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Modelling and Simulation of Collaborative Innovation System in Colleges and Universities Based on Interpreted Structural Equation Model

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Abstract

This article summarises 15 factors that affect the collaborative innovation of industry, university and research through literature research and establishes the innovation entity and innovation environment subsystem of the collaborative innovation system of colleges and universities based on the theory of synergy. By setting system boundaries and causal relationship analysis, the dynamic model of the collaborative innovation system in colleges and universities is established, and the model's validity is verified. Combining the actual work, the enlightenment of collaborative innovation management in colleges and universities is as follows: Develop collaborative innovation led by scientific and technological talents strategy. Strengthen the policy and system support for collaborative innovation of colleges and universities. Improve the collaborative innovation input mechanism of institutions of higher learning.

Keywords: collaborative innovation system, structural characteristics, explanatory structural model**AMS 2010 codes:** 62J10

1 Introduction

China, which has entered the new economic normal, has put forward higher requirements for innovation. However, a phenomenon that cannot be ignored is that various innovative organisations still focus on allocating resources or competition. Still, they do not pay much attention to the coordination between the main body, departments and regions. Innovation is a complex process that covers three levels such as micro, meso (medium) and macro levels. Micro-level innovation emphasises that innovation is human self-realisation and that innovation requires recombining production factors and conditions to generate new technologies and products [1]. At the meso (medium) and macro levels, innovation is centred on industries and rises to national and regional innovation capabilities. The multi-level characteristics of innovation determine the diversity of its influencing factors. Innovative subjects are generally in a state of division in space, making the innovation process more complicated, leading to non-coordination becoming a constraint on development.

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Collaborative innovation combines collaboration and innovation, which strengthens the feature of ‘synergy’ in innovation. Most scholars agree that collaborative innovation is a process from communication to coordination to cooperation and finally achieving synergy [2]. Under the intervention of the external environment, multiple collaborative innovation subjects produce a process of synergistic effects that a single subject cannot achieve innovation through complex, non-linear and autonomous interactions. In short, collaborative innovation guides the entire process of coordinated operation of various elements within the system for ‘innovation’.

The academic research on the collaborative innovation system roughly follows the ‘enterprise→ industry→ government-industry-university-research→ region.’ Early scholars focused their attention on companies with high innovation performance and thus sought entry points for synergy. Some scholars discussed the degree of synergy between technological innovation and organisational structure innovation and proposed that with the continuous emergence of high technology, organisations should pay more attention to organisational structure innovation rather than technological innovation [3]. Some scholars believe that the innovation performance of enterprises in the stage of organisational structure innovation is higher than that of technological innovation. Under the guidance of the spirit of open innovation, scholars’ thinking on collaborative innovation broke through corporate barriers and began to expand to universities, governments and industries.

From a domestic perspective, the research on the collaborative innovation system shows four obvious trends: First, research on the factors that influence collaborative innovation, such as enterprises, governments, industry, academia, regions, technologies and markets. The second is to discuss collaborative innovation methods, such as paths, models and mechanisms [4]. The third is to link the elements and their operating mechanisms. We can attribute these studies to the field of ‘innovation clusters.’ The fourth is the study of collaborative innovation ability or degree of synergy.

In summary, the previous results have laid a good foundation for this article to think deeply about collaborative innovation. But there are still shortcomings: First, the preliminary research is mostly fragmented with only partial discussions, which do not help the systematic understanding of collaborative innovation. The second is that the research mostly focuses on the subject of innovation, while other elements are not taken into consideration. The third is the incomplete analysis of the composition of the ‘innovation synergy system’ elements and the relationship between elements. Fourth, the proposed construction path of the ‘collaborative innovation system’ is too universal and not highly targeted. To further deepen the understanding of the ‘collaborative innovation system’, this article uses the explanatory structure model to establish a ‘collaborative innovation system structure model.’ This model analyses the structural characteristics of the collaborative innovation system and proposes the implementation path to promote the construction of China’s ‘collaborative innovation system’.

2 Collaborative innovation architecture model

The collaborative innovation system has specific functions formed by combining several interconnected things in a certain order and internal relations. It emphasises the relationship between the various elements to achieve the same goal. It is well known that when developing or transforming a system, we must first understand the relationship between the various elements in the system. Only in this way can we develop or transform the system fully in a better way [5]. There are three reasons why this article uses the explanatory structural model method to model: First, the explanatory structural model uses a directed graph to express the relationship between the elements. The structure is very intuitive and easy for managers to understand. The second is that the explanatory structure model is a conceptual model that can transform ambiguous thoughts and opinions into intuitive and well-structured models. Existing research involves many elements. It is difficult to clarify hundreds of relationships with the human brain. We need to use computers. Third, this article must construct a multi-level hierarchical structure model based on prior knowledge and using a computer.

2.1 Element selection and relationship determination

Our selection of the elements required for modelling and determining the relationship is based on related models and related research. There are many structural models proposed by scholars around the theme of the collaborative innovation system. Some scholars position universities, industry and government as a three-in-one innovation model. Some scholars believe that enterprises, universities, research institutes and the government are the four executive bodies of the innovation system, and there is a two-way connection between the four. Some scholars proposed that the regional innovation system environment includes a soothing environment and a hard environment. The peaceful environment includes the market environment, legal protection and innovation culture [6]. The hard environment includes the basic conditions of the city, such as information access, road traffic, economic aggregates and innovative talents. Some scholars place small and medium-sized enterprises in the centre of innovation subjects. The government, universities, scientific research institutions and social service systems provide resources, funds, services and innovation needs for small and medium-sized enterprises to innovate. Some scholars believe that enterprises are the core of technological innovation. Governments, universities, scientific research institutions and social intermediary service organisations provide enterprises with platform construction, technical support, service support and needs. Some scholars have proposed a framework for analysing industry-university-research collaborative innovation from the three levels: strategic collaboration, knowledge collaboration and organisational collaboration. For the first time, his analysis jumped out of the ‘main body’ thinking mode, putting the main content strategy, organisation and knowledge of the collaborative process in the first place. From his ‘Theoretical Framework of Industry-University-Research Collaborative Innovation’, the government’s policies, projects and institutional mechanisms play a supporting role.

In contrast, the financial institutions of intermediary organisations play a supporting role. Some scholars believe that universities and scientific research institutions, enterprises, industries and governments form a ‘four-wheel’ driving model connected through trust, convergence, platform and extension mechanisms. Some scholars attribute the cooperation motivation of collaborative innovation to market motivation, technology motivation, organisation motivation and learning motivation. In the triple helix model, some scholars divide the enterprise

Table 1 Relationship between elements of the regional collaborative innovation system

Code	Feature name	Code	Feature name	Code	Feature name	Code	Feature name
S1	Innovation	S11	organise	S21	Agency	S31	Creativity
S2	need	S12	Knowledge	S22	NGO	S32	Capital investment
S3	customer	S13	Culture	S23	Service	S33	Innovation platform
S4	market	S14	Technological innovation	S24	Cooperation motivation	S34	Financial institution
S5	government	S15	Technology diffusion	S25	Learn	S35	Innovation cluster
S6	industry	S16	System	S26	Innovation environment	S36	Agglomeration
S7	University	S17	information	S27	Innovation network	S37	Innovation performance
S8	Research institute	S18	Innovation risk	S28	mutual benefit	S38	Economic Growth
S9	enterprise	S19	competitor	S29	Innovation resources	S39	Economic space
S10	Division of labor	S20	Policy	S30	Human Resources		

NGO, non-governmental organizations

dimension into two sub-categories: producer service industry and manufacturing industry. He believes that regional industrial collaborative innovation is accomplished through government, university, productive service industry, manufacturing and industrial interaction. In the ‘Double Diamond Model,’ enterprises, governments, universities, scientific research institutions and intermediary institutions are the main innovation entities [7]. The market, technological, policy system and social-cultural environments are the external environments of collaborative innovation, which play an intervening role in collaborative innovation. One has to summarise and sort out the elements and sources of the collaborative innovation system obtained from the previous research. The content includes the elements of the triple helix theory of mainstream research (industry-university-research), four main bodies (government-industry-university-research), five main bodies (government-industry-university-research funds), and six main elements (government-industry-university-research finance), as well as those in the field of research. Elements are related to the collaborative innovation system. According to the element relationship identified in the literature, we sorted out 39 elements of the collaborative innovation system (see Table 1).

2.2 Establish an explanatory structure model

First, establish the adjacency matrix. Establish the upper triangular relationship matrix based on the relationship of the element $S_i, S_j (i, j = 1, 2, \dots, 39)$. See formula (1). Write the adjacency matrix $A_{39 \times 39}$ according to the upper triangular relation matrix.

$$\begin{cases} (1) S_i \times S_j, S_i \text{ and } S_j \text{ are related to each other;} \\ (2) S_i \circ S_j, S_i \text{ and } S_j \text{ are not related;} \\ (3) S_i \wedge S_j, S_i \text{ is related to } S_j, \text{ and } S_j \text{ has nothing to do with } S_i; \\ (4) S_i \vee S_j, S_j \text{ is related to } S_i, \text{ and } S_i \text{ has nothing to do with } S_j; \end{cases} \quad (1)$$

Second, calculate the reachable matrix. The reachable matrix R is obtained by adding the adjacency matrix to the identity matrix after $n - 1$ times of operations. The reachable matrix conforms to the transition characteristics:

$$A_1 \neq A_2 \neq \dots \neq A_{r-1} = A_r, \quad r \leq n - 1 \quad (2)$$

The formula n is the order of the matrix. $A_{r-1} = (A + I)^{r-1} = R$ is calculated as:

$$A_1 \neq A_2 \neq \dots \neq A_{10} = A_{11} = R \quad (3)$$

The third is regional division. When dividing the area, it is necessary to divide the relationship between the elements into reachable and unreachable. We need to determine which elements are connected, that is, divide the system into several parts or sub-parts that are related. Determine the underlying elements through the operations on the lookahead set and the reachable set, and then determine the connectivity of these elements [8]. If the intersection of the reachable sets of the elements is empty, the elements belong to different connected domains, otherwise the same connected domain. Find the lowest element:

$$T = \{S_3, S_{18}, S_{19}\} \quad (4)$$

Because of $R(S_3) \cap R(S_{18}) \neq \Phi$. So S_3, S_{18} belongs to the same connected domain. Similarly, S_3, S_{18}, S_{19} belongs to the same connected domain. Then divide between levels. We divide all the elements in the system into different levels based on the reachability matrix. The different layer elements are obtained in turn as follows:

$$\begin{aligned} T &= \{S_3, S_{18}, S_{19}\}; \quad L_1 = \{S_2, S_{11}\}; \quad L_2 = \{S_5, S_7, S_8, S_9, S_{22}\}; \\ L_3 &= \{S_{13}, S_{16}\}; \quad L_4 = \{S_{25}\}; \quad L_5 = \{S_{20}, S_{24}\}; \quad L_6 = \{S_7, S_{28}\}; \\ L_7 &= \{S_{21}, S_{29}, S_{33}, S_{34}\}; \quad L_8 = \{S_{23}\}; \quad L_9 = \{S_6, S_{26}\}; \quad L_{10} = \{S_{36}\}; \\ L_{11} &= \{S_{10}, S_{12}, S_{17}\}; \quad L_{12} = \{S_{14}, S_{15}, S_{27}, S_{30}, S_{32}, S_{35}\}; \quad L_{13} = \{S_{31}\}; \\ L_{14} &= \{S_1\}; \quad L_{15} = \{S_{37}, S_{38}, S_{39}\}; \end{aligned} \quad (5)$$

According to the calculation results, draw a hierarchical directed graph and then build a ‘collaborative innovation system structure model’ according to the system’s hierarchical structure model (see Figure 1). Considering a feedback mechanism in the system, we added a feedback line (dotted line).

Fig. 1 Collaborative innovation architecture model

The ‘collaborative innovation system structure model’ has the following two characteristics: First, it breaks through the subject constraints of the three-helix, four-subject, five-subject and six-subject conceptual models. It describes the collaborative innovation system more comprehensively. Second, it has a clear hierarchical structure, which is intuitive and easy for decision-makers to understand.

3 Structural characteristics of the collaborative innovation system

3.1 Structural characteristics of the collaborative innovation system

The collaborative innovation system is complex. The system includes 39 elements, divided into 17 layers. The layer with the most elements is the layer L_{13} , which has 6 elements. The layer with the fewest elements is the layer L_4 , L_7 , L_9 , L_{11} , L_{14} , L_{15} , each with 1 element. There is a direct or indirect relationship between these elements and other elements. Factors such as the government, intermediaries, innovation resources, innovation platforms, financial institutions, etc., have a direct impact on ‘services’, and the direct influence factors of these factors become the indirect influence factors of ‘services’.

The collaborative innovation system has two characteristics: closed and open. From a static perspective, the ‘collaborative innovation system’ is an independent and closed system with innovation as the goal [9]. The constituent elements of the ‘collaborative innovation system’ originate from the interior of a certain region (organisation or department). From a dynamic perspective, developing the ‘collaborative innovation system’ is a process from small to large and weak to strong. A region (organisation or department) collaborative innovation system and B region (organisation or department) collaborative innovation system have energy exchange, information exchange and resource exchange, which restrict and influence each other. Therefore, in the context of economic integration, the construction of a ‘collaborative innovation system’ will inevitably take ‘openness’ as its main feature. It is necessary to achieve dynamic synergy in fields such as the world and the entire industry chain.

The collaborative innovation system includes seven functional modules (see Figure 2). They are innovation orientation, innovation subject, innovation resources, innovation environment, government functions, innovation capabilities and economic influence from bottom to top. These seven functional modules run around their respective centres. Still, there is a direct or indirect relationship with each other, which can drive the delicate operation of the large-scale system. The elements contained in each module are shown in Table 2.

Fig. 2 Seven functional modules of the collaborative innovation system

Table 2 Seven functional modules and their elements

Function classification	Contains elements
Innovation-oriented	Customers, competitors, innovation risks
Innovation subject	Enterprises, research institutions, governments, universities, NGO, intermediary organisations
Creativity	Technological innovation, technological diffusion, capital investment, human resources, innovation networks, innovation clusters, innovation capabilities
Innovation environment	Culture, systems, policies, markets, financial institutions, competitors, innovation platforms, services
Innovation resources	Human resources, capital investment, technological innovation, service
Government function	System, culture, policy, service, market, innovation network
Affect the economy	Economic growth, economic space, innovation performance

NGO, non-governmental organizations

The innovation-oriented functional module is at the bottom layer of the diagram, and the content includes three elements: customers, competitors and innovation risks. Different customer groups have different needs at different stages, and they guide innovation subjects. To obtain a price advantage, SMEs will focus on innovation. The two grow together in the game. Innovation risk is a negative element that hinders innovation behaviour. The smaller the risk, the greater the motivation for innovation entities to innovate [10]. The main functional innovation modules are distributed in the figure's second, third, and eighth layers. The content includes six elements: organisations, enterprises, universities, research institutions, intermediary agencies and non-governmental organisations (NGO). 'Innovation risk' directly impacts companies, universities and research institutions, while the 'demand' generated by customers directly impacts companies, governments, universities and research institutions. The functional module of innovation capability is in the 13th layer of the figure. The content includes six elements: technological innovation, technological diffusion, capital investment, human resources, innovation network and innovation clusters. The innovation resource modules are distributed in the 8th, 9th and 13th layers of the figure, and the content includes the four elements of human resources, capital investment, technological innovation and service.

Innovation resources are an important source of regional innovation capabilities, but they are not the only source. Government function modules are distributed in the 4th, 6th, 7th, 9th and 13th layers, including six systems, culture, policy, service, market and innovation network elements. The government's influence on the industry is realised through the market as an element; the government's influence on the 'innovation environment' is realised through the 'innovation platform' as 'service' and then the 'service' as the 'innovation environment'. The innovation environment modules are distributed in the first layer, the fourth layer, the sixth layer, the seventh layer, the eighth layer, the ninth layer and the tenth layer. The content includes culture, system, policy,

market, financial institutions, competitors and innovation. The eight elements of platform and service. These are the soft elements of the innovation environment. The distribution of influencing economic modules is at the top layer (layer 16) of the graph, including three elements: economic growth, innovation performance and economic space. In addition, elements such as culture, learning, systems, cooperation motivation and common interests constitute a ‘synergy chain’ that guides collaborative innovation. Market, industry and division of labour have a relatively direct impact on innovation networks, technological innovation and human resources.

3.2 Important nodes in system operation

In addition to focusing on the main body of collaborative innovation, the operation of the guarantee system also needs to pay attention to nodes such as culture, environment, knowledge, resources and government.

3.2.1 Cultural node

Most innovative regions or organisations have a good innovation culture, and the culture expresses values and visions. Over the past 30 years of China’s reform and opening up, the rapid economic development has formed a successful culture of ‘emphasis on economy, the light of spirit’, ‘results, light process’, and ‘success, light struggle’ in the whole society [11]. This culture is contrary to the growth environment with a relaxed preference for innovation. Getting through cultural nodes requires correcting wrong values and changing the value orientation of the organisation and society of ‘using success as heroes.’

3.2.2 Environment node

‘Innovation environment synergy’ is another important point besides ‘subject synergy.’ ‘Innovation environment synergy’ promotes integration with a more consistent code of conduct, system, and culture and reduces the obstacles to collaboration between subjects. As far as the service environment is concerned, standardisation can easily achieve the goal, but the coordination of deep-level elements such as culture and system requires a long wait. Opening up environmental nodes requires reducing the gap in the system and driving environmental balance through service standardisation.

3.2.3 Knowledge node

The knowledge base is the foundation of the regional innovation system. The regional nature of the knowledge base is the main reason the innovation system is difficult to transplant. Enterprises gather around universities and research institutes. The spatial gathering of high-tech enterprises in Zhongguancun, China, Silicon Valley in the United States, Hsinchu Science and Technology Park in Taiwan, China, and Bangalore in India eliminates the regional knowledge.

Resource node. For most regions, the elements of innovation resources are not lacking but unreasonable in structure. Some resources are too large, and some resources are too few. Because different regions have the potential to protect their resource advantages, the subjects have essential differences in resource use, management decision-making, key tasks, and personnel deployment [12]. Therefore, in the process of collaborative innovation, it often shows the competition for resources in different regions and different departments, rather than sharing. To open up resource nodes, it is necessary to enhance the awareness of resource complementarity.

3.2.4 Government nodes

Collaborative innovation requires effective collaboration among government departments. Because some of the ‘coordination’ responsibilities are not included in departmental responsibilities, some are not included in the evaluation index system of the leadership team or included in the evaluation of employees. These tasks beyond the responsibilities of the department and employees are likely to be deliberately forgotten or ignored. Therefore, it is fundamental to drive joint stability with the system. Getting through government nodes requires strengthening the department’s prior agreement.

4 System path to promote collaborative innovation

4.1 Create a culture of innovation and advocate failure studies

To create an innovative cultural atmosphere, the concepts of encouraging innovation and tolerating failure must be placed in the same dimension, so we proceed from the following four aspects. The first is to give play to the role of the new and old media, set up a ‘civilian (grassroots) innovation model’ and increase the intensity of positive media coverage. The second is building a ‘crowd creation space’ network and physical platforms [13]. Establish a ‘Crowd Creation Space’ website, link it with national and provincial science and technology information and service platforms, and encourage small and micro technological innovation enterprises, innovative individuals and innovative teams to become platform members. The third is establishing a ‘real-name system idea bank’ and encouraging enterprises to write ‘war books.’ Welcome innovative individuals and innovative teams to actively prepare for the battle. Innovative, collaborative services are provided by technology exchanges, innovation stations, productivity centres, etc. The fourth is to promote the study of failure and establish a database of failure knowledge. Learn from the experience of the Japan Agency for the Promotion of Science and Technology (JST) in establishing a failed knowledge database. While encouraging failure studies, it collects failure cases in organisational innovation and conducts event descriptions and context analysis.

4.2 Innovate the collaborative model and leverage the advantages of KICs/PP

First, learn from the practice of establishing innovative engineering colleges in Europe and effectively integrate higher education, enterprises and research institutions around important areas of future development. Aiming at the key areas of China’s next innovation and development stage, relying on the well-known university platform to establish the ‘China Institute of Innovation and Technology’ to form 10 knowledge and innovation communities (KICs). We need to achieve two goals: to gather global talents and use national and departmental projects to support mobile projects. This rapidly improves China’s level in these key research areas. The second is to cultivate top entrepreneurial talents through entrepreneurship education and reform higher education courses and teaching models to drive higher education reform. In this way, it promotes the combination of theory and practice. Also play the role of the patent alliance as a link.

4.3 Focus on environmental collaboration and promote tacit knowledge sharing

We need to use environmental synergy to drive the sharing of tacit knowledge. First, start the apprenticeship model among the innovative subjects, and promote the dissemination of knowledge among individuals by ‘passing and leading.’ Second, pay attention to the impact of uncoded knowledge on the collaborative innovation system, and create a soft and hard environment conducive to spreading tacit knowledge. In terms of the hard environment, it is necessary to create a good production and living environment for innovative people and provide more room for development. Create a slow culture in innovation resource clusters such as industrial, innovation and technology parks. High-end service carriers such as water bars, book bars, tea rooms, coffee houses, Internet bars and cultural salons provide innovative groups convenient for communication and leisure. A peaceful environment, industry associations, technology alliances, seminars, etc., can provide in-depth communication opportunities for innovative groups.

5 Conclusion

The collaborative innovation system is a large and complex system that includes seven functional modules: innovation orientation, innovation subject, innovation resources, innovation environment, innovation capabilities, government functions and economic impact. In addition to the main body, the coordination of elements such as culture, environment, knowledge, resources and the government is the focus of system operation. The

path to systematically promote collaborative innovation is to create an innovation culture and advocate failure studies. Innovate the collaborative model and give full play to the advantages of the knowledge and innovation community and patent alliance. Pay attention to environmental collaboration and promote tacit knowledge sharing. Cultivate innovation clusters and upgrade industrial and technological clusters. Develop a sharing plan to realise the synergy of the main body's interests.

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