Int j simul model 14 (2015) 2, 313-324
ISSN 1726-4529 Original scientific paper

AN AGENT-BASED SIMULATION MODEL FOR SUPPLY CHAIN COLLABORATIVE TECHNOLOGICAL INNOVATION DIFFUSION

Zhang, H. P.
Management & Economics School of North China University of Water Resources and Electric Power, Zhengzhou, 450046, China
E-Mail: zhanghuaping@ncwu.edu.cn

Abstract
Despite the wideness of the literature on technological innovation, the diffusion of the supply chain collaborative technology innovation has not still received much attention. This paper is an attempt to answer the question that how the supply chain collaborative technological innovations emerge and diffuse. An agent-based model of collaborative supply chain technological innovation including the supplier agents, manufacture agents and customer agents is established in this paper, and the simulation experiments are conducted in terms of two kinds of the competitive technology innovation diffusion process under four scenarios. The results show that the supply chain collaborative supply chain technological innovation diffusion is different from the traditional technology innovation diffusion, and the relationship between suppliers and manufacturers has important influence on diffusion speed and efficiency.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: Agent-Based Model, Collaborative Technological Innovation, Supply Chain, China

1. INTRODUCTION

In recent years, technological development becomes more significant to countries as well as enterprises. As the main source and driving force to realize the development of science and technology, technological innovation plays an important role in the strength of technology. Technological innovation is one of the key factors to improve the competitiveness of enterprises. On the one hand, the rapid transmission of information makes it possible for the companies' collaborative technological innovation. In addition, the development of global economy leads to the decrease of the traditional large-scale benefits in industrial production. Therefore, enterprises are facing the changes and challenges for high value-added production. The company can make a higher profit in the competition with high technologies and key technological innovation. In the global knowledge economy, more and more companies are realizing that only high efficiency, high quality, and even flexibility can maintain competitive advantage. Complexity, uncertainty and rapidly changing competitive environment make the innovation particularly important for the survival and development of a company [1]. On the other hand, with the development of information technology and management theory, collaborative technological innovation has become more mature than ever, which makes it much easily to obtain core competitiveness through effective innovation collaboration. The development of information technology leads to the faster communication, flatter organization, virtualization and networking which greatly promote the sharing of knowledge. In addition, due to the applications of the extensive advanced computer equipment and management methods, innovation cycle is significantly shortened [2].

In fact, technological development not only presents as fresh innovation, but also includes technological innovation diffusion. Because of that, the specific innovation can make widely influence in society or industry. As Schumpeter thought, technological innovation has the ability to push the social economy development as the way in cyclicity. Once the most beneficial technological innovation adopted by individual enterprise, the follows will simulate this innovation in order to obtain own interests through diverse technological innovation diffusion. As a result, it promotes the development of economy. However, the influence of technological innovation is limited in economy and social productivity, and with the help of innovation diffusion can these innovations maximize their interests in society and industry. The reasons underlying the technological innovation diffusion have been profoundly studied in the related literature by adopting different theoretical perspective coming from many research streams, namely social sciences, enterprise economy and industrial economy.

Technological innovation diffusion can be defined as the process that the innovation technologies are commercially spread and used among potential users through certain channels. With the diffusion among the outside and inside adopters, the technological innovation can be repeatedly reused and maximize own values to influence social and economic development. The study of innovation diffusion began at the early 20th century. Tarde (1904), who is known as the theorist of “innovation” in social life, thought that a new invention at the source there is something else than just combined imitations of prior inventions. There is the main originality of this combination and come up the S-type (1943) model for better research [3]. Based on that, Fielder (1944) expanded the theory and assumed that science communication was realized through the public media as well as the communication among the core people. Since then, there are many researches focused on the diffusion of the technological innovation. However, literature about supply chain collaborative technology innovation diffusion is relatively scarce, which is the primary motivation of this research.

The paper is organized as follows: The next section is the literature review regarding to the technological innovation, following is the agent-based model of collaborative supply chain technological innovation including the supplier agents, manufacture agents and customer agents. Section 4 describes simulation experiments in terms of two kinds of the competitive technology innovation diffusion process under four scenarios, and then the simulation analysis is discussed by analysing simulation results. Finally, the analysis results and the conclusions are discussed along with the related managerial implications.

2. LITERATURE REVIEW

In this section, the former research about collaboration on technological innovation in supply chain will be discussed progressively in the order of “Innovation-Collaborative innovation-Technological innovation diffusion”.

2.1 Innovation

Innovation has a significant impact on the competitiveness of enterprises. In fact, innovation has become a major social development drive. Since 1912 Schumpeter first proposed the concept of innovation, it has experienced a great development for almost a century. According to Schumpeter, innovation includes new products (Product innovation), the new technology that is new production methods (process innovation), opening up new markets (market innovation), controlling new sources of supply of raw materials (strategic innovation value chain, etc.), and achieving a new industrial organization (organizational innovation). Technological innovation has gradually extended from the innovative concept of a simple product or technology to a more comprehensive overall concept: "from technological innovation to value realization" [4].

Innovation, in a very long period of time, was considered to be an independent, individual concept. It has been stereotyped believed that innovation was the achievement of "individual genius scientist behaviour", but this concept is not widely accepted. In business, innovation is often considered to be completed in a single company [5]. According to Rothwel's division of industrial innovation model and stage of development, technological innovation was also identified "individual, single innovation" in 1940s to 1970s. In this period, innovation management research focuses on an individual innovative organization problem.

2.2 Collaborative innovation

However, innovation is in fact an integrated behaviour. Despite the innovation and scientific discovery are often attributed to individuals, almost every technological breakthrough is based on the contributions of many others much more than individual creativity [6-8].

For enterprises, the complexity of the process and product innovation has been greatly enhanced since 1980s. At the same time, the organization also has a higher demand for innovation performance [9, 10]. Traditional single innovation theory and methods cannot effectively adapt to the environment, because the concept of integration and cooperation in integrated innovation consciousness gradually accepted by enterprises. According to technological innovation and integration of different objects, integrated innovation can be divided into innovative elements integration and innovative body integration, the content of the former include technology integration, combination innovation, enterprise internal systems integration etc. The innovative body integration, which refers to inter-firm knowledge / technology sharing and joint innovation exchange, is the major form today.

After the 1980s, the most significant sign for collaborative innovation is the formation and development of strategic alliances based on core technology in the next generation [11]. Interdisciplinary generated between the different disciplines (such as raw biotechnology in the chemical, pharmaceutical, food processing industry) is the outcome of integrated innovation.

Meanwhile, since the scientific and technological knowledge are owned by a large number of dispersed individuals or enterprises. In order to collaboration, dependent organizations have to cooperate, exchange and influence with each other [12-14].

Baumol [15] summarized inter-organizational innovations into two forms: joint research institutions and knowledge exchange alliance. Von illustrated an empirical study of the iron & steel companies in the United States and found out that 10 out of 11 mini-mills with the highest productivity were frequently exchanging of technical knowledge. Another example is provided by the new equipment technology alliance and encourages technology transfer, the Italian tradition of small enterprises' successful cooperation between the regions to stimulate the competitiveness [16].

2.3 Technological innovation diffusion

The collaboration of the supply chain can promote the business performance of members take part in the collaboration process [17, 18]. Many of the researches for the supply chain collaboration focused on information sharing, inventory forecasting and control [19], improvement of operational process between enterprises [20], and scenario analysis [6] et al. In recent years, the concern has grown about the performance promotion through supply chain collaborative technological innovation [21, 22]. The main benefits of technology innovation among the members in supply chain are better new product development, higher quality improvement and more cost reduction [23].

The types of enterprises may affect the innovation performance. For the high-tech industry, a good supply chain relationship with the downstream companies has positive impact on the new product development process and can reduce the transaction costs [7]. The research by Rowley et al. found out that flexible collaborative innovation was successful in semiconductor industry supply chain, while the stable form is preferable in the iron &steel industry [24]. Motohashi [25] argued that collaborative innovation performance was better in small business than in large enterprises. However, according to the research of Rose and Allen, there was not linear relationship between the size of the organization and the performance of innovation.

As discussed, the early stage of technological innovation diffusion researches are considered from the perspective of communication theory and limited by specific products.

Based on the above thinking, many different notions and models about technological innovation diffusion have been developed. These are typed as 3 steps. In the 60s the majority of research on this topic has focus on mathematical model and most of the studies have adapted the fitting of time series to forecast the explanatory variable. The most representative of these research is the Bass model, which of the diffusion of innovation has become the forecasting the sales growth of new products and technologies and been termed an empirical generalization [26]. With the introduction of time series variables into nonlinear diffusion models, issues involving the potential for "spurious regression," that have been extensively examined in time series econometrics studies in the context of linear models, arise for nonlinear models as well. To answer questions like these new theoretical approaches and methodologies are needed. The two nonlinear diffusion models based on Bass model, the Generalized Bass Model (GBM) and the Cox proportional hazard model (PHW) have been partly examined the character of the explanatory variables.

According to the above research, the early researches have mostly accepted experience, experimental proof and mathematical modelling analysis method to confirm their studies. In the present study, however, with the use of computer simulation, multi-agent makes a new study of multiple competitive (or complementary) technology innovation diffusion system. An agent-based simulation modelling defined as a collection of heterogeneous, intelligent, and interaction agents, which simulates the real environment. The main uses of agent-based simulation are: tested for new ideas, prediction of the impact of a new technology, development of new theory, decision-making aids, what-if training tools, conduct of critical experiments, and hypotheses generators. Thus, agent-based simulation modelling is a bottom-up approach to understanding the systems' detail, which provides a powerful tool for analysing complex, non-linear markets [27].

As a result, multi-agent is accepted by the study of technological innovation diffusion. Many marketing studies have focus on how new technology is perceived by consumers, which is represented by their daily behaviours and reactions to technological innovation. For example, IT use is the result of goodness of fit between the technological innovation and people's lives. This in turn is influenced by complex structures and multi-agent [28]. One of the recent developments in the field of heterogeneous diffusion modelling can also be seen in the multi-agent diffusion modelling, from which individuals are considered as an independent agent that exhibits unique characteristics and make decision depending on their own wills [29]. Moreover, the research of agent-based modelling (ABM) covered the area in emerging market, especially when data for empirical work is limited, non-existent, or prohibitively expensive to gather. Agent-based modelling does not replace empirical work, but means to clarify past research and develop early theory so that if data becomes available, empirical work can be sharp and quickly come up convictive theoretical guidance [30].

3. AN AGENT-BASED MODEL

Three agents and the corresponding decision behaviours are considered in this paper, which includes: manufacture agent, supplier agent and consumer agent. The behaviour models and decision rules are different among these agents. The agent-based simulation model of supply chain collaborative technological innovation consists of two parts: society environment and the technological innovation product.

The technological innovation product refers to the external environment of the agents. The agents are affected by the external environment, and the external environment in turn is influenced by the agents. Society environment includes technology innovation diffusion driving force and multi-agent system. In the multi-agent system, the agent can change the state of the technological innovation utilization because of the technology innovation diffusion driving force. The technology innovation diffusion driving force is divided in external driving force which includes the size of the market, competitors' behaviour, consumer behaviour, etc. and internal driving force which includes scale, preference, conformity, utility and coordinated ability, technological innovation ability.

In this agent-based simulation model, the technological innovation is finished by the collaboration of the supplier agent and the manufacture agent. So it is assumed supplier agent can't finish the technological innovation process individually. In addition, the supply chain collaborative technological innovation can only be adopted by the other supply chain instead of a single company.

The detailed assumptions are as follows:

(1) The adoption of supply chain collaborative technological innovation is not repeatable, which means that once the innovation is adopted, it is applied to the practical production. So it is impossible for the secondary use. While the buying behaviour of the consumers can repeat, this means that the consumers can buy multiple productions.

(2) There is no capital constraint in the supply chain, which means that once the effectiveness of technological innovation reaches the given threshold, it is adopted.

(3) There is capital constrain for the consumer, and they buy the products with the best technological innovations considering the funding permits.

(4) There is no supply constrain for all the agents.

(5) No delay for knowing the latest technological innovation product.

(6) The products spread along with the diffusion of technology innovation, and the diffusion of technology innovation in turn depends on the products.

3.1 Correspondence of technological innovation

In this model, there are mainly three kinds of agents: manufacturers, suppliers and consumers. Suppliers are responsible for supplying the row materials or half-finished products. Manufacturers are responsible for designing and producing different products. Consumers evaluate and purchase these products. Every product is composed of several design parameters. And as commodities, the performance parameters of the products can bring utilities to consumers. The design parameter space (DPS) can reflect the technological innovation from the perspective of the manufacturers. While to the customers, the technological innovation is reflected thorough performance parameter space (PPS). The correspondence from DPS to PPS is dealt with by using Kauffman's NK model. The agent-based model indicates that an innovation in technology is the result of both constructional selection and environmental selection.

The set of manufacture agents can be denoted as:

$$M = \{M_1, M_2, \ldots, M_r\} \tag{1}$$

The set of supplier agents can be denoted as:

$$S = \{S_1, S_2, \ldots, S_t\} \tag{2}$$

The set of consumer agents can be denoted as:

$$C = \{C_1, C_2, \ldots, C_s\} \tag{3}$$

In every time step, manufacture M_i ($i = 1, 2, \ldots, r$) will produce L_i types of products.

Let $\tilde{A}_i$ indicates the types of the products of manufacture i, then：

$$\tilde{A}_i = \{A_i^1, A_i^2, \ldots, A_i^{L_i}\} \tag{4}$$

In each time period, supplier S_j ($j = 1, 2, \ldots, t$) will provide Q_j types of products or row materials. Let $\tilde{B}_j$ indicates the types of the products or raw materials of supplier j, then:

$$\tilde{B}_j = \{B_j^1, B_j^2, \ldots, B_j^{Q_j}\} \tag{5}$$

The NK model is used to illustrate the correspondence from DPS to PPS because it explicitly shows the epispastic structure of the genotype–phenol type map. In the NK model, N represents the number of genes in a haploid chromosome and K represents the number of linkages that each gene has to other genes in the same chromosome. The traditional NK model can be described as the following:

The genome consists of N genes (design parameters) that exert control over U phenotypic performance parameters, each of which contributes a component to the total fitness (performance). Each gene controls a subset of the U performance parameters, and in turn, each performance parameter is controlled by a subset of the N genes. This genotype–phenotype map can be represented by a matrix:

$$M = \left(m_{ij}\right)_{N\times U},\ i = 1, 2, \ldots, N, j = 1, 2, \ldots, U \tag{6}$$

of indices $m_{ij} \in \{0, 1\}$, where $m_{ij} = 1$ indicates that gene i affects performance parameter j. M is randomly initialized in the simulation. M will be static unless the DPS or PPS changes.

The columns of M, called the polygeny vectors, $q_j = \left(m_{ij}\right)_{N\times 1}$ ($i = 1, 2, \ldots, N$), give the genes controlling each performance parameter j.

The rows of M, called the pleiotropy vectors, $q_j = \left(m_{ij}\right)_{1\times U}$ ($j = 1, 2, \ldots, U$), give the performance parameters controlled by each gene i.

If any of the genes controlling a given performance parameter mutates, the new value of the performance parameter will be uncorrelated with the old. Each performance parameter is a uniform pseudo-random function of the genotype, $x \in \{0, 1\}^N$.

$$f_i = f(x \odot q_i\,;\, i, q_i) \sim \text{uniform on } [0, 1] \tag{7}$$

where:

$$f: \{0, 1\}^N \times \{1, 2, \ldots, N\} \times \{0, 1\}^N \rightarrow [0, 1] \tag{8}$$

Here $\odot$ is the Schur product.

$$x \odot q_i = (x_i m_{ij})_{N\times 1},\ i = 1, 2, \ldots, N \tag{9}$$

Any change in i, q_i, or $x \odot q_i$ gives a new value for $f(x \odot q_i\,;\, i, q_i)$ that is uncorrelated with the old.

If a performance parameter is affected by no genes, it is assumed to be zero.

$$f_i = 0,\ \text{if } q_i = (0, 0, \ldots, 0) \tag{10}$$

Total fitness is defined as the normalized sum of the performance parameters:

$$FC = \frac{1}{U}\sum_{i=1}^{U} f_i \tag{11}$$

3.2 Decision rules of manufacture agents

The manufacture agents are the leading promoter of the technological innovation diffusion.

Manufacture agents need to make the decisions of whether to adopt the technological innovation, and the main factors affecting the decisions of the manufacture agents are conformity, preferences, and technical innovation ability.

(1) Conformity

When the manufacture agent makes the decision of whether to adopt the technological innovation, it will be affected by the other manufacture agents. If other manufacture agents adopt one kind of technological innovation and benefit from it, the manufacture agents are trend to adopt it, and vice versa.

In this model, a two-dimensional space is used to imitate the real market. The two-dimensional space is divided into grids of $n \times n$, we call each grid "cellular". There are eight neighbouring cellular for each cellular, which is called "neighbour". In the simulation, manufacture agent is affected by the eight neighbours while making decisions.

The utility function illustrating the affect of the surrounding neighbours is:

$$U_I = I_i \times I_j \tag{12}$$

where I_i represents the affect coefficient of the manufacture agent i, $i \in M$, and I_j represents the influence strength of manufacture agent j to manufacture agent i:

$$I_j = \begin{cases} 1, x_j \ge h \\ 0, x_j < h \end{cases}. \tag{13}$$

where:

$$x_j = \frac{n_j}{8}. \tag{14}$$

n_j is the number of the neighbours of manufacture agent j which adopt the technological innovation.

(2) Preference

In this model, the preference of manufacture agent refers to the attitude of the manufacture agent to the risk of the technological innovation adoption. It is assumed that the preference of manufacture agent i follows the normal distribution with the mean value of μ_i and variance value of σ_i^2, and let R_i represents the preference of manufacture agent i, then:

$$R_i \sim N[\mu_i, \sigma_i^2] \tag{15}$$

(3) Technological innovation ability

The technological innovation ability of manufacture agent refers to the basis of the manufacture agent. Considering the differences of transformation ability, collaborative ability, enterprise scale, enterprise resources and enterprise culture, etc., they may result in the differences of the technological innovation abilities among the manufacture agents.

3.3 Decision rules of supplier agents

The supplier agents can't proceed the technological innovation by themselves, but they can affect the decisions of the manufacture agents. The influence of supplier agent is decided by the enterprise scale, market share and coordination ability of the supply agent. For example, the supplier with higher market share has a stronger effect to the manufacture.

In the agent-based simulation model of supply chain collaborative technological innovation, there is a close interaction between the suppliers and manufacturers. Let α_{ij} ($i = 1, 2, \ldots, r$, $j = 1, 2, \ldots, t$) represents the interaction strength between the suppliers and manufacturers, then:

$$\alpha_{ij} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \cdots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \cdots & \alpha_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{n1} & \alpha_{n2} & \cdots & \alpha_{nn} \end{bmatrix} \tag{16}$$

where the matrix α_{ij} reflects the internal structure of the interaction among the agents.

3.4 Desicion rules of consumer agents

Product is the carrier of technology innovation. Consumers are the final buyers and users of products. Therefore, the purchasing behaviour of customer agents has important effects on the diffusion process of technology innovation.

A consumer's purchasing behaviour can be simply described as: he/she evaluates several types of products, and select one whose utility is the biggest for him/her among those types evaluated by him/her. Now the problem is to model how consumers evaluate products. The weighted average method is considered in this paper.

In weighted average method, for any consumer C_i ($i = 1, 2, \ldots, s$), its weights for different performance parameters can be denoted as:

$$W_{C_i} = \{W_{1C_i}, W_{2C_i}, \cdots, W_{UC_i}\},\ i = 1, 2, \ldots, s \tag{17}$$

subject to

$$\begin{cases} w_{iC_j} \in [0,1], i = 1, 2, \cdots, U, \\ \sum_{i=1}^{U} w_{iC_j} = 1. \end{cases} \tag{18}$$

A consumer's evaluation for a type of product is:

$$E = \sum_{i=1}^{U} w_i f_i \tag{19}$$

Every consumer will select the product which has the biggest E for him/her among those products evaluated by him/her.

4. SIMULATION PROCESS AND RESULTS

4.1 Model parameter setting

Simulation is conducted by considering 30 agents, where 6 manufacturers, 8 suppliers and 16 consumers. The simulation space is 8×8. In simulation experiment, the parameters of multi-agent technology innovation diffusion model are set. Consider four different scenarios simulation experiment, each scenario of specific parameter values as shown in the following Table I.

Table I: The parameters in four scenarios.

Parameter	Value in scenario 1	Value in scenario 2	Value in scenario 3	Value in scenario 4	Explanation
U_{min}	Uniform (0, 1)	Uniform (0, 1)	Uniform (0, 1)	Uniform (0, 1)	Adopt utility thresholds of technological innovation
Adopters1	Uniform (0, 3)	Uniform (0, 6)	Uniform (0, 3)	Uniform (0, 6)	The number of adopters of technological innovation 1
Adopters2	Uniform (0, 3)	Uniform (0, 6)	Uniform (0, 3)	Uniform (0, 6)	The number of adopters of technological innovation 2
AdEffect1	Uniform (0.5, 1.5)	Uniform (0.5, 1.5)	Uniform (0.3, 1.5)	Uniform (0.3, 1)	Technological innovation effect coefficient of 1 to 2
AdEffect2	Uniform (0.5, 1.5)	Uniform (0.5, 1.5)	Uniform (0.3, 1.5)	Uniform (0.3, 1)	Technological innovation effect coefficient of 2 to 1
L_i	2	2	2	2	Total number of types of technological innovation, $i = 1, 2, \ldots, r$
I_i	Uniform (0, 1)	Uniform (0, 1)	Uniform (0, 1)	Uniform (0, 1)	The conformity of the manufacture, $i = 1, 2, \ldots, r$
h	0.3	0.3	0.6	0.6	Threshold of the manufacture affected by the neighbours

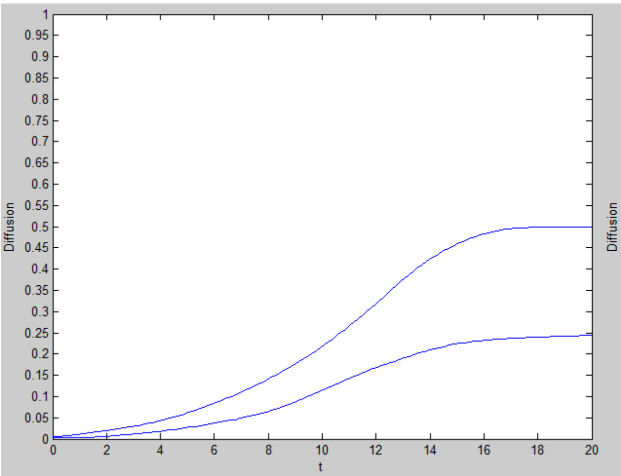
Table II illustrates the affect matrix of suppliers to manufactures.

Table II: The affect matrix of suppliers to manufactures.

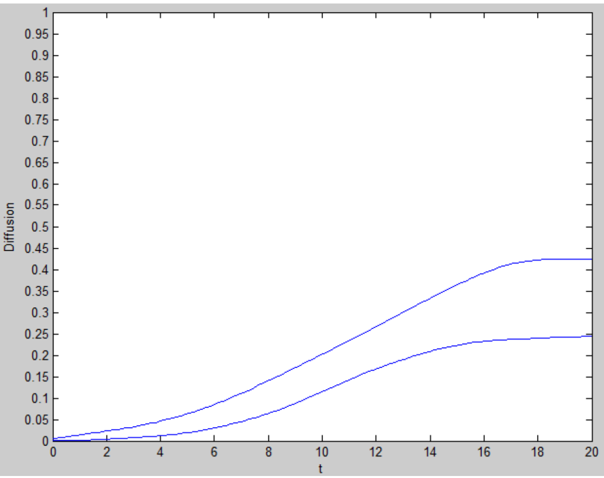
Suppliers	**Manufactures**					
	M_1	M_2	M_3	M_4	M_5	M_6
S_1	0.81	0.96	0.42	0.68	0.28	0.44
S_2	0.91	0.96	0.92	0.76	0.05	0.38
S_3	0.13	0.16	0.79	0.74	0.10	0.77
S_4	0.91	0.97	0.96	0.39	0.82	0.80
S_5	0.63	0.96	0.66	0.66	0.69	0.19
S_6	0.10	0.49	0.04	0.17	0.32	0.49
S_7	0.28	0.80	0.85	0.71	0.95	0.45
S_8	0.55	0.14	0.93	0.03	0.03	0.65

4.2 Analysis of the results

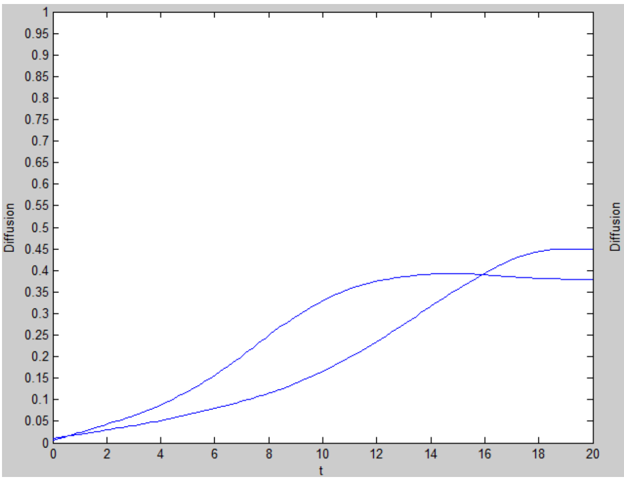
The simulation experiments in terms of two kinds of the competitive technology innovation diffusion process are done in this paper. One technological innovation is alternative to the other, which means that the increase of one technological innovation diffusion will result in the decrease of the other one. In practice, there are generally two results for the two kinds of the competitive technology innovation diffusion processes: one of them monopolized the market or both of them share the market half by half.



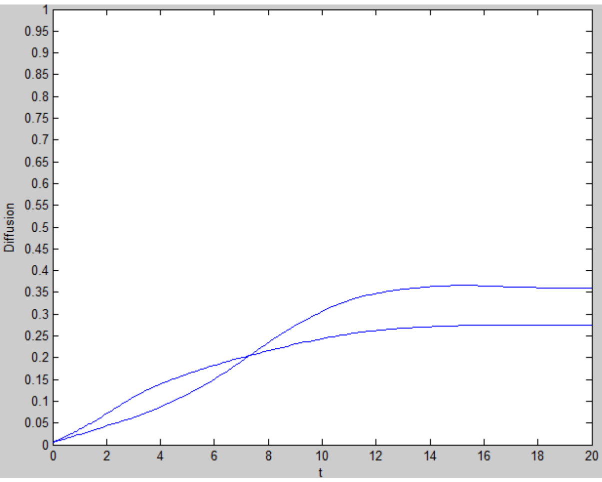
a) Simulation result of scenario 1



b) Simulation result of scenario 2



c) Simulation result of scenario 3



d) Simulation result of scenario 4

Figure 1: Simulation results of the diffusion under the four scenarios.

It is can be seen from the results that: the first technological innovation is always in a leading position, and finally occupies a larger share in the market in the scenario 1 and scenario 2.While in scenario 3, the second technological innovation surpasses the first technological innovation after the sixteenth iteration, and surpasses the first technological innovation after the seventh iteration in scenario 4.

5. CONCLUSIONS

This paper attempts to investigate the diffusion process of the supply chain collaborative technological innovation to provide practical insight and guidelines for the technological innovation in China. An agent-based model of collaborative supply chain technological innovation including the supplier agents, manufacture agents and customer agents is established in this paper, and the simulation experiments in terms of two kinds of the competitive technology innovation diffusion process under four scenarios are done.

When the manufacture is going to make the collaborative technological innovation with the suppliers in the supply chain, it is essential to do the related research about the competitive innovations in the current market, and find out the diffusion path, which could help the manufacture to launch or adopt a technological innovation at the right time.

When the company is going to promote a new product or technology, it should not only consider the advertising investment, but also synthesize each kind of situation and affect factors. Only in this way, the company could become competitive, even at the later stage of the diffusion process. In addition, the supply chain collaborative supply chain technological innovation diffusion is different from the traditional technology innovation diffusion, because the relationship between suppliers and manufacturers has important influence on diffusion speed and efficiency. Therefore, it is essential to improve the coordination among the supply chain companies to better promote the supply chain collaborative technological innovation diffusion.

REFERENCES

[1] Christy, D. P.; Grout, J. R. (1994). Safeguarding supply chain relationships, *International Journal of Production Economics*, Vol. 36, No. 3, 233-242, doi:10.1016/0925-5273(94)00024-7

[2] Davenport, T. H.; Prusak, L. (1993). Blow up the corporate library, *International Journal of Information Management*, Vol. 13, No. 6, 405-412, doi:10.1016/0268-4012(93)90057-B

[3] Michaelides, P. G.; Theologou, K. (2010). Tarde's influence on Schumpeter: technology and social evolution, *International Journal of Social Economics*, Vol. 37, No. 5, 361-373, doi:10.1108/03068291011038945

[4] Salerno, M. S.; de Vasconcelos Gomes, L. A.; da Silva, D. O.; Bagno, R. B.; Freitas, S. L. T. U. (2015). Innovation processes: Which process for which project?, *Technovation*, Vol. 35, 59-70, doi:10.1016/j.technovation.2014.07.012

[5] Recker, J.; Mendling, J.; Hahn, C. (2013). How collaborative technology supports cognitive processes in collaborative process modelling: A capabilities-gains-outcome model, *Information systems*, Vol. 38, No. 8, 1031-1045, doi:10.1016/j.is.2013.04.001

[6] Rendón-Sagardi, M. A.; Sánchez-Ramírez, C.; Cortás-Robles, G.; Alor-Hernández, G.; Moncayo-Martínez. L. A. (2014). Dynamic evaluation of production policies: Improving the coordination of an ethanol supply chain, *Journal of Applied Research and Technology*, Vol. 12, No. 4, 724-733, doi:10.1016/S1665-6423(14)70089-6

[7] Eng, T.-Y.; Wong, V. (2006). Governance mechanisms and relationship productivity in vertical coordination for new product development, *Technovation*, Vol. 26, No. 7, 761-769, doi:10.1016/j.technovation.2004.10.015

[8] Ouyang, X.; Guo, F.; Shan, D.; Yu, H.; Wang, J. (2015). Development of the integrated fuzzy analytical hierarchy process with multidimensional scaling in selection of natural wastewater

treatment alternatives, *Ecological Engineering*, Vol. 74, 438-447, doi:10.1016/j.ecoleng.2014.11.006

[9] Bougrain, F.; Haudeville, B. (2002). Innovation, collaboration and SMEs internal research capacities, *Research Policy*, Vol. 31, No. 5, 735-747, doi:10.1016/S0048-7333(01)00144-5

[10] Loof, H.; Heshmati, A. (2006). On the relationship between innovation and performance: A sensitivity analysis, *Economics of Innovation & New Technology*, Vol. 15, No. 4-5, 317-344, doi:10.1080/10438590500512810

[11] Kuo, Y.-C.; Lua, S.-T.; Tzeng, G.-H.; Lin, Y.-C.; Huang, Y.-S. (2013). Using fuzzy integral approach to enhance site selection assessment – a case study of the optoelectronics industry, *Procedia Computer Science*, Vol. 17, 306-313, doi:10.1016/j.procs.2013.05.040

[12] Tabas, J.; Beranova, M. (2014). Innovations effect in the company's value, *Procedia Economics and Finance*, Vol. 12, 695-701, doi:10.1016/S2212-5671(14)00395-5

[13] Dewangan, V.; Godse, M. (2014). Towards a holistic enterprise innovation performance measurement system, *Technovation*, Vol. 34, No. 9, 536-545, doi:10.1016/j.technovation.2014.04.002

[14] Hassanzadeh, F.; Collan, M.; Modarres, M. (2012). A practical R&D selection model using fuzzy pay-off method, *The International Journal of Advanced Manufacturing Technology*, Vol. 58, No. 1-4, 227-236, doi:10.1007/s00170-011-3364-9

[15] Baumol, W. J. (2001). When is inter-firm coordination beneficial? The case of innovation, *International Journal of Industrial Organization*, Vol. 19, No. 5, 727-737, doi:10.1016/S0167-7187(00)00091-6

[16] Tsai, K.-H.; Hsu, T. T. (2014). Cross-functional collaboration, competitive intensity, knowledge integration mechanisms, and new product performance: A mediated moderation model, *Industrial Marketing Management*, Vol. 43, No. 2, 293-303, doi:10.1016/j.indmarman.2013.08.012

[17] Santoso, L. A.; Indrayadi, Y.; Pratama, A. T. (2015). Optimizing inventory control at PT. Total Pack Indonesia by using kanban system, *Journal of System and Management Sciences*, Vol. 5, No. 1, 52-66

[18] Jian, Z.; Zhou, Y. (2015). Corporate social capital, market orientation, organizational learning and service innovation performance: An empirical survey in the Pearl river delta of China, *Journal of Industrial Engineering and Management*, Vol. 8, No. 2, 303-321, doi:10.3926/jiem.1318

[19] Cedillo-Campos, M.; Sánchez-Ramírez, C. (2013). Dynamic self-assessment of supply chains performance: an emerging market approach, *Journal of Applied Research and Technology*, Vol. 11, No. 3, 338-347, doi:10.1016/S1665-6423(13)71544-X

[20] Simatupang, T. G.; Sridharan, R. (2005). An integrative framework for supply chain collaboration, *The International Journal of Logistics Management*, Vol. 16, No. 2, 257-274, doi:10.1108/09574090510634548

[21] Schilling, M. A.; Phelps, C. C. (2007). Interfirm collaboration networks: The impact of large-scale network structure on firm innovation, *Management Science*, Vol. 53, No. 7, 1113-1126, doi:10.1287/mnsc.1060.0624

[22] Herguera, I.; Lutz, S. (2003). The effect of subsidies to product innovation on international competition, *Economics of Innovation & New Technology*, Vol. 12, No. 5,465-480, doi:10.1080/1043859031000078461

[23] Irwin, D. A.; Klenow, P. J. (1996). High-tech R&D subsidies – Estimating the effects of Sematech, *Journal of International Economics*, Vol. 40, No. 3-4, 323-344, doi:10.1016/0022-1996(95)01408-X

[24] Rowley, T.; Behrens, D.; Krackhardt, D. (2000). Redundant governance structures: an analysis of structural and relational embeddedness in the steel and semiconductor industries, *Strategic Management Journal*, Vol. 21, No. 3, 369-386, doi:10.1002/(SICI)1097-0266(200003)21:3<369::AID-SMJ93>3.0.CO;2-M

[25] Motohashi, K. (2005). University-industry collaborations in Japan: The role of new technology-based firms in transforming the National Innovation System, *Research Policy*, Vol. 34, No. 5, 583-594, doi:10.1016/j.respol.2005.03.001

[26] Bass, F. M.; Srinivasan, S. (2002). A study of spurious regression and model discrimination in the generalized bass model, Franses, P. H.; Montgomery, A. L. (Eds.), *Advances in Econometrics*

(Econometric Models in Marketing), Vol. 16, Emerald Group Publishing Limited, Bingley, 295-315

[27] Twomey, P.; Cadman, R. (2002). Agent-based modelling of customer behaviour in the telecoms and media markets, *Info – The Journal of Policy, Regulation and Strategy for Telecommunications, Information and Media*, Vol. 4, No. 1, 56-63, doi:10.1108/14636690210426640

[28] MacVaugh, J.; Schiavone, F. (2010). Limits to the diffusion of innovation: A literature review and integrative model, *European Journal of Innovation Management*, Vol. 13, No. 2, 197-221, doi:10.1108/14601061011040258

[29] Shi, X.; Chumnumpan, P.; Fernandes, K. (2014).A diffusion model for service products, *Journal of Services Marketing*, Vol. 28, No. 4, 331-341, doi:10.1108/JSM-11-2012-0224

[30] de Lange, D. E. (2012). Emerging market research opportunities with agent-based simulations, Wang, C. L.; Ketchen, D. J.; Bergh, D. D. (Eds.), *West Meets East: Toward Methodological Exchange (Research Methodology in Strategy and Management)*, Vol. 7, Emerald Group Publishing Limited, Bingley, 183-212, doi:10.1108/S1479-8387(2012)0000007010