A Modified Model of Cooperative Innovation Based on Numerical P Systems - The CI-NP System: An Empirical Study of Shandong, China

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Abstract. Innovative firms attribute a greater role to their financing strategy in explaining their success and they have a different financial make-up for different departments. And different financial make-up reflects different cooperative innovation strategy. Traditional models of cooperative innovation are always streamlined or annular where the relationship of overlapping or inclusion among elements ignored. In this paper, based on the idea of numerical P systems, we modify the traditional model to improve the indivisibility and visualization into the shape of the membrane which is named CI-NP systems. We process the financial data of firms' development and have found the correlation among various elements and express it based on the case of Shandong, China.

Keywords: Cooperative innovation · CI-NP systems · Finance · Numerical P systems

1 Introduction

Innovation is broadly seen as an essential component of competitiveness, embedded in the organizational structures, processes, products, and services within a firm [1]. And the relationship between cooperation and innovation has been observed for many countries. By the combination of cooperation and innovation, they can get the necessary, various sources to create value [2] the impact of cooperation on firms' innovation propensity in emerging economies. Cooperative innovation is regarded as an interesting alternative for a firm that is trying to improve its innovation performance in the market [3]. Meanwhile, a firm must finance its activities, deploy physical and human resources, market its products and services, and coordinate all of these activities [4]. It is as important to understand the supporting role of these elements as it is to investigate the breadth of the cooperative activities in innovation of a firm [5].

There are some studies classify different cooperative innovation on the view of various processes in the business. For example, some studies are carried out to verify market orientation, internal cooperation practice, and process formality on product innovation performance and business performance in product innovation [6]. It is found that market orientation, internal cooperation practice, process formality and product

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innovation performance have positive effects on the product innovation performance [7]. In maintained that efficient communications and information exchange in the research and development and marketing sector have a positive effect on research and development and cooperate performances and state that communications and information exchange between functional departments, which can draw cooperation between them are necessary for an efficient progression. Because priority is different on various elements to be considered in new product development due to difference in characteristics of marketing function and R&D function meets a high level of new product development resources, new product effect increases [8]. Furthermore, marketing and R&D cooperation improves development capability and has a positive effect on product innovation performance [9]. Many studies have explored the differences in the element affecting the firm probability to establish different types of cooperation. However, elements which influence cooperative innovation sometimes do not clearly define the scope whether it belongs to the internal or the external [10]. It also ignored the correlation among various elements.

For it is now acknowledged as a result of the cooperation between a wide variety of actors both inside and outside the firm [11]. Innovative firms attribute a greater role to their financing strategy in explaining their success and they have a different financial make-up. Financial point of view of the company, including the innovation of the company's cooperation and research institute with financiers, can take advantage of the public and private funds more effectively and improve the innovation and accelerate the commercialization and diffusion process [12]. In this paper, we process the financial data of firms' development, analyze the correlation among different financial inputs and outputs due to both internal- and external-firm heterogeneity. To coordinate complementary assets and activities is important in financial view [13]. It is a sensible way to conceptualize capabilities as the efficiency with which a firm transforms available inputs into outputs in financial view [14]. Meanwhile, based on the idea of Numerical P Systems, we modify the traditional. In the process of financial data, we have found the correlation among various elements, and try to express the modified model based on the case study of Shandong in China.

The financial data used for the present study corresponds to the survey face to 2000 high-tech firms in Shandong Province, China. And the remainder of this paper is organized as follows. In Sect. 2, we review the basic notions of innovation and demonstrate the model we modified based on Numerical P Systems. Section 3 demonstrates the case study and uses the case to visualize the modified model. In Sect. 4, we analyze the data in the case and use it to certify our model. Section 5 concludes.

2 Basic Notions and the Model

A 2013 survey of previous works on innovation found definitions which are more than 40. In an industrial survey of how the software industry defined innovation, the definition given by Crossan and Apaydin was regarded as the most complete [15], and it is said that innovation is production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres, and renewal and enlargement of products, services, and markets, and also development of new methods of production and establishment of new management systems. It is a process and also an outcome. For innovation, cooperation becomes more and more important. Several studies have examined some of the necessary and hot cooperative complements to innovation. It is shown that 11 subjects are always the central issues in last 15 years. The study hot spot areas vary in different stages, but the combination of high-frequent key words are denser. Cooperative innovation management discipline represents the tendency from dispersion to fusion. Hot spots are closely related to firm environment at all stages. The study subject from 2000 to 2002 is strategic alliance and innovation, from 2003 to 2005 is alliance and knowledge innovation, from 2006 to 2008 is social network and innovations, and from 2012 to 2014 is dynamic network organization and innovation according the study of bibliometric analysis from SCI in 15 years (2000–2014). There are also other studies of hot spots at different time points [16] and we can get that none of them ignores cooperation and innovation though they have different names at different times.

Many other studies of the hot spot on cooperative innovation mentioned above have been researched where it is found that exploration of knowledge plays an critical part on innovation performance [17]. Firms pay attention not only to the amount of knowledge they can gain from their potential partner but also to the partner's absorptive capacity. The performance of cooperative innovation for firms' development depends on its absorptive capacity of combination [18]. These elements were combined in a static model where cognitive distance between cooperation partners is set exogenously [19]. Under different knowledge regimes, the structure of networks that emerge and how firms perform within the network has been examined when the study combines the innovation networks with endogenous absorptive capacity [20]. For example, there is a traditional structural model like in Fig. 1 in order to identify the effect of different elements based on the previous studies. The structural model has been designed to be streamlined, suggests that the firms' performance of cooperative innovation make a positive effect on the development, except to the streamlined model, for example, as shown in Fig. 2 [21]. However, both of them lack the interaction or overlapping effect among elements for cooperative innovation.

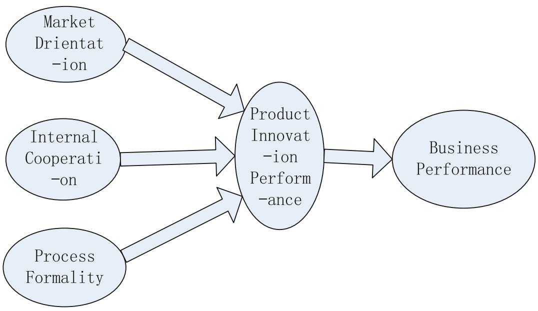

Fig. 1. This is a streamlined model of cooperative innovation which identify the effect of different elements, such as market orientation, internal cooperation practice, and process formality, on the performance of cooperative innovation.

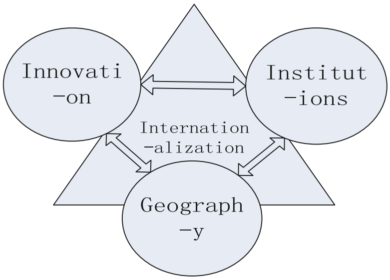

Fig. 2. A annular model where provide a glimpse into the interconnections between the constructs of institutions, innovation, geography, and internationalization.

The integration of the firm into a group has a positive influence on cooperation as it indicates access to a substantial pool of resources, which are complementary to different elements. In order to express the effect of each element on the cooperative innovation more clearly, different from the original model is designed, based on numerical P systems, we improved a new cooperative innovation model, which is called as the CI-NP system (the cooperative innovation based on NP systems).

Membrane computing is a bio-inspired branch of natural computing, abstracting computing models from the structure and functioning of living cells and from the organization of cells in tissues or other higher order structures. In short, in cell-like membrane system (which is usually called P system), multisets of abstract objects are associated with the compartments defined by membranes [22]. Numerical P systems are branches of P systems and motivated by the cell structure and the economic reality. Numerical variables are placed in the regions of a membrane structure [23]. These variables can evolve by means of programs, which are composed of two components, a production and a repartition function. A numerical P system is conceived as a dynamical system.

Formally, the form of numerical P systems is considered as follows:

$$\Pi = (m, \mathrm{H}, \mu, (\mathrm{V}ar_1, \mathrm{P}r_1, \mathrm{V}ar_1(0)), \ldots, (\mathrm{V}ar_m, \mathrm{P}r_m, \mathrm{V}ar_m(0))) \tag{1}$$

Where $m \geq 1$ is the number of membranes used in the system (also called the degree of $\prod$), H is an alphabet with m membranes, labeled in a one-to-one manner with the elements of H, Var_i is the set of variables from compartment i, Pr_i is the set of programs from compartment i of μ, $1 \leq i \leq m$ (all sets $Var_i, \ Pr_i, \ 1 \leq i \leq m$, are finite).

Regarding firm development as the cell life, what the element does influence the performance of cooperative innovation for firms. So, we put forward the modified model which is called cooperative innovation numerical P systems and its abbreviation is CI-NP systems. Based on NP systems, we denote the CI-NP system as follows:

$$CI = (m, H, \mu, (El_1, Pe_1, El_1(0)), \ldots, (El_{1m}, Pe_m, El_{1m}(0))) \tag{2}$$

And in order to make it easier to understand, we illustrate it by the example as follows.

$$CI = (3, H, \mu, (El_1, Pe_1, El_1(0)), (El_2, Pe_2, El_2(0)), (El_3, Pe_3, El_3(0))) \quad (3)$$

With the following components:

$H = \{1, 2, 3\}$,	the H is defined by m which means the number of membranes consisting of different affecting elements and here the system holds three membranes.
$\mu = [[\ ]_2[\ ]_3]_1$,	μ demonstrates the membrane structure.
$El_1 = \{El_2, El_3\}$,	membrane 1 means the performance of cooperative innovation, it depends on element 2 (El_2) and element 3(El_3). In order to express clearly, we write it as El_1.
$\mathrm{P}e_1 = (\mathrm{F}_1 \vert El_2, El_3), (\mathrm{W}_2 \vert El_2, \mathrm{W}_3 \vert El_3)$,	consider the performance of an elementary membrane can be estimate by the function among its affecting elements and the weight of every element also matters.
$El_1(0)$,	the initial value of the element.
$El_2 = \{El_{1,2}, El_{2,2}, El_{3,2}\}$,	the elementary membrane 2 represents one main element that affects El_1, it contains three sub-elements which are $El_{1,2}$, $El_{2,2}$ and $El_{3,2}$.

The follow is consistent with mentioned above, the expression is given only.

$$\begin{aligned}
&\mathrm{P}e_2 = (\mathrm{F}_2 | El_{1,2}, El_{2,2}, El_{3,2}), (\mathrm{W}_{1,2} | El_{1,2}, \mathrm{W}_{2,2} | El_{2,2}, \mathrm{W}_{3,2} | El_{3,2}),\\
&El_2(0),\\
&El_3 = \{El_{1,3}, El_{2,3}\},\\
&\mathrm{P}e_3 = (\mathrm{F}_3 | El_{1,3}, El_{2,3}), (\mathrm{W}_{1,3} | El_{1,3}, \mathrm{W}_{2,3} | El_{2,3}),\\
&El_3(0).
\end{aligned}$$

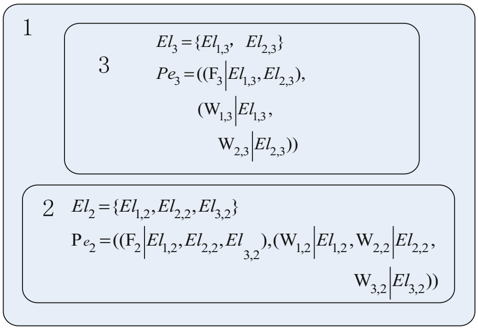

Fig. 3. An model of CI-NP systems. The model consists of three membranes where one of them is the skin membrane and represents the performance of cooperative innovation here. And other two are elementary membranes, which are representative of the number 2 and 3 and represent two main elements (El_2, El_3). And other specific meanings are mentioned above.

For an easier understanding, the system is given in Fig. 3 in a graphical representation, with the initial values specified in square brackets for each element, and with the programs given in the form production function to repartition procedure.

3 Case Study and Model Specification

Shandong Province is the third largest province in China's economy, and its GDP ranks the third which takes the 1/9 of China's GDP. Shandong was named China's one of the most comprehensive competitiveness of provinces and autonomous regions in 2013. With the continuous development of economic integration and knowledge economy, the regional economy is closely related to high-tech firms development.

High-tech firm has gradually become a leader to promote the development of regional economy. No matter taking a new road to industrialization, realizing the coordinated development of regional economy, adjusting and optimizing economic structure, or changing the pattern of economic development, it relies on the independent innovation and technological progress. That means transforming and upgrading traditional industries, and developing high-tech industry. In Shandong, high-tech firms reflect obviously the effect on the economy growth. Increasing capital formation, improving the level of technology and developing human capital are key elements to promote regional economic development. High-tech firms make an effect on the production structure through influencing the above elements to promote regional economic development.

Firms in Shandong play a critical role on the economic development, while high-tech firms matter. The study on cooperative innovation of high-tech firms in Shandong, China is important. And it is also important to research its model of cooperative innovation.

We have denoted the CI-NP system and a CI-NP system is conceived as a dynamical system. Based on the analysis we have done to the financial data of Shandong's high-tech firms, we illustrates the model specifically as follows.

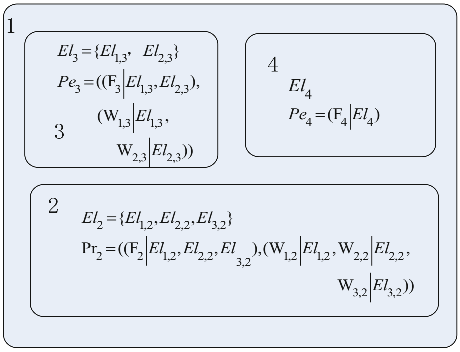

Fig. 4. In the rough expression of CI-NP systems based on Shandong's case, there are three main elements (*El*) for the performance of cooperative innovation (PCI) and each element holds some sub-elements.

$$CI = (4, H, \mu, (El_1, Pe_1, El_1(0)), (El_2, Pe_2, El_2(0)), (El_3, Pe_3, El_3(0)), (El_4, Pe_4, El_4(0))) \quad (4)$$

For an easier understanding, the system is given in Fig. 4 in a graphical representation, with the initial values specified in square brackets for each element, and with the programs given in the form production function to repartition procedure. In order to see the difference between the modified model and original model more clearly and demonstrate the relationship between the cooperative innovation elements more visually, we put the model specification as Fig. 5 shown.

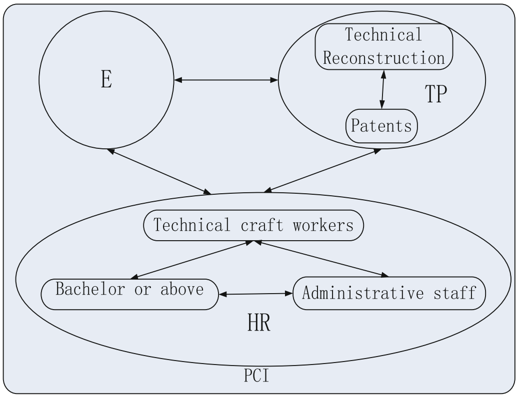

Fig. 5. The model specification based on Shandong's real study. there are three main elements which affect the performance of cooperative innovation (PCI) and they are human resources (HR), energy sources (E) and the fund for technical project (TP). And some main elements have sub-elements.

It reveals that there are different elements which all affect the performance of cooperative innovation, the element also has an effect on each other and some sub-elements are included in each of them. Each sub-element plays a role on each other and they may have overlapping or cooperation with others. In our model specification, there are three main elements which affect the performance of cooperative innovation (PCI) and they are human resources (HR), energy sources (E) and the fund for technical project (TP). These elements play a role in the process of the development of cooperative innovation and promote each other to a certain extent. Meanwhile, we take performance of cooperative innovation as the skin membrane which can include other elements in the development but their roles are not prominent as the three main element.

Most original models ignore the relationship demonstration among sub-elements. In the modified model, sub-elements containing by main elements is represented. Specifically, the fund for technical project contains the fund for technical reconstruction and patents, while human resources consists of three main sub-elements and they are technical craft workers, administrative staff and the staff who has bachelor or above. What calls for special attention is that not all the sub-element has strict independent relation with each other. They may have overlapping and also dependence with each other in the same elementary membrane.

On the whole, the model modified by numerical P systems based on the financial data regards the development in firms as cell lives. It demonstrates various elements and their relationships for cooperative innovation of high-tech firms in Shandong, China.

4 Data and Certification

The data used for the present study corresponds to the survey made by Technology Office of Shandong Province. The data is collected on high-tech firms about their financial input and output on innovation and development during the three-year period 2011 to 2013.

The total number of firms participating to the survey is 2000, 60.7% (1214 firms) of which operates in the new and high technology transformed by traditional industry. And the traditional industry transformed by new and high technology accounts for a large proportion. Electronic information technology industry and new medicine industry occupy the proportion of 11.4% (228 firms) and 13% (260 firms) respectively. The proportions occupied by the industry of new material technology, new energy and energy efficiency technology and resource and environment technology are less than 10%. They are 6.7% (134 firms), 3.1% (62 firms) and 4.3% (86 firms) respectively. There are only 4 firms (0.2%) of aerospace technology and 12 firms (0.6%) of high-tech service industry. The firm comes from different industries, and their competitiveness mainly relies on innovation and development according to the standard of high-tech industry and the development data. It is demonstrated by Fig. 6.

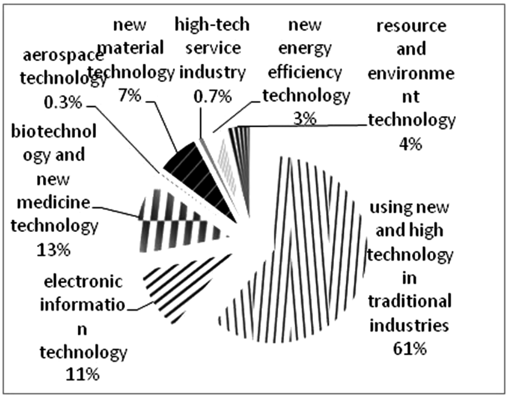

Fig. 6. The industry distribution.

We selected 30% of the data as test set, and conducted an analysis of the other 70% (1500 firms) of the data at first. By using the principal component analysis, we found three main aspects which include some inferior attributes that make effect on the development of cooperative innovation in the firms according to the financial data, as shown in Fig. 7.

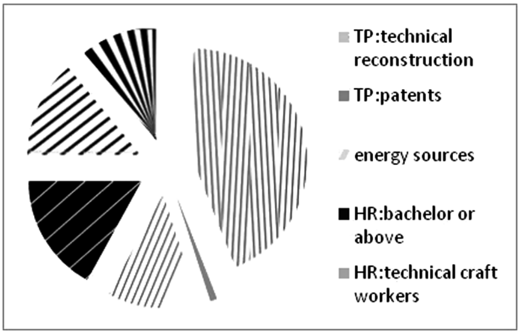

Fig. 7. The element distribution of cooperative innovation.

The dependent variable of the model is the gross industrial output value, which is dummy variable equal to one in the firm, during the three years 2011 to 2013. As we have seen in Tables 1, 2 and 3, independent variables correlation with the dependent variables have been shown clearly.

Table 1. Correlation analysis among main elements.

Correlations

		Gross Industrial Output Value	Energy Sources	HR	TP
Gross Industrial Output Value	Pearson Correlation	1	.236**	.719**	.808**
	Sig. (2-tailed)		.000	.000	.000
	N	1509	1509	1509	1509
Energy Sources	Pearson Correlation	.236**	1	.258**	.244**
	Sig. (2-tailed)	.000		.000	.000
	N	1509	1509	1509	1509
HR	Pearson Correlation	.719**	.258**	1	.677**
	Sig. (2-tailed)	.000	.000		.000
	N	1509	1509	1509	1509
TP	Pearson Correlation	.808**	.244**	.677**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	1509	1509	1509	1509

**. Correlation is significant at the 0.01 level (2-tailed).

By conducting Pearson correlation for the rest of the data, we verified the relationship among all or different elements. If the Pearson Correlation coefficient is less than 0.5, in other words, the significance level is less than 0.05, we regard that the overall trend for the two variables as be in consistency, but not dramatically. For example, the cost of energy sources is not correlated dramatically with any other elements, even for the value

Table 2. Correlation analysis among HR and its components.

Correlations

		HR	Bachelor or above	Technical Craft Workers	Administrative Staff
HR	Pearson Correlation	1	.858**	.782**	.514**
	Sig. (2-tailed)		.000	.000	.000
	N	1509	1509	1509	1509
Bachelor or above	Pearson Correlation	.858**	1	.689**	.467**
	Sig. (2-tailed)	.000		.000	.000
	N	1509	1509	1509	1509
Technical Craft Workers	Pearson Correlation	.782**	.689**	1	.478**
	Sig. (2-tailed)	.000	.000		.000
	N	1509	1509	1509	1509
Administrative Staff	Pearson Correlation	.514**	.467**	.478**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	1509	1509	1509	1509

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3. Correlation analysis among TP and its components.

Correlations

		TP	Technical Reconstruction	Patents
TP	Pearson Correlation	1	.372**	.035
	Sig. (2-tailed)		.000	.179
	N	1509	1509	1509
Technical Reconstruction	Pearson Correlation	.372**	1	.058*
	Sig. (2-tailed)	.000		.024
	N	1509	1509	1509
Patents	Pearson Correlation	.035	.058*	1
	Sig. (2-tailed)	.179	.024	
	N	1509	1509	1509

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

of Gross Industrial Output. But we can not ignore its influence on the development, though it only takes a small perception in innovative firms and its influence is going smaller and smaller faced with other cooperative elements.

Table 1 reports the three main complements of firms for innovation through comparing to gross industrial output value, namely the consumption of energy sources, human resources and the fund for technical project. The table shows that three elements exhibit a higher correlation of cooperative innovation. Additionally, the three elements include different secondary attributes which contribute to the gross industrial output value.

Tables 2 and 3 reports the secondary attributes belonged to different main elements respectively. To be specific, HR is composed of the staff who are bachelors or above, technical craft workers and administrative staff. And technical craft workers have the strongest correlation with human resource. The cost of patents and technical reconstruction attributes most to the fund for technical project. But the cost of technical reconstruction takes more proportion than the cost of patents. Tables 4 and 5 report the correlation coefficient using standard deviation, mean value, maximum value and minimum value.

Table 4. Summary statistic 1.

El	Gross Industrial Output Value	E	HR	Bachelor or above
Gross Industrial Output Value	×	Min:0.042;Max:0.257;Mean:0.178;SD:0.097	Min:0.719;Max:0.853;Mean:0.771;SD:0.059	×
E	Min:0.042;Max:0.257;Mean:0.178;SD:0.097	×	Min:0.03;Max:0.266;Mean:0.185;SD:0.109	×
HR	Min:0.719;Max:0.853;Mean:0.771;SD:0.059	Min:0.030;Max:0.266;Mean:0.185;SD:0.109	×	Min:0.717;Max:0.905;Mean:0.827;SD:0.080
Bachelor or above	×	×	Min:0.717;Max:0.905;Mean:0.827;SD:0.080	×
Technical Craft Workers	×	×	Min:0.782;Max:0.875;Mean:0.821;SD:0.039	Min:0.595;Max:0.776;Mean:0.687;SD:0.074
Administrative Staff	×	×	Min:0.514;Max:0.783;Mean:0.648;SD:0.110	Min:0.467;Max:0.687;Mean:0.586;SD:0.074
TP	Min:0.808;Max:0.877;Mean:0.853;SD:0.032	Min:0.035;Max:0.351;Mean:0.21;SD:0.017	Min:0.677;Max:0.920;Mean:0.784;SD:0.101	×
Patents	×	×	×	×
Technical Reconstruction	×	×	×	×

Cooperation networks can be distinguished in different types of cooperative behavior and most of them consider cooperating with elements external firm. For example, as known as horizontal R&D cooperation tends to form matches between competing firms that might have similar needs in terms of product or process development, looking for resources of the same type (technological, human and so on). We tend to analyze the correlation to the gross industrial output value internal firms but on the view of finance. And as shown on Tables 4 and 5, summary statistics of their correlation among various elements also classify their mutual cooperation.

Table 5. Summary statistic 2.

El	Technical Craft Workers	Administrative Staff	TP	Patents	Technical Reconstruction
Gross Industrial Output Value	×	×	Min:0.808;Max:0.877;Mean:0.853;SD:0.032	×	×
E	×	×	Min:0.035;Max:0.351;Mean:0.21;SD:0.017	×	×
HR	Min:0.782;Max:0.875;Mean:0.821;SD:0.039	Min:0.514;Max:0.783;Mean:0.648;SD:0.110	Min:0.677;Max:0.92;Mean:0.784;SD:0.101	×	×
Bachelor or above	Min:0.595;Max:0.776;Mean:0.687;SD:0.074	Min:0.467;Max:0.687;Mean:0.586;SD:0.074	×	×	×
Technical Craft Workers	×	Min:0.478;Max:0.811;Mean:0.633;SD:0.137	×	×	×
Administrative Staff	Min:0.478;Max:0.811;Mean:0.633;SD:0.137	×	×	×	×
TP	×	×	×	Min:0.362;Max:0.503;Mean:0.412;SD:0.064	Min:0.034;Max:0.383;Mean:0.151;SD:0.164
Patents	×	×	Min:0.362;Max:0.503;Mean:0.412;SD:0.064	×	Min:0.058;Max:0.315;Mean:0.171;SD:0.107
Technical Reconstruction	×	×	Min:0.034;Max:0.383;Mean:0.151;SD:0.164	Min:0.058;Max:0.315;Mean:0.171;SD:0.107	×

5 Conclusions

There are many previous works to explore the elements which have impact on the cooperative innovation. Previous works can be roughly divided into studying the internal element, the external element and elements on the view of process in business. However, most of them ignore the correlation among various elements.

This paper analyze the element that affecting performance of cooperative innovation in firms from the perspective of financial data. Networks are considered an economic reality. From this perspective, our model shows the relationship of inclusion which usually ignored in original model and correlation among various elements. Meanwhile, our model is constructed according to the instance data, validated the economic development of most high-tech firms in Shandong, China. At the same time, we change the original model and propose CI-NP system model based on numerical P systems, making joint among elements which play a role on the performance for cooperative innovation at the same time. It conforms to the characteristics of firms with development vitality and demonstrates the relationship between each element more fully.

However, elements in different types of firms play different roles. Meanwhile, various firms in multiple development periods emphasize on different aspects. In changing and increasingly competitive environments, successful innovations must provide a competitive edge in changing the relative position of a firm within an industry. Though based on NP systems, we have just give the model demonstrating the relationship among various elements and we haven't given the concrete expression of the production function. To do that, the next step for our work is to classify firms in different scale and its value of each element in order to find the function relation among them.

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