

## System Dynamics of Firm's Knowledge Creation under SECI

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*Abstract: A 'storm eye' model for firm's knowledge creation was constructed from SECI knowledge spiral, and then its system dynamic expressing, training and simulation was carried out. The simulation results showed that firms could effectively absorb external knowledge and conduct an internal knowledge conversion cycle in a good environment, which would result in a huge knowledge creation storm. However, the knowledge creation storm might weaken or even die out when the environment was deteriorated, or the stock of firm's knowledge declined, and or firm's knowledge transformation ability dropped. The results implied that a knowledge creation firm could be to maintain excellence only by improving its ability of knowledge absorption and conversion and preventing its knowledge from loss.*

*Keywords: Knowledge creation; Knowledge storm; System dynamics.*

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### 1. INTRODUCTION

As we all known, China is in a critical period of development transformation, and the real subject of the development transformation is the firms. But how can our firms decide to finally complete their development transformation in such mixed circumstances of many risks and temptations? As Nonaka & Takeuchi (1995) said, there are many factors to influence the success of firms, and too many factors will make the firms lost in it and cannot extricate themselves. In this case, the two scholars suggest that knowledge is the ultimate resource to obtain competitive advantages, and knowledge creation is the primary factor to help firms to achieve the excellence, therefore, a pursuit of firms should and must be to create knowledge, and eventually become a "knowledge-creation firm".

Now the key problem is how the firms to create knowledge. Nonaka & Takeuchi (1995) constructed the firm's knowledge- creating SECI framework, based on the experience of Japanese firms' innovation transformation, and demonstrated the principle and mechanism that firms can create new knowledge through the mutual conversion between tacit knowledge and explicit knowledge. They provide firms a concept model to create knowledge. However, it is the short board that SECI framework is only a qualitative concept model, and the two scholars mainly use the method of case analysis to demonstrate the SECI framework, while failing to convert it into an automatically dynamic model.

Based on the above background, this paper intends to use the storm generation principle to make the SECI knowledge spiral system reconstruct a system dynamics model which is similar to the “storm eye” model for knowledge creation, and by training the model, it can dynamically simulate the firm’s knowledge creation mechanism. This paper will help for the improvement of SECI framework from the black box type mode of qualitative concept to the mathematical model which can see the internal structure and make the model work, thus interpreting the firm’s knowledge creation mechanism in a subtler level.

This paper organizes the rest of parts as follows: the second part is relevant research in the knowledge creation and system dynamics model related literature review. The third part is a ‘storm eye’ model for firm’s knowledge creation based on SECI knowledge spiral. The fourth part is the system dynamic expressing of firm’s knowledge creation model. The fifth part is the simulation of firm’s knowledge- creation model. The sixth part is conclusions and inspirations.

## **2. OVERVIEW OF STUDIES**

For the value of knowledge, the academic circles have reached a consensus that knowledge is the most important intangible asset of firms, rooted in and scattered around all aspects of the firm’s organization system, and is difficult to imitate and has social complexity, which can bring sustainable competitive advantage for firms. Compared to the knowledge, mainstream firms believe that the more important resource is the ability of using knowledge effectively, particularly using existing knowledge to create new knowledge. Therefore, how to improve the firm’s ability of knowledge creation has become an important issue concerned by the academia.

Early research on knowledge creation pays more attention to the source of knowledge and the state of knowledge, but later research pays more attention to the condition of knowledge creation (Alavi & Leidner, 2001). Yang Yan and Shanxing Gao (2011) suggest that the conditions of driving firms to do knowledge creation can be divided into two aspects of external and internal. Zhang Lijun (2006) and Zhang Yuanyuan, Zongyi Zhang (2009) found that external conditions include infrastructures, market demands, labor quality, financial conditions, entrepreneurship levels and so on. Hu Mingyong and Jizhong Zhou (2001) show that the funding of government for private sectors has certain influence on technological innovation. Zhang Yan and Tao Wang (2012) think institutional environment is the important foundation of activities to promote innovation, and the external institutional environment can not only help to absorb external knowledge but also help to create internal knowledge. Rao Ynagde and Xuejun Wang (2006) show that innovative culture, incentive mechanism and social capital have an important influence to improve the innovation ability. Wang Jiancheng and Yunshi Mao (2007) found that internal conditions include entrepreneurship, creative employees, knowledge base, organizational structure and so on. Qing Shilaing (2004), Jiang Junfeng (2008), Niu Panqiang (2001) show that knowledge base influences the process and the essence of firm’s innovation, has an impact on the construction of innovation system. Han

Zhihui and Nan Li (2004) think organization strategy, organization structure, knowledge, technology, organizational culture and organizational mechanism affect the organization to access, create and apply knowledge. Hao Yinchao (2007) confirmed that there is significant positive correlation among working team support, challenging work, work resources and knowledge creation activities. Zhu Chunyan (2010) proposed that organizational culture is the driving force for the knowledge management of organization, and the supportive organizational culture and sharing organizational culture have a positive influence on knowledge management of organization. Chen Jianxun (2010) suggest social interaction can promote the knowledge process of socialization and combination, and standard can promote knowledge externalization process, while shared vision can promote the knowledge internalization process. Wang Yi and Guisheng Wu (2005) think the interaction of shadow system and legitimate system decides the firm's creativity.

In recent years, the application of system dynamics in the study of knowledge management is increasing. He Xiaolan and Xianyu Wang (2012) proposed to divide the management tasks of organization tacit knowledge into three parts to design system dynamics model, simulating and analyzing the causal and feedback relationship among various factors, and put forward several measures to enhance the efficiency of the tacit knowledge management. Wang Yunmei and Yuan Liu (2009) use the system dynamics method to analyze internal and external support subsystem of organization knowledge creation to explore the influence factors of organization knowledge creation and its operating mechanism, provide the referenced results. Yang Gang and Huifeng Xue (2009) use the system dynamics method to analyze the causal relationship of knowledge transfer within college team, show that can better fit the actual process of knowledge transfer within the team, and can provide similar knowledge transfer process with effective decision support. Wang Xiuhong and Yuan Liu (2006) build a system dynamics model of the main body of tacit knowledge conversion, describing the influence of various factors on the firm's knowledge stocks from the quantitative point. Wang Xin and Bing Sun (2012) construct the system dynamics model of knowledge transfer within the enterprise, and analyze the causality of firm's internal knowledge transfer, which provide the theoretical basis for firms to make effective strategies of knowledge transfer.

As is universally acknowledged, the modern society is a society of knowledge explosion, and new knowledge continue to generate, faster and faster. But there are few researches to systematically investigate and draw the dynamic path of social knowledge creation from the angle of knowledge explosion, and that is the subject what this paper will to explore.

### **3. A 'STORM EYE' MODE OF FIRM'S KNOWLEDGE CREATION UNDER SECI**

#### **3.1 The framework of SECI knowledge system**

In the book of "the knowledge-creating company", Nonaka & Takeuchi (1995) argue that the new knowledge is created by the mutual conversion between tacit knowledge and explicit knowledge, use the SECI knowledge spiral model to vividly describe the continuously dynamic process of new knowledge creation. The name of the SECI model is derived from the

four kinds of transformation process between tacit knowledge and explicit knowledge, and among them, “S” refers to the socialization process of tacit knowledge spreading from organization to individuals, “E” refers to the externalization process of transforming tacit knowledge into explicit knowledge, “C” refers to the combination process of integrating a series of explicit knowledge, “I” refers to the internalization process of transforming explicit knowledge into tacit knowledge again. The above four types of process are connected and associated each other, constituting a spiral circulation for firms to create new knowledge. (See fig.1).

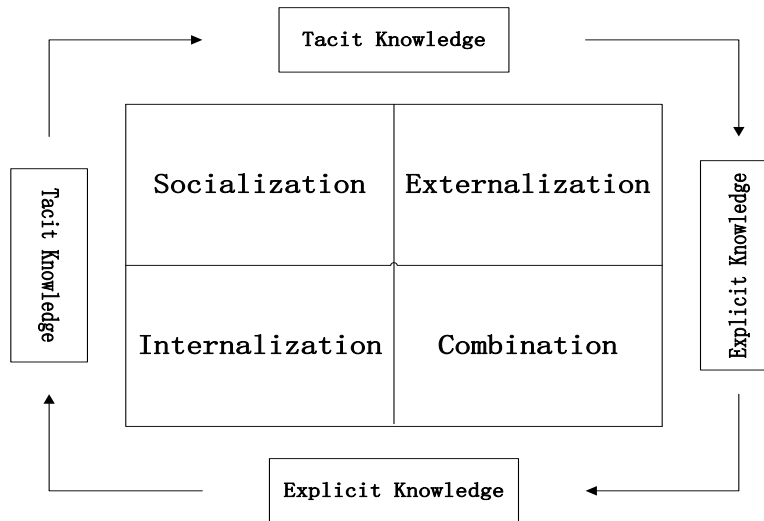


Fig 1. The framework and transformation process of SECI knowledge system

### 3.2 A ‘storm eye’ model for firm’s knowledge creation

For the SECI knowledge spiral system, we can use the storm creation concept to systematically describe the inner running mechanism. Reviewing the development process of the storm, there are three decisive factors: a huge supply of vapor-the seawater, a huge source of energy-the solar radiation, a smooth and vast space-the sea surface. Similarly, firm’s knowledge creation process also needs the three main factors. The first one is the large stock of knowledge, the second one is the strong power of knowledge transformation, and the third one is the open environments to facilitate knowledge transformation. On this basis, we build a ‘storm eye’ model for firm’s knowledge creation. (See fig.2).

In the figure 2, we can know the three main factors respectively to as: the four types of knowledge in the outer ring representing the firm’s stock of knowledge, the four types of transformation among the socialization, externalization, combination and internalization representing the firm’s power of knowledge transformation, and the smooth connections among four types of knowledge, four types of process and new knowledge representing the environment space of knowledge transformation. The operating principles are as follows: the four types of knowledge transform mutually through the four processes, creating the new knowledge; the new generation knowledge is back to four types of knowledge, to participate in the next round of knowledge transformation process; as a perpetual cycle; as a perpetual cycle, there will be more and more new generation knowledge, more and more knowledge stocks and the power of knowledge transformation will be stronger, and eventually form a supersize new

knowledge storm. In addition, the external knowledge base (in figure 2) is also an important source of firm's knowledge stock, and with the continuous strengthening of new knowledge storm, the knowledge in external knowledge base will flow to the firm at an accelerating pace. However, if the firm's knowledge stocks fell sharply, or the power of knowledge transformation was weakened greatly, or the contact with the external knowledge base was interrupted, the generation process of firm's new knowledge will be reversed and eventually grind to a halt. (See fig.3).

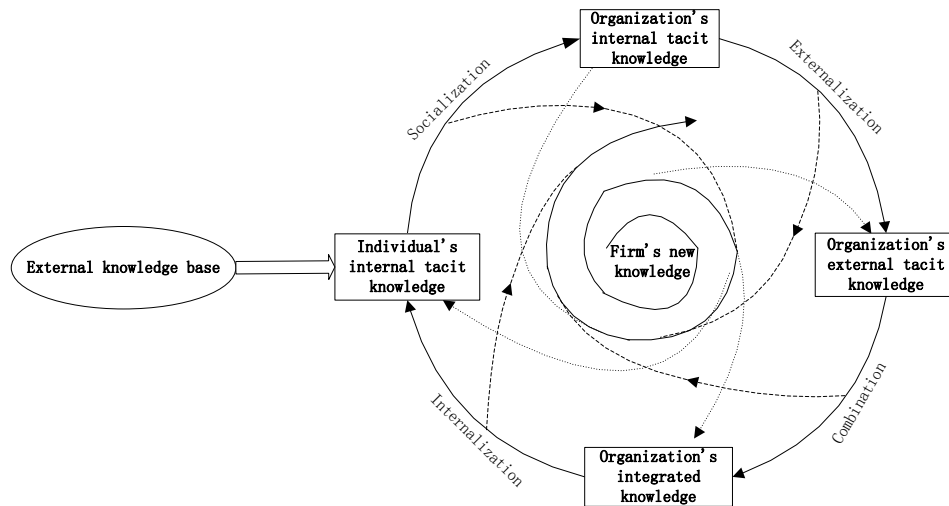


Fig 2. A 'storm eye' model for firm's knowledge creation

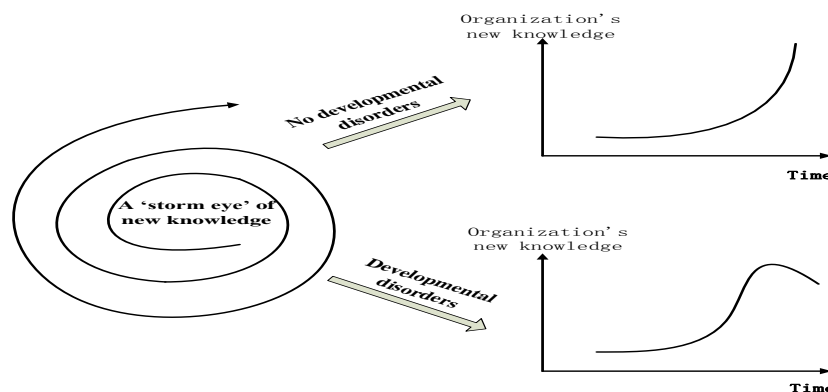


Fig 3. The evolution of the knowledge generation process

#### 4. SYSTEM DYNAMICS EXPRESSING OF FIRM'S KNOWLEDGE CREATION MODEL

In order to simulate the model of firm's knowledge creation in figure 2, the model must be transformed into system dynamic model first. This is the system dynamics expressing of firm's knowledge creation model. (See fig.4). For the meaning of acronyms, see the see the appendix I.

In the figure 4, the four kinds of transformation process of four types of knowledge among the socialization, externalization, combination and internalization, are promoted respectively by socialization multiplier, externalization multiplier, combination multiplier and internalization multiplier and are restrained respectively by socialization friction coefficient, externalization

friction coefficient, combination friction coefficient and internalization friction coefficient. In order to reflect the knowledge flow between organization and environment, we add five variables in the model of figure 4 respectively to be as the external knowledge acquisition rate, individual's internal tacit knowledge loss rate, organization's internal tacit knowledge loss rate, organization's external tacit knowledge loss rate, organization's integrated knowledge loss rate. For the quantitative relationships of the variables, see the appendix II.

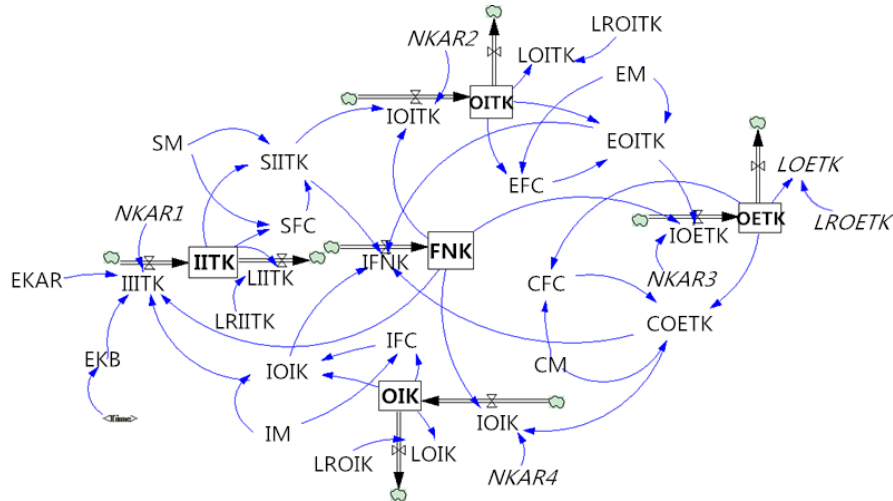


Fig 4. System dynamics expressing of firm's knowledge creation model

## 5. SYSTEM DYNAMICS SIMULATION OF FIRM'S KNOWLEDGE CREATION MODEL

### 5.1 Model training

To check the simulation results of the model in the figure 4, we can use the representative firm's real data for model training. Because of the trade secrets and data availability, national data can be used to the model training. So we choose the real data from 2002 to 2011 in our country to the model training respectively to be as using the international patent applications to agent for the stock of external knowledge (Source: China Statistical Yearbook from 2002 to 2011), using the level of education and the age structure of firm's employees to agent for the individual's internal tacit knowledge (Source: China Labor Statistical Yearbook from 2002 to 2011), using the number of enterprise organization and its size to agent for the organization's internal tacit knowledge (Source: China Statistical Yearbook from 2002 to 2011), using the number of firm's vocational training to agent for the organization's external tacit knowledge (Source: China Labor Statistical Yearbook from 2002 to 2011), using the number of firm's new products, R&D projects and staff number to agent for the organization's integrated knowledge (Source: Science and Technology of China from 2002 to 2011), using the number of firm's patent grants to agent for the firm's new knowledge (Source: China Statistical Yearbook from 2002 to 2011). For the agency relationships of the stable variables, see the appendix III.

For the exogenous variables in the model, we give them an initial value as follows:

1. The domain of definition of socialization multiplier, externalization multiplier, combination multiplier and internalization multiplier are  $[0, 1]$ , and the initial value is set to 0.5.

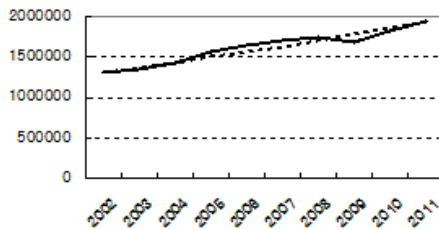
2. The domain of definition of individual's internal tacit knowledge loss rate, organization's internal tacit knowledge loss rate, organization's external tacit knowledge loss rate and organization's integrated knowledge loss rate is  $[0, 1]$ , and the initial value is set to 0, representing no loss.

3. The domain of definition of new knowledge allocation rate 1 to 4 is  $[0, 1]$ , and the initial value is set to 0.5, because the sum of four rates is 1.

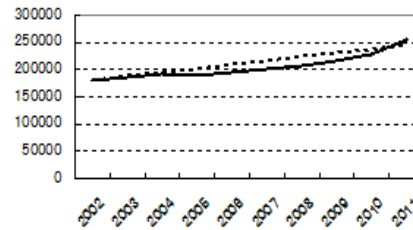
4. The domain of definition of external knowledge acquisition rate is  $[0, 1]$ , and the initial value is set to 0.001, because of the universality of external knowledge.

According to the data, we use the six stable variables of the stock of external knowledge, individual's internal tacit knowledge, organization's internal tacit knowledge, organization's external tacit knowledge, organization's integrated knowledge and organization's new knowledge for system dynamics simulation training. When the simulation values sufficiently reach the real values, the training is over. There are the final simulation results of six stable variables. (See fig.5).

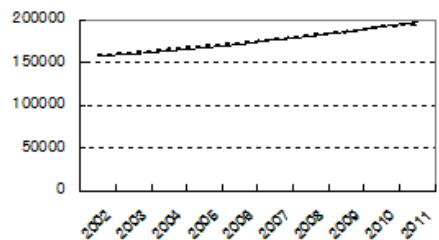
The stock of external knowledge stock



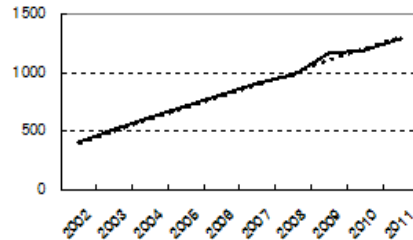
the individual's internal tacit knowledge



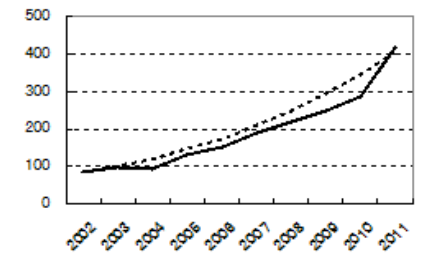
The organization's internal tacit knowledge



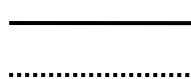
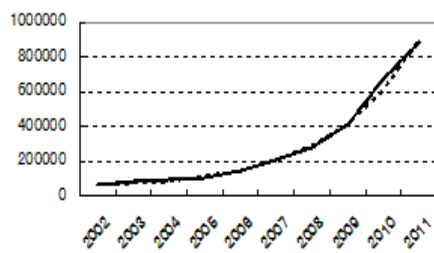
the organization's external tacit knowledge



The organization's integrated knowledge



the organization's new knowledge



The real values

The simulation values

Fig 5. The final simulation results of six stable variables

As we can see in the figure 5, the simulation values of six stable variables (dotted lines in the figure 5) have sufficiently reached the real values (solid lines in the figure 5). That is to say, the model has resulted in high fit degree, and we can do the next simulations.

### 5.2 The formation process simulation of firm’s knowledge creation storm

When the firm has a large stock of knowledge, powerful abilities of knowledge transformation and a good environment of knowledge conversion, the four types of knowledge of individual's internal tacit knowledge, organization's internal tacit knowledge, organization's external tacit knowledge and organization's integrated knowledge can be converted into each other through the four processes of socialization, externalization, combination and internalization, creating organization's new knowledge. Then the organization's new knowledge participated in the next round of knowledge conversion process back to the four types of knowledge. In such circulation, organization's new knowledge will show explosive growth.

Using the trained model of firm’s knowledge creation in the figure 5, we simulate the process of firm’s knowledge creation and get the generated trajectory. (See figure 6a). It is an evolution path of firm’s knowledge creation with no developmental disorders.

By mathematical fitting the growth curve of firm’s knowledge creation, we can get the mathematical expression as follow:

$$y = 44821e^{0.4855t} \tag{1}$$

In the formula of (1), organization's new knowledge(y) is exploding in the form of exponential, and unit time (t) growth rate is close to 50%. If the firm has one unit of new knowledge in 2002, basing on its relative growth rate, there will be 3300 unit of new knowledge. That is to say, the new knowledge expanded 10 times in the 20 years. This is no doubt an explosion.

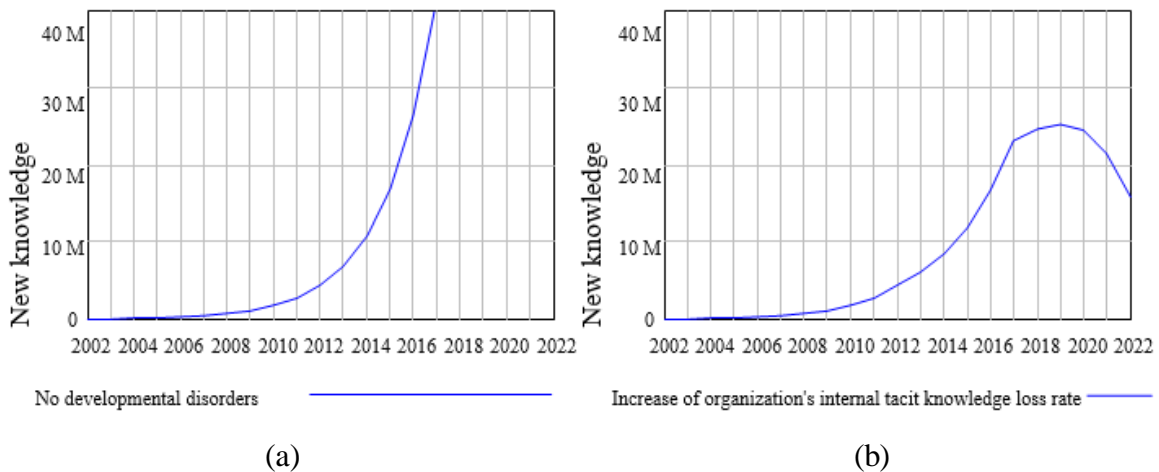


Fig. 6a the simulation of firm’s knowledge creation storm Fig. 6b the decline of the stock of firm’s knowledge leads to the dissipation of knowledge creation storm



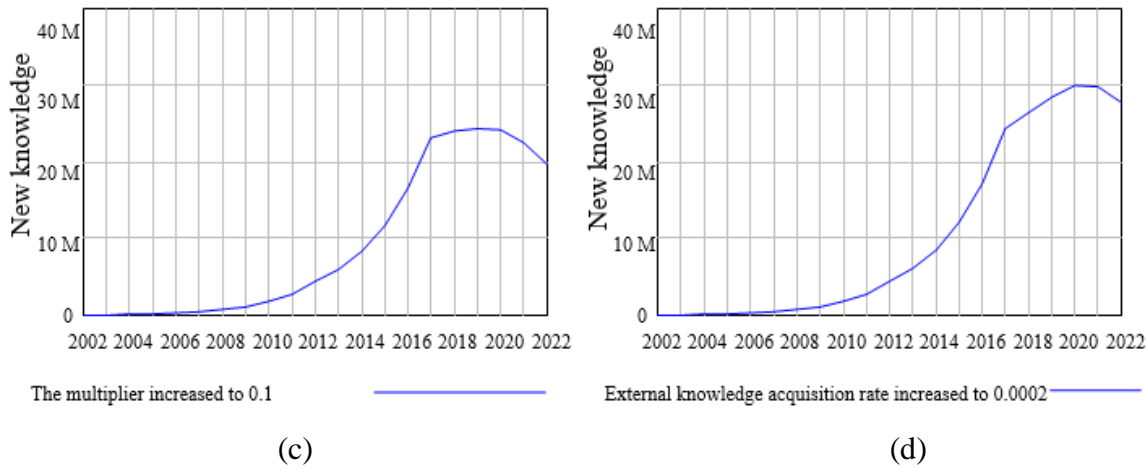


Fig. 6c the weakening of abilities of knowledge transformation leads to the dissipation of knowledge creation storm

Fig. 6d the obstacles of the contact between firm and external knowledge base lead to the

### 5.3 The dissipation process simulation of firm’s knowledge creation storm

The graphs in Figure 3 show that the process of new knowledge creation will go into reverse and grind to a halt finally when the firm encounter developmental disorders. The developmental disorders mainly include the decline of the stock of firm’s knowledge, the weakening of abilities of knowledge transformation and the obstacles of the contact between firm and external knowledge base. Here are the three scenarios to simulate the dissipation process of knowledge creation storm.

### 5.4 The decline of the stock of firm’s knowledge leads to the dissipation of knowledge creation storm

The stock of firm’s knowledge is the sum of individual's internal tacit knowledge, organization's internal tacit knowledge, organization's external tacit knowledge and organization's integrated knowledge. The increase of stock of firm’s knowledge can promote the four new knowledge transformations, creating more new knowledge. On the contrary, the decline of stock of firm’s knowledge can restrain the four new knowledge transformations, blocking the new knowledge creation.

The decline of stock of firm’s knowledge can use the increase of four types of knowledge loss rate to express. In order to simulate the blocking effect of the decline of firm’s knowledge stock on knowledge creation, we increase the loss rate at the four points. Based on the graph 6a, we increase the knowledge loss rate 0.1 unit every three years, respectively in 2012, 2015, 2018 and 2021, and finally make the four types of knowledge loose rate increase from 0 to 0.4. The step formulas are as follows:

$$\text{Individual's internal tacit knowledge loss rate} = 0 + \text{STEP}(0.1, 2012) + \text{STEP}(0.1, 2015) + \text{STEP}(0.1, 2018) + \text{STEP}(0.1, 2021)$$

$$\text{Organization's internal tacit knowledge loss rate} = 0 + \text{STEP}(0.1, 2012) + \text{STEP}(0.1, 2015) + \text{STEP}(0.1, 2018) + \text{STEP}(0.1, 2021)$$

Organization's external tacit knowledge loss rate =  $0 + \text{STEP}(0.1, 2012) + \text{STEP}(0.1, 2015) + \text{STEP}(0.1, 2018) + \text{STEP}(0.1, 2021)$

Organization's integrated knowledge loss rate =  $0 + \text{STEP}(0.1, 2012) + \text{STEP}(0.1, 2015) + \text{STEP}(0.1, 2018) + \text{STEP}(0.1, 2021)$

In this case, the graph 6a evolves into graph 6b. As you can see in the graph 6b, with the increase of four types of knowledge loose rate, the growth of firm's new knowledge is suppressed. It reaches the peak in 2019. Then start to decline rapidly, and grind to a halt finally.

### **5.5 The weakening of abilities of knowledge transformation leads to the dissipation of knowledge creation storm**

The firm's abilities of knowledge transformation are mainly depending on the four types of multipliers respectively to be as socialization multiplier, externalization multiplier, combination multiplier and internalization multiplier. The increase of four types of multipliers can promote the four new knowledge transformations, creating more new knowledge. On the contrary, the decline of four types of multipliers can restrain the four new knowledge transformations, blocking the new knowledge creation.

The weakening of abilities of knowledge transformation can use the decline of four types of multipliers to express. In order to simulate the blocking effect of the weakening of abilities of knowledge transformation, we decline the multipliers at the four points. Based on the graph 6a, we decline the multipliers 0.1 unit every three years, respectively in 2012, 2015, 2018 and 2021, and finally make the four types of multipliers decline from 0.5 to 0.1. The step formulas are as follows:

Socialization multiplier =  $0.5 - \text{STEP}(0.1, 2012) - \text{STEP}(0.1, 2015) - \text{STEP}(0.1, 2018) - \text{STEP}(0.1, 2021)$

Externalization multiplier =  $0.5 - \text{STEP}(0.1, 2012) - \text{STEP}(0.1, 2015) - \text{STEP}(0.1, 2018) - \text{STEP}(0.1, 2021)$

Combination multiplier =  $0.5 - \text{STEP}(0.1, 2012) - \text{STEP}(0.1, 2015) - \text{STEP}(0.1, 2018) - \text{STEP}(0.1, 2021)$

Internalization multiplier =  $0.5 - \text{STEP}(0.1, 2012) - \text{STEP}(0.1, 2015) - \text{STEP}(0.1, 2018) - \text{STEP}(0.1, 2021)$

In this case, the graph 6a evolves into graph 6c. As you can see in the graph 6c, with the decline of four types of multipliers, the growth of firm's new knowledge is suppressed. It reaches the peak in 2019. Then start to decline rapidly, and grind to a halt finally.

### **5.6 The obstacles of the contact between firm and external knowledge base lead to the dissipation of knowledge creation storm**

The contact between firm and external knowledge base is mainly expressed by the external knowledge acquisition rate. The increase of external knowledge acquisition rate can promote the four new knowledge transformations, creating more new knowledge. On the contrary, the decline of external knowledge acquisition rate can restrain the four new knowledge transformations, blocking the new knowledge creation.

The obstacles of the contact between firm and external knowledge base can use the decline of external knowledge acquisition rate to express. In order to simulate the blocking effect of the obstacles of the contact between firm and external knowledge base, we decline the external knowledge acquisition rate at the four points. Based on the graph 6a, we decline the external knowledge acquisition rate 0.0002 unit every three years, respectively in 2012, 2015, 2018 and 2021, and finally make the external knowledge acquisition rate decline from 0.001 to 0.0002. The step formulas are as follows:

External knowledge acquisition rate = 0.001 - STEP (0.0002, 2012) - STEP (0.0002, 2015) - STEP (0.0002, 2018) - STEP (0.0002, 2021)

In this case, the graph 6a evolves into graph 6d. As you can see in the graph 6d, with the decline of external knowledge acquisition rate, the growth of firm's new knowledge is suppressed. It reaches the peak in 2020. Then start to decline rapidly, and grind to a halt finally.

## 6. CONCLUSION AND ENLIGHTENMENT

A 'storm eye' model for firm's knowledge creation was constructed from SECI knowledge spiral and storm creation concept, and its system dynamic expressing was carried out. Then we use the empirical data from 2002 to 2011 to construct the model, use the trained model to simulate the firm's knowledge creation mechanism. The research contents and results were listed as follows:

1. When the firm has a large stock of knowledge, powerful abilities of knowledge transformation and a good environment of knowledge conversion, they can absorb more and more external knowledge and conduct a positive feedback loop of internal knowledge conversion strongly, creating more and more new knowledge. Finally, there will be an explosive growth trend.

2. When the firm shows knowledge stock declines, or internal knowledge conversion power weakening, or external knowledge absorption blocked, firm's knowledge creation will be reversed and grind to a halt, making the knowledge creation storm weaken or even die out.

The results implied that a knowledge creation company could be to maintain excellence only by improving its ability of knowledge absorption and conversion and preventing its knowledge loss from brain drain or technology spillovers.

In the future, we can make deep sensitivity analysis for the key influence factors of firm's knowledge creation, providing more accurate quantifiable results for the research of firm's knowledge creation mechanism.

## 7. THE MEANING OF ACRONYMS IN THE FIGURE 4

IITK= individual's internal tacit knowledge

OITK=organization's internal tacit knowledge

OETK=organization's external tacit knowledge

OIK=organization's integrated knowledge

FNK= firm's new knowledge

IIITK =the increments of individual's internal tacit knowledge  
IOITK=the increments of organization's internal tacit knowledge  
IOETK the increments of organization's external tacit knowledge  
IOIK the increments of organization's integrated knowledge  
IFNK=the increments of firm's new knowledge  
LIITK= the loss of individual's internal tacit knowledge  
LOITK= the loss of organization's internal tacit knowledge  
LOETK=the loss of organization's external tacit knowledge  
LOIK=the loss of organization's integrated knowledge loss rate  
LRIITK= the loss of individual's internal tacit knowledge  
LROITK= the loss of organization's internal tacit knowledge  
LROETK=the loss of organization's external tacit knowledge  
LROIK=the loss of organization's integrated knowledge loss rate  
SIITK=the socialization of individual's internal tacit knowledge  
SM=socialization multiplier  
SFC=socialization friction coefficient  
EOITK=the externalization of organization's internal tacit knowledge  
EM=externalization multiplier  
EFC=externalization friction coefficient  
COETK=the combination of organization's external tacit knowledge  
CM=combination multiplier  
CFC=combination friction coefficient  
IOIK=the internalization of organization's integrated knowledge  
IM=internalization multiplier  
IFC=internalization friction coefficient  
EKAR=the external knowledge acquisition rate  
NKAR=the new knowledge allocation rate

## **8. THE QUANTITATIVE RELATIONSHIPS OF THE VARIABLES IN THE FIGURE 4**

### **8.1 The formulas of stable variables**

Individual's internal tacit knowledge=INTEG 【the increments of individual's internal tacit knowledge - the loss of individual's internal tacit knowledge】

Organization's internal tacit knowledge=INTEG 【the increments of organization's internal tacit knowledge - the loss of organization's internal tacit knowledge】

Organization's external tacit knowledge=INTEG 【the increments of organization's external tacit knowledge - the loss of organization's external tacit knowledge】

Organization's integrated knowledge=INTEG 【the increments of organization's integrated knowledge - the loss of organization's integrated knowledge】

Firm's new knowledge = INTEG 【the increments of firm's new knowledge】

### 8.2 The formulas of rate variables

The increments of individual's internal tacit knowledge = DELAY1 【the internalization of organization's integrated knowledge + firm's new knowledge × new knowledge allocation rate1 + stock of external knowledge × external knowledge acquisition rate, 1】

The increments of organization's internal tacit knowledge = DELAY2 【the socialization of individual's internal tacit knowledge + firm's new knowledge × new knowledge allocation rate2, 2】

The increments of organization's external tacit knowledge = DELAY3 【the externalization of organization's internal tacit knowledge + firm's new knowledge × new knowledge allocation rate3, 2】

The increments of organization's integrated knowledge = DELAY4 【the combination of organization's external tacit knowledge + firm's new knowledge × new knowledge allocation rate 4, 0.5】

The increments of firm's new knowledge = the socialization of individual's internal tacit knowledge + the externalization of organization's internal tacit knowledge + the combination of organization's external tacit knowledge + the internalization of organization's integrated knowledge

The loss of individual's internal tacit knowledge = individual's internal tacit knowledge × individual's internal tacit knowledge loss rate

The loss of organization's internal tacit knowledge = organization's internal tacit knowledge × organization's internal tacit knowledge loss rate

The loss of organization's external tacit knowledge = organization's external tacit knowledge × organization's external tacit knowledge loss rate

The loss of organization's integrated knowledge loss rate = organization's integrated knowledge × organization's integrated knowledge loss rate

### 8.3 The formulas of assistant variables

The socialization of individual's internal tacit knowledge = individual's internal tacit knowledge × socialization multiplier × (1 - socialization friction coefficient 2)

The externalization of organization's internal tacit knowledge = organization's internal tacit knowledge × externalization multiplier × (1 - externalization friction coefficient 2)

The combination of organization's external tacit knowledge = organization's external tacit knowledge × combination multiplier × (1 - combination friction coefficient 2)

The internalization of organization's integrated knowledge = organization's integrated knowledge × internalization multiplier × (1 - internalization friction coefficient 2)

Socialization friction coefficient =  $(1 - \text{socialization multiplier})^2 \times \text{EXP}(A \times \text{LN}(\text{IF THEN ELSE}(\text{individual's internal tacit knowledge} \leq 0, 1, \text{individual's internal tacit knowledge})))$

Externalization friction coefficient =  $(1 - \text{externalization multiplier})^2 \times \text{EXP}(A \times \text{LN}(\text{IF THEN ELSE}(\text{organization's internal tacit knowledge} \leq 0, 1, \text{organization's internal tacit knowledge})))$

Combination friction coefficient =  $(1 - \text{combination multiplier})^2 \times \text{EXP}(A \times \text{LN}(\text{IF THEN ELSE}(\text{organization's external tacit knowledge} \leq 0, 1, \text{organization's external tacit knowledge})))$

Internalization friction coefficient =  $(1 - \text{internalization multiplier})^2 \times \text{EXP}(A \times \text{LN}(\text{IF THEN ELSE}(\text{organization's integrated knowledge} \leq 0, 1, \text{organization's integrated knowledge})))$

The stock of external knowledge =  $a \times \text{EXP}(b \times \text{Time})$

### 9. THE AGENCY RELATIONSHIPS OF THE STABLE VARIABLES IN THE FIGURE 5

1. The stock of external knowledge = the international patent applications (unit: piece)

2. Individual's internal tacit knowledge =  $\alpha \times A \times \beta^i$  (unit: million)

$A = \{a_{ij}\}$ : The Education level of national employment divided by age group;

$a_{ij}$ : The number of employed persons in age group  $i$  and in degree  $j$  (unit: million);

$i$  ( $i=1, 2, \dots, 11$ ): The 11 age groups of employed persons (from young to old: 16-19, 20-24, ;25-29, 30-34, 35-39岁, 40-44, 45-49岁, 50-54岁, 55-59, 60-64, over 65);

$j$  ( $j=1, 2, \dots, 7$ ): The 7 kinds of education level of employed persons (from low to high: no education, primary school, junior high school, high school, college, undergraduate, graduate and above);

$\alpha = (1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9 \ 10 \ 11)$ : The weight of 11 age groups of employed persons;

$\beta = (2^0 \ 2^1 \ 2^2 \ 2^3 \ 2^4 \ 2^5 \ 2^6)$ : The weight of 7 kinds of education level of employed persons.

3. Organization's internal tacit knowledge =  $B \times \gamma^T \times \bar{x}$  (unit: million)

$B = \{b_{ij}\}$ : The firm's scales and structures;

$b_{ij}$ : The number of firms in year  $i$  and in scale  $j$ ;

$i$  ( $i=1, 2, \dots, 10$ ): The 10 years (from early to late: 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011);

$j$  ( $j=1, 2, 3$ ): The 3 scales of firms (from small to big: small business, middle scale enterprises, large enterprises);

$\gamma = (2^0 \ 2^2 \ 2^4)$ : The weight of firm's scales;

$\bar{x}$ : The Average number of all firm's employees (unit: million).

4. Organization's external tacit knowledge = the number of firm's vocational training (unit: million);

5. Organization's integrated knowledge = the number of firm's new products + the number of firm's R&D projects + the number of firm's average R&D staffs (unit: million);

6. Firm's new knowledge =  $C \times \delta^T$

$C = \{c_{ij}\}$ : The number of firm's patent grants;

$c_{ij}$ : The number of firm's patent grants in year  $i$  and in patent  $j$ ;

$i (i=1, 2, \dots, 10)$ : The 10 years (from early to late: 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011);

$j (j=1, 2, 3)$ : The 3 kinds of patent grants (design patent, utility model patent, invention patent);

$\delta = (2^0 \ 2^1 \ 2^2)$ : The weight of 3 kinds of patent grants.

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