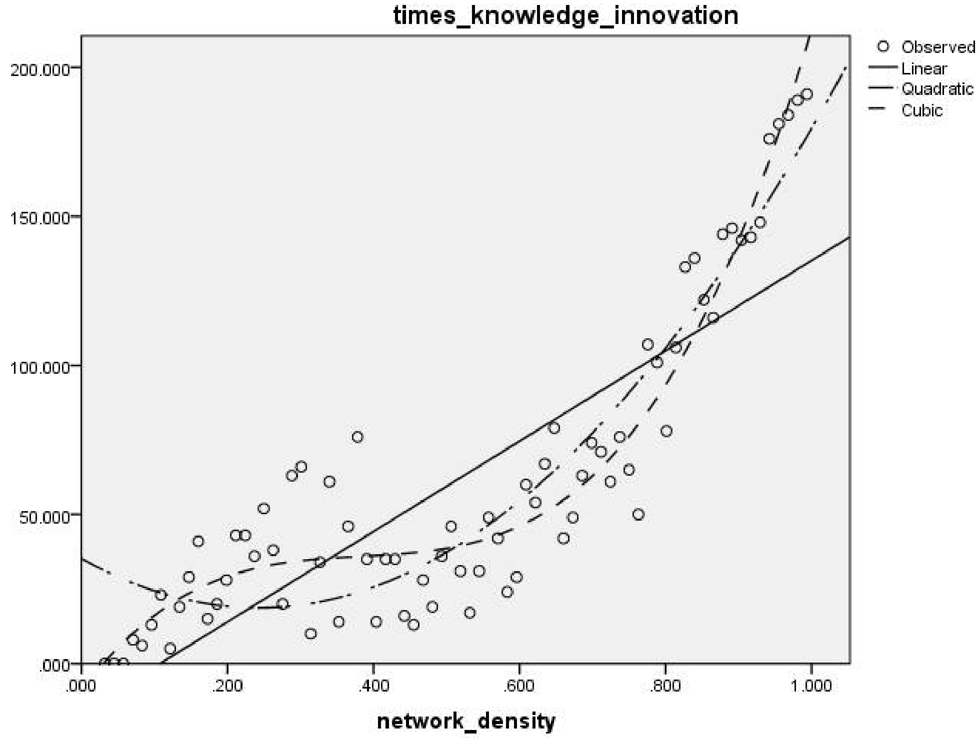

Fig.5 The regression curve of times of knowledge innovation and network density

4. Conclusion, limitations and directions for future research

On the basis of complex network theory and knowledge management theory, the influence of network density on the knowledge increase. of supply chain network was analyzed. Agent-based model and simulation were used to simulate and analyze the process. Our results indicate that the increase of network density is beneficial to knowledge innovation and knowledge diffusion when the entire structure of a whole supply chain network is relatively sparse or dense. At that time, the growth of network density substantially promotes the knowledge increase of the supply chain network. Our findings also show that knowledge growth of the supply chain network will decreases when the network density is in a certain range . It means that the effect of network density on the knowledge increase of supply chain network is nonlinear. A network density that is high or low is conductive to knowledge increase but not the middle value. A cubic relationship between network density and knowledge increase of a supply chain network exists. Furthermore, the most appropriate network densities for knowledge innovation in a supply chain network are equal to those for knowledge increase.

The findings presented here have some suggestions for enterprises. First of all, in order to improve the performance of innovation, the density of supply chain network should continue to increase. Secondly, enterprises in the supply chain network have taken measures, including the harsh management system and technical structure arrangement to mitigate the risk of knowledge leakage. Our research suggests that these actions shouldn’t hinder the sharing and flow of knowledge in supply chain network. Finally, there are still some deficiencies in the process of internal innovation in supply chain network, so it is important for enterprises to strengthen cooperation with the external partners in the field of innovation.

The conclusions of this research have important significance for the sustainable development of supply chain. The conclusion of most previous studies tends to encourage supply chain network to keep moderate degree of concentration. However, with the consideration of difficult for the sample acquisition, these studies did not analyze all cases of the network density which can increase to 1. After the analysis along this line of thoughts, we have found that the relation between network density and innovation would be first positive, then negative, and finally positive. In fact, this paper shows that supply chain with dense structure can obtain the highest innovation. The above research conclusion is of great significance for the choice of innovation strategy for sustainable development of supply chain

The implication of conclusions for the practice is as follows: Firstly, enterprises in edge of supply chain network should be encouraged to actively participate in the innovation cooperation through the combination of external attraction and internal encouragement, thus promoting the continuous growth of relations between network nodes. Secondly, to speed up the knowledge increase of enterprises with low knowledge level, the direct connection relationship in the network should be appropriately increased. Thirdly, it is important to attach great importance to the cultivation of social capital in the network and promote the formal and informal interaction between different enterprises in the network to enhance the trust level. In addition, it should build a shared cognitive system in the network and remove the mutual prevention and suspicion to promote effective collaboration among the enterprises so as to encourage the transfer and sharing of knowledge resources in the network.

Despite these valuable insights, this study has certain limitations, which offer opportunities for future research. First, in the models, it is assumed that the number of the innovative subjects in a supply chain network is fixed without any members joining or exiting. But there are always some enterprises entering or exiting. Second, in this study we focus on how network density affect the knowledge increase. Other factors might affect this relationship as well. For example, the enterprises may differ across industries. Further research could explore how the industries affect the relationship between network density affect the knowledge increase. Third, network density is considered as an important factor in the paper, but other features of network structure can also be considered.

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