An Empirical Study on University-Industry Collaborative Innovation from Science of System Perspective[1]

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Abstract--The collaborative innovation of university-industry was discussed from the science of system perspective. On basis of the synergetic perspective, this paper analyzes the dynamic evolution law of innovation capability of university under the process of university- industry collaborative innovation. The research indicates that: the science of system can be used to solve the uncertainty of administrative decision. This paper established the Logistic model composed of university knowledge production capability, knowledge transmission capability, and knowledge dissemination capability on the basis of "B-Z" model. Through stability analysis and simulation, we discussed these three capabilities' evolution law and determines dominate capability elements, then the evolution law of the 3 Chinese universities in the process of University-Industry collaborative innovation will be studied by confirmatory empirical analysis. The study tried to provide policies of internal capability coordination for university-industry collaborative innovation.

I. INTRODUCTION

Innovation is widely regarded as a critical source of competitive advantage in an increasing changing environment[1-2]. With the understanding of collaborative innovation by research and practice, many countries have developed a strategic plan to promote the innovative collaboration between universities, industries, and governments. Take EU's Knowledge triangle strategy for example, university reform has become a mean for promoting research, education and innovation to enhance the university and regional competitiveness. Also. Promoting University-Industry Collaboration activities is a major policy priority in Japan, as demonstrated by a series of legislative actions, such as the 1998 Technology Licensing Organization Promotion Law and the 2000 Law to Strengthen Industrial Technological Capabilities[3]. In China, the government has developed "Higher Education Innovative Capacity Building Program" to promote the reform of institutional mechanisms of colleges and universities. Fact shows that innovation capability of universities has become critical for university-industry collaborative innovation. University–industry links and their impact on innovation processes have been a longstanding object of analysis in various scholarly communities in management studies, the economics of innovation, industrial organization, the sociology of science and science studies, and science and technology policy[4-8].

Meanwhile, with the development of the theory of self-organization, many scholars began to explore innovation mechanism of research universities in the process of university- industry collaboration from the perspective of self-organization theory. However, most studies do not enough concerned about the role of university in the process of university- industry collaboration. With the development of the concept of knowledge triangle, we need to explore innovation mechanism of research universities in the process of university- industry collaboration from the theoretical and empirical perspective.

This study aims to identify the university innovation capabilities (knowledge production capability, knowledge dissemination capability, knowledge transfer capability) base on "B-Z" reaction model of self-organization theory in the process of university- industry collaboration to predict the evolution laws of university innovation capabilities in the process of university- industry collaboration. Lastly, we carried out confirmatory empirical analysis on the evolution laws of Chinese 3 universities' capabilities in the process of university- industry collaboration with the aim to provide policy for enhancing university- industry collaboration performance on how to reconstruct the university innovation capabilities.

II. THEORETICAL BACKGROUND

A. Self-organization theory

Self-organization refers to the formation of ordered structures by mutual understanding of the system in accordance with certain rules and duty with automatically coordinating[9-10]. Self-organization theory focus on the formation and development of complex systems and analysis the process of evolution of system from disorder to order, which has four basic conditions: open system, far from equilibrium, nonlinear interaction, fluctuations[11]. In the bio-sciences--biology, biophysics, biochemistry--'self-organization' has been established as a label for a new, overarching, paradigm focusing on the emergence and change of living structures during evolution[12]. Systems are constituted by elements and subsystems, which are described by variables, such as control variables and state variables. In addition, self-organization theory divides state variables of the system into fast variables and slow variables; State variables will promote the evolution of system, when it reaches the threshold by changing the control variable. Finally, the system will become order

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system evolved from disorder system.

B. "B-Z" reaction and knowledge triangle

In this study, knowledge triangle and its co-evolution model will be discussed based on "B-Z" reaction model. "B-Z" reaction, is a well-known non-equilibrium thermodynamics of chemical oscillation reaction, the model can be used to analyze the interaction between the three elements.

The process of university-industry collaboration is essentially a process of knowledge development and change, including access to information, knowledge production, knowledge integration, knowledge diffusion and application[13]. Knowledge Triangle Strategy aims to promote synergy and development of university- industry collaboration from three aspects of education, research and innovation, which is also the three elements of universities---scientific research, personnel training and technological innovation. Based on the "B-Z" reaction model, each subsystem of university make function independently from the micro level, the system as a whole does not have orderly behavior and does not have cross-interaction relationship; From the macro level, the benefits of the motion and collisions between three subsystems gained is more than the sum of individual benefits for each subsystem, which is called synergistic effect, such as the knowledge production from university that meets the industrial demand of technology innovation, which can enhance the contribution of science and technology to socio-economic growth. Knowledge creation from academic achievement is a source of teaching materials for education a certain way, and the training of talents in the research work can also provide pools of high-quality talents for industrial technology innovation.

III. DYNAMIC EVOLUTION MODEL OF UNIVERSITY-INDUSTRY COLLABORATION BASED ON THE KNOWLEDGE TRIANGLE

A. Variables of university system

Any system is running under environment, the relationship between system and environment determines the evolution of the system. Universities involved in the innovation process will inevitably effected by external macro-environment factors, including policy, cultural values[14] and geographic factors. In this paper, the external inputs of university system as a control variable, greatly influence the motivation of universities involved in University-Industry collaboration. The universities involved in University-Industry collaboration aims to achieve capability building through research, training and industrial innovation activities, so knowledge production capability, knowledge dissemination capability and knowledge transfer capability are sub-capabilities of university, which are also elements of university system.

B. Basic assumptions

Based on self-organization theory, this research needs to satisfy the following assumptions:

1) University system is an open system.
2) The equilibrium point for universities system to achieve co-evolution in the process of university-industry collaboration is not unique.
3) The parameters of university system is available to be quantified.

IV. MODEL CONSTRUCTION

A. Variables and Parameters

The evolution of university system in the process of university-industry collaboration needs to determine the interaction parameter between the three state variables, which is the adjustment parameters. Adjustment parameter is a set of statistics data, which can be used to measure by indicators like the reaction rate of a chemical reaction. The main variables and parameters for high education system (see Table 1).

TABLE1:THE MAIN VARIABLES AND PARAMETERS FOR UNIVERSITY SYSTEMS

Variables	Name	Explanation of variables
State variable1	State of knowledge production	Measure the level of knowledge production and development capabilities of university system in the process of university-industry collaboration;
State variable2	State of Knowledge Transfer	Measure the level of technology innovation ability of university system in the process of university-industry collaboration;
State variable3	State of knowledge dissemination	Measure the level of personnel training ability of university system in the process of university-industry collaboration;
Control variable	External input mechanisms	Describe the external investment mechanisms as motivation strength index for university system in the process of university-industry collaboration.
Adjustment parameter 1	Index for Knowledge production capability	Measure the level of knowledge production capability of university system through a comprehensive evaluation index system
Adjustment parameter 2	Index for Knowledge Transfer capability	Measure the level of knowledge transfer capability of university system through a comprehensive evaluation index system
Adjustment parameter 3	Index for Knowledge dissemination capability	Measure the level of knowledge dissemination capability of university system through a comprehensive evaluation index system

The evolution between the three abilities states within university system have similarities with the self-organization rule of the "B-Z" reaction model, which usually uses the Logistic equation to analysis the evolution. We have defined y_1, y_2, y_3 to describe the three state variables, which are knowledge production , knowledge transfer and knowledge dissemination before the construction of the Logistic equation of the dynamic evolution of the knowledge triangle. We define $\frac{dy_i}{dt}(i=1,2,3)$ as the change rate of state variable over time; α, β, γ are respectively adjustment parameters of y_1, y_2, y_3; δ is control variables in this study, which describe the external investment mechanisms as motivation strength index for university system in the process of university-industry collaboration.

B. Literature Review for Mathematical Relationship between the State Variables

By summarizing previous research, this paper identifies mathematical relationships between three state variables for university system in the process of University-Industry collaboration.

1) The synergy between knowledge production state variable and knowledge dissemination state variable. Early studies suggest that high scientific capability did not directly bring significantly rich teaching resources, and in the teaching and research relations theory more emphasis on research and teaching that may exist opposition. Broxton(1996) statistically analyzed 30 studies about teaching and research-relationship from 1962 to 1984 and found that the result is a weak positive correlation of 37%, zero correlation of 60%, a negative correlation accounted for 3%. For this reason, many scholars have tried to explore the nature of the separation between the teaching and scientific research, in particular the idea of combining the teaching and scientific research proposed, which has aim to achieve effective talent training by combining the teaching activities with scientific research. This idea was originally embodied in “reflective academic" by Boyer, who said: Research was beneficial to the teaching that was the basic concept of the University, the integration of teaching and research is the foundation for survival and development of University. In addition, Clark argued that "exploration" is an intermediary link between teaching and research, we should reject the theory of the dichotomy between teaching and research, and establish a "exploration" model , in this model, participating in research is also a kind of teaching[15]. Humboldt University in Berlin, establishes a principle of unity of research and teaching: teachers must conduct scientific research and the latest scientific research result should be used in teaching, while students should be involved in research activities in order to carry out effective learning.

Assumption 1: scientific research and personnel training has essentially consistency, meaning knowledge production state variable and knowledge dissemination state variable is mutually reinforcing.

2) The synergy between knowledge production state variable and knowledge transfer state variable. After the Humboldt reform in 19th century, scientific research has become the important mission of university, the university has been in the core center of the production of scientific knowledge. With the evolution of demand of knowledge production, knowledge production mode is also changed from "academic science" to "post-academic science". "Academic science" is pure science, whose purpose is to obtain a deep understanding of the natural world, rather than the actual use of knowledge. Then the development of "post-academic science" is in response to the needs for the application of scientific and technological development in the industrial areas. It is characterized as follows: (1) Establish a technology partnership between universities and industry, the university has paid more attention to applied science than basic science knowledge gradually, scientists have widely participated in projects commissioned by the companies with great contributions to the development of economic.

For this reason, many scholars have pointed out that there is a certain repulsion between two modes of knowledge production in university. Firstly, there are goals and value judgments conflict between the knowledge production and knowledge transfer. Industry and universities have different needs for knowledge production. The former concerns the recognition of knowledge application, while universities are concerned about the knowledge itself, which results in scientific and technological achievements provided by the University are out touch with the market, while enterprises excessive intervention university research. Businesses often have obvious profit-oriented, focusing on cooperation in economic value; university is research-oriented, consider whether cooperation is conducive to academic research.

Secondly, the contradictions reflected in the allocation of material resources. There are limit research personnel, funding and equipment in universities, the more knowledge transferred into the industrial R&D, the less knowledge production for purely scientific exploration, because the R&D activities for industry take more resources; Supporting for industrial technology innovation activities will take more time from the production of knowledge, which will result in crowding out effect for the scientific exploration of knowledge, and vice versa;

In the process of university-industry collaboration, the university must grasp the synergies between knowledge production and knowledge transfer capabilities for researchers, and identify the balance between the two capabilities.

Assumption 2: In the process of university-industry collaboration, the synergetic effect between industrial R&D and knowledge production for scientific exploration are negative in some extent;

3) **The synergy between knowledge dissemination state variable and knowledge transfer state variable**. The synergy between talents cultivation and industrial technology innovation was called "Cooperative Education", with the first program launched in 1906, aiming at addressing the gap in the demand of school education and social issues. In 2001, World Association for Cooperative Education interpreted Cooperative Education as 'By putting the classroom learning and working together, students can apply theoretical knowledge into associated work to obtain gainful employment practice, then the challenges encountered in the work and growth of knowledge will be took back to the classroom, helping them to further learning and thinking. "

In addition, studies have been explored further. Such as "Stanford-Silicon Valley" is a model of cultivate innovative talents through cooperative education, Stanford University has formed the educational philosophy of " technical-academic-productivity", there is a highly interactive contact with major companies in Silicon Valley, demonstrated by collection of innovative projects, different types of academic lectures, field trips, social interaction with renowned scholars and other activities, with the formation of innovative educational model by combining curricular and extra-curricular, teaching and practice to inspire students' innovative spirit and strengthen practical ability; Again U.S. Antioch Senanayake University has established all-round education (Whole person education) model, which requires every student in the school must take the "learning to learn in a job " way to complete their studies.

Assumption 3: In the process of university-industry collaboration, the synergy effect between talents cultivation and industrial technology innovation is positive.

V. MODEL ANALYSIS

Based on the above analysis, we come to discuss the specific quantitative relationship between the three variables of university system:

Firstly, for knowledge production variables of university system y_1, Logistic evolution equation is as follows:

$$\frac{1}{\alpha}\frac{dy_1}{dt} = \delta y_1 - \delta\frac{\beta}{\alpha}y_2 + \lambda y_1 y_3 \qquad (1)$$

δy_1 describes the impact factor of knowledge production variables, which means that the external environment mechanisms will play a catalytic role in knowledge production capability over time. $-\delta\frac{\beta}{\alpha}y_2$ describes that universities tend to allocate research resource to knowledge transfer projects, and not knowledge production projects, which will result in that the accumulation of knowledge itself will fall under the influence of the control variables. $\lambda y_1 y_3$ describes that the dissemination of knowledge is not subject to external factors in the early time, but the interaction between the knowledge production and dissemination of knowledge may promote the knowledge production capability of university system over time.

Secondly, in terms of knowledge transfer state of university system, Logistic evolution equation is as follows:

$$\frac{1}{\beta}\frac{dy_2}{dt} = \delta y_2 - \alpha\delta y_1 y_2 + \frac{\gamma}{\beta}y_3 \qquad (2)$$

δy_2 describes that the control variable have positive influence on y_2. $-\alpha\delta y_1 y_2$ describes that y_1 has negative effect on y_2 under the influence of the control variable, because there is a dilemma for resource allocation in the process of university-industry collaboration, firstly, knowledge transfer depends on knowledge production capability, and then it will generate crowding effect on knowledge production. $\frac{\gamma}{\beta}y_3$ describes that State of knowledge dissemination y_3 has impact on the state of knowledge transfer y_2, knowledge dissemination ability can promote the industrial technology innovation by cultivating talents.

Finally, considering that the state of knowledge dissemination has time lag, because the personnel training needs much more time, the state variables Logistic evolution equation is as follows:

$$\frac{1}{\lambda}\frac{dy_3}{dt} = \eta_1 y_3 + \eta_2\delta\frac{\alpha}{\lambda}y_1 \qquad (3)$$

$\eta_1 y_3$ describes that the state of knowledge dissemination y_3, has positive impact factor by itself over time. In the absence of outside influence, knowledge dissemination variables that describe the ability of personnel training is rising under the background of personnel training enrollment policy. $\eta\delta\frac{\alpha}{\lambda}y_1$ describes that knowledge production variables are influencing factors of the knowledge dissemination variables, namely knowledge production capability has the ability to promote the dissemination of knowledge. $\frac{\alpha}{\lambda}$ is the impact factor, η_2 is a constant (usually greater than 1, reflecting that knowledge production of the university system has multiplier effect on talents training).

(1), (2), (3) constitute collaborative evolutionary model of university system based on the Logistic evolution equation, such as (4)

$$\begin{cases} \frac{1}{\alpha}\frac{dy_1}{dt} = \delta y_1 - \delta\frac{\beta}{\alpha}y_2 + \lambda y_1 y_3 \\ \frac{1}{\beta}\frac{dy_2}{dt} = \delta y_2 - \alpha\delta y_1 y_2 + \frac{\gamma}{\beta}y_3 \\ \frac{1}{\lambda}\frac{dy_3}{dt} = \eta_1 y_3 + \eta_2\delta\frac{\alpha}{\lambda}y_1 \end{cases} \qquad (4)$$

Among them, η_1, η_2 are the coefficients and assumptions as follows:

$\eta_1=2$, The knowledge dissemination capabilities of university system namely personnel training capabilities are increasing

$\eta_2=2$, The knowledge production capability of university system has a strong role in promoting the dissemination of knowledge

Definition and analysis of α, β, γ, δ see Appendix 2

Finally, we obtain complete mathematical evolution model, the formula (5) shown as follows:

$$\begin{cases} \frac{dy_1}{dt} = \alpha\delta y_1 - \beta\delta y_2 + \alpha\lambda y_1 y_3 \\ \frac{dy_2}{dt} = \beta\delta y_2 - \alpha\beta\delta y_1 y_2 + \lambda y_3 \\ \frac{dy_3}{dt} = 2\alpha\delta y_1 + 2\lambda y_3 \end{cases} \quad (5)$$

Further, according to the Hurwitz discrimination method, for the linear system, when all real part of eigenvalues are negative, the system is stable, the determine conditions are that (1) all coefficients of eigenvalue equation is greater than 0; (2) The determinant value of Hurwitz and its principal minor are greater than 0.

Finally, we obtained condition for the system reaches steady state as follows:

$$\begin{cases} \alpha\delta - \beta\delta - 2\lambda > 0 \\ 2\beta\lambda - 2\alpha\lambda - \alpha\beta\delta > 0 \\ \alpha\beta(\beta-\alpha)\delta^2 + 2\lambda(\alpha\beta - \alpha^2 - \beta^2)\delta + 4\lambda^2(\alpha-\beta) > 0 \end{cases} \quad (6)$$

Meanwhile, according to the stability theory of differential equations, we analysis the stability of equation (6), the solution was the following equations:

$$\begin{cases} -\alpha\delta y_1 - \beta\delta y_2 + \alpha\lambda y_1 y_3 = 0 \\ \beta\delta y_2 - \alpha\beta\delta y_1 y_2 + \lambda y_3 = 0 \\ 2\alpha\delta y_1 + 2\lambda y_3 = 0 \end{cases} \quad (7)$$

Get the equation is:

$$P_1(0,0,0),\ P_2 = \left(\frac{\sqrt{2}}{\alpha}, \frac{-\sqrt{2}-2}{\beta}, \frac{-\sqrt{2}}{\lambda}\delta\right),\ P_3 = \left(-\frac{\sqrt{2}}{\alpha}, \frac{\sqrt{2}-2}{\beta}, \frac{\sqrt{2}}{\lambda}\delta\right)$$

Which are balance equations when the time tends to infinity, i.e. the balance equations of ability to form ordered structures when the three capabilities of university system achieve steady state conditions by synergistic interactions overtime.

VI. SIMULATION

According to the description of the equation (5), we set the initial state variables to simulate the evolution law of knowledge production, knowledge transfer, and knowledge dissemination in university by using the simulation software of Matlab7.5.0.

A. Level index

Under the guidance of U-I cooperation policy and development goals, universities need to establish a balance between knowledge production, knowledge transfer and knowledge dissemination. This article sets α=β=λ=1/3 to reflect the state of equilibrium, which means research universities as an important part of our country's colleges and universities take the same responsibility of scientific research, personnel training and technical innovation at the same time, with the goals to maintain scientific research competitiveness of research universities in our country, meet the requirements of personnel training and industrial technology for national industry development.

B. Input mechanism index

Input mechanism index describes the comprehensive level of motivation strength for universities to participate in U-I cooperation under the influence of external environment system. This paper adopts the variable parameters δ to reflect this level, from δ=1 to δ =10 respectively. First, δ=1 means that the comprehensive level of motivation strength for universities to participate in U-I cooperation is low, and the influence of external environment system on universities is weak; δ=10 means that the comprehensive level of motivation strength for universities to participate in U-I cooperation is high, and the influence of external environment system on universities is strong, which also means that external input mechanism has a great impact on the knowledge production, knowledge transfer and knowledge dissemination in the evolution process of U-I cooperation.

C. The initial state value

Only reflect the evolution system In this paper, we set up the initial state value X_0 = [1, 0, 1] for knowledge production, knowledge transfer and knowledge dissemination in the differential equation, that is to say, the initial state value for knowledge production is 1, which means research universities only focus on scientific research and talent training in the early stages and the scientific research and talent training were original target and basic functions for research universities. Technological innovation is the basic function for the enterprise, is not a basic duty of the universities, with the development of the interaction between universities and industries, more and more colleges and universities bear the service of personnel training and technology innovation for the enterprise or industry by the diffusion and transfer of knowledge with the aim to promote the value of scientific research and talent cultivation in colleges and universities.

VII.THE RESULTS

A. The weak input mechanism δ=1

The fig. 1 shows that under the environment of weak input mechanism, the system of university's scientific research eventually cannot reach steady state. Especially, the knowledge production ability is falling strongly. That means, under the external weak input mechanism, due to the limited resources in colleges and universities, the weakening of scientific research will result in disordered system structure, which will adverse to long-term development of U-I collaboration.

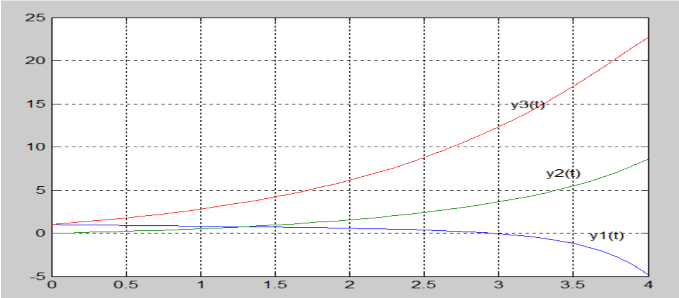

Fig. 1: The disorder status within the system of university

B. *The strong input mechanism δ=10*

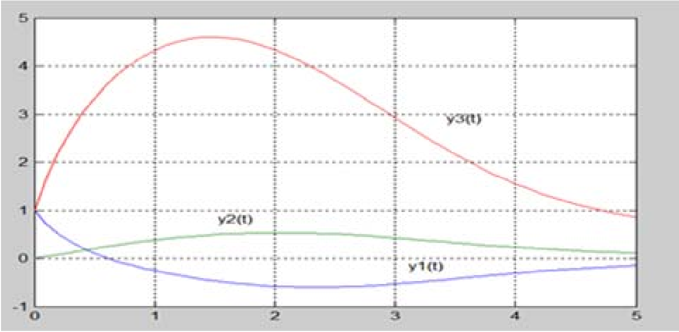

Fig. 2: The order status within the system of university

The fig. 2 shows that under the environment of strong input mechanism, the three ability of universities also have changed, and finally reached a state of balance (i.e., functions are ultimately toward a convergence point). It indicates universities need to rely on external necessary resources and policy support of the input mechanism to effectively improve the coordination of knowledge production, knowledge transfer and knowledge dissemination. Under the strong input mechanism of U-I cooperation, the university internal system will become a self-organized system, and after a certain period of development , the subsystems of knowledge production, knowledge transfer and knowledge dissemination, finally formed a stable and orderly state, and achieve synergy.

VIII. CONFIRMATORY CASE ANALYSIS AND DISCUSSIONS

In order to further predict the evolution rule between knowledge production, knowledge transfer and knowledge dissemination capabilities1 by using the Matlab7.5.0 mathematical software, the paper selected related indicator data of 64 universities directly under the ministry of education to calculate the average standard of the adjustment parameters and control variables in mathematical model, then calculated the ratios of 3 universities indicator data and average standard to get the dimensionless indicator data. The related data and the ratio of the three universities we had done case studies, see Appendix Table 2 and Table 3.

Meanwhile, according to the adjustment parameters and the control variable calculation formula, we obtain 3 universities adjustment parameter value of the control variable as shown in Table 4.

A. The evolutionary trajectory of Tsinghua University system

From the fig.3, we found that: under the environment of strong input mechanism, Tsinghua University system achieved order status in the shortest time (0-1), and there is relative convergence between the abilities of knowledge production, knowledge dissemination and knowledge transfer. Among them, knowledge dissemination capability developed at a higher rate of growth in the shortest time (0-0.5), and tended to return at a faster rate (0.5-10). Finally, personnel training achieved a stabilization mechanism. Meanwhile, the mutually exclusive relationship between the performance of knowledge production capability and knowledge transfer capability was more gentle, which reflected that Tsinghua University system was better able to deal with the resource allocation during the U-I collaboration to some extent. Overall, the performance of Tsinghua University is more active, the synergies between knowledge production, knowledge dissemination and knowledge transfer capabilities are more stable.

TABLE 4: VALUES OF ADJUSTMENT PARAMETER α, β, λ AND CONTROL VARIABLE δ FOR THE 3 UNIVERSITIES

University	Tsinghua university	Nanjing university	Wuhan university of technology
Adjustment parameter α of Knowledge production capability	α1	α3	α6
	3.546	1.324	0.770
Adjustment parameter β of Knowledge Transfer capability	β1	β3	β6
	2.720	0.210	0.684
Adjustment parameter λ of Knowledge dissemination capability	λ1	λ3	λ6
	2.202	0.770	1.439
Control variable δ	δ1	δ3	δ6
	5.164	1.429	0.939

Specifically, the characteristics of the evolutionary trajectories of the 3 universities systems are shown as follows:

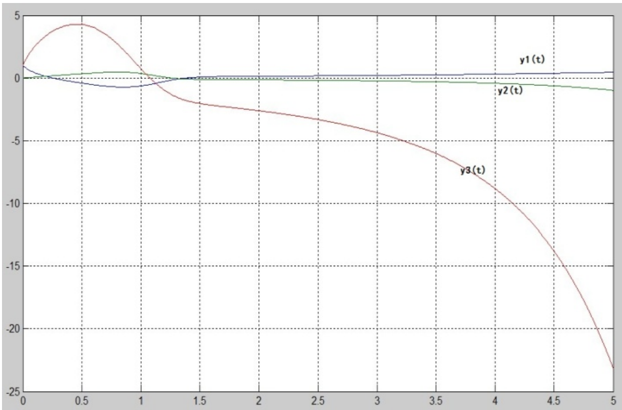

Fig. 3: Evolutionary trajectory of Tsinghua University system

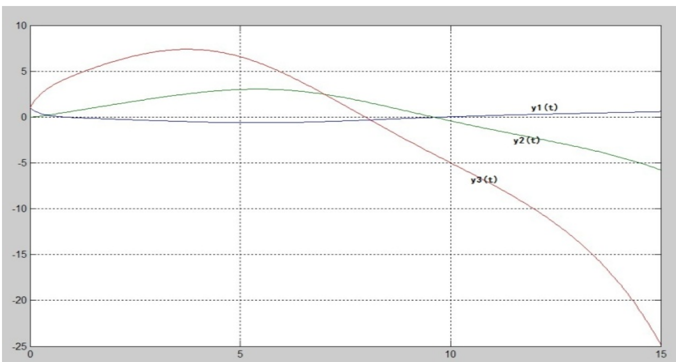

Fig.4: Evolutionary trajectory of Nanjing University system

B. The evolutionary trajectory of Nanjing University system

From the fig. 4, we found that: under the environment of relatively weak input mechanism, the evolutionary tracks of Nanjing University system reached to the stable state between the capabilities of knowledge production, knowledge dissemination and knowledge transfer in a relatively slow time interval (0-8). Among them, knowledge dissemination capability are growing at relatively slow (0-4) time interval firstly, and then tends to return in the time interval (4-8), which means personnel training finally achieved a stabilization mechanism at a relatively long time. Meanwhile, the mutually exclusive relationship between the knowledge production capability and knowledge transfer capability is more evident in the time interval (5-6), and compared to the performance of knowledge production capability, the performance of knowledge transfer capability is even stronger. So under this condition, when the management departments want to deal with problems related to the allocation of resources, they need to focus on the development of the knowledge production capability. Overall, Nanjing University system is relatively stable, but compared to Tsinghua University system, the synergy between knowledge production, knowledge dissemination and knowledge transfer capabilities is weak.

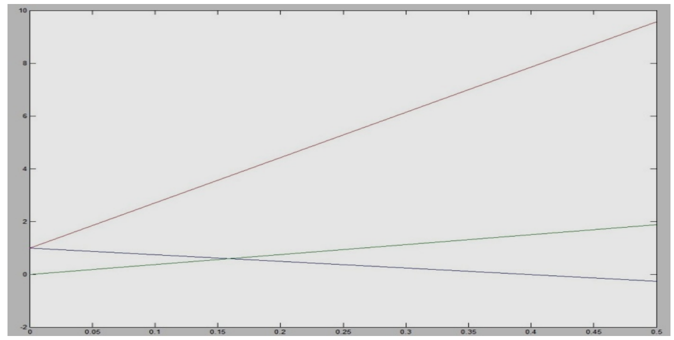

Fig. 5: Evolutionary trajectory of Wuhan University of technology system

C. The evolutionary trajectory of Wuhan University of technology system

From the fig.5, we found that: under the environment of lack input mechanism, the evolutionary tracks of Wuhan University cannot be met to achieve convergence and orderly state condition. From a short period of beginning time range (0-0.5), the synergy between knowledge production, knowledge dissemination and knowledge transfer capabilities evolves toward a state of disorder divergence. Although, knowledge dissemination capability is growing relatively fast at the (0-0.5) interval, but we can't make sure if the Talents training will achieve stabilization mechanism or not in the future. In addition, the mutually exclusive relationship between the knowledge production capability and transfer knowledge ability is strong in a short time interval (0-0.5), the decreasing trend of knowledge production capability restricts the overall development of U-I collaboration to a certain extent. Therefore, if the university administration departments want to change the situation of relatively weak innovation capability, first of all, they must actively create a favorable external environment for U-I collaboration with strong external funding, including research and financial assistance. Secondly, when the administration departments want to deal with the allocation of resources, especially need to strengthen the capability building of knowledge production with the aim to improve the unfavorable situation of U-I collaboration foundation. Overall, Wuhan University of Technology system has relatively weak synergy between the three capabilities, and needs further development.

IX. OUTLOOK AND DISCUSSION

Generally, the uncertainty of public management policy is the chief problem of policy makers. Under the background of U-I collaboration, as a university system, how to make use of their own advantages of capability to promote the interaction between the scientific research, personnel training and industrial technology innovation is an important issue for their capability-building and the development of U-I collaboration. By taking advantage of the similarity between self-organization phenomena "B-Z" reaction system and the university system, we establish an evolution model of the three capabilities include knowledge production, knowledge dissemination and knowledge transfer within university system based on the Self-organization theory. Then, we got three balance points of the evolution model by stabilizing analysis (shown as Equation 6).At these points, the university system has formed an ordered structure through self-organizational behavior, and jointly promoted the development of U-I collaboration. Then, we make a confirmatory case analysis by using mathematical simulation models under different input mechanisms of three university systems.

According to the results, we made a conclusion that although it is difficult to develop capability building programs in strict accordance with the conditions of steady-state of university system in the actual process of management, in order to achieve the synergy of resources, the university administration needs to achieve and maintain stable conditions and balance ability points through a variety of means and methods, such as building a variety of incentives to adjust the allocation of resources to strengthen the capability building.

In the future, this research needs to further improve the model parameters (θ, α, β, γ) quantitative indicators, so that it can be more fully reasonable to simulate the evolutionary trends of capabilities within the university system in the process of U-I collaboration. Meanwhile, this study needs to fully simulate the path to achieve stability condition and parameters equation for university system from the real practice, making this kind model based on complexity science truly become real effective decision-making tool to solve our public management problems.

X. MANAGEMENT IMPLICATION

The research analyzes the mechanism of promoting U-I collaboration innovation by keeping the dynamic balance of knowledge production capability, knowledge dissemination capability and knowladge transfer capability, the management implication is as follows: (1). Strengthening the leading role of knowledge production capability. The results indicate that in the collaboration innovation process, knowledge production capability is only the dominant factor affecting the collaborative innovation performance but also the order parameter in the evolution of self-organization of university research system.As the fundamental strategic objective on science research,deciding the competitiveness of university, university knowledge capability has a direct impact on the level of activity of collaboorative innovation; (2). Strengthening the input mechanism of collaborative innovation and building the dynamic mechanism of university's internal capabilities. The internal capability of university research system is influenced by external control factors, that with the high external innovation incentives, internal capabilities tend to be under orderly state. Thus, in the U-I collaborative innovation process, different development needs of knowledge production capability, knowledge dissemination capability and knowladge transfer capability should match the appropriate resource input such as financial input, infrastructure input and human resource input; (3). Improving the balance mechanism of U-I collaborative innovation capabilities.Management of university research system needs to rely on the capabilities evolution rule which indicates the influence between different capability and innovation performance.

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APPENDIX 1

TABLE2: THE RELATED DATA FOR THE INDICATORS OF THE THREE UNIVERSITY SYSTEMS

		Tsinghua university	**Nanjing university**	**Wuhan university of technology**
Knowledge production capability	Personnel number for R&D	3810	1212	1639
	Published papers in international conference	2431	1527	149
	Science and Technology Achievement Award	86	22	26
	Published Academic papers	10941	4163	3050
Knowledge dissemination capability	Published works of science and technology	94	16	48
	Number of teaching staff	2079	1138	1880
	Number of graduate students	6602	3035	3991
Knowledge Transfer capability	Personnel number of Science and technology service	291	185	295
	The real incomes for technology transfer	306567	3845	14100
	Actual funding for R&D application (T RMB)	62070	75594	4411
	Actual funding for technology services (T RMB)	58366	213	70545
Control variable	Funds for basic research(T RMB)	671584	318021	44791
	Funds for R&D (T RMB)	1444619	106317	263976
	Education funds (T RMB)	125601.57	76385.59	62001

TABLE3: THE RATIO OF DATA RELATED INDICATOR FOR THE THREE UNIVERSITY SYSTEMS

		Average standard	**Tsinghua university**	**Nanjing university**	**Wuhan university of technology**
Knowledge production capability	Personnel number for R&D	1368.063	2.785	0.886	1.198
	Published papers in international conference	513.453	4.735	2.974	0.290
	Science and Technology Achievement Award	23.141	3.716	0.951	1.124
	Published Academic papers	3390.922	3.227	1.228	0.899
Knowledge dissemination capability	Published works of science and technology	31.734	2.962	0.504	1.513
	Number of teaching staff	1267.594	1.640	0.898	1.483
	Number of graduate students	3004.719	2.197	1.010	1.328
Knowledge Transfer capability	Personnel number of Science and technology service	258.406	1.126	0.716	1.142
	The real incomes for technology transfer	16387.859	18.707	0.235	0.860
	Actual incomes for R&D application (T RMB)	38463.609	1.614	1.965	0.115
	Actual incomes for technology services (T RMB)	36255.078	1.610	0.006	1.946
Control variable	Funds for basic research(T RMB)	76380.047	8.793	4.164	0.586
	Funds for R&D (T RMB)	278260.609	5.192	0.382	0.949
	Education funds(T RMB)	41633.557	3.017	1.835	1.489

APPENDIX 2

DEFINITION AND ANALYSIS OF α, β, γ, δ

Variables	Name	Explanation of variables	Indicators of variables
$\delta = \sqrt[i]{\prod_{i=1}^{n} \frac{\delta_i}{\bar{\delta}_i} k_{\delta_i}}$	Control variable	Describe the external investment mechanisms as motivation strength index for university system in the process of university-industry collaboration.	δ_i（i=1,2,3）reflect "Funds for basic research(T RMB)", "Funds for R&D (TRMB)", "Education funds(TRMB)" for university system each year. $\bar{\delta}_i$ reflect Average standard for all university systems, k_{δ_i} reflect weight coefficient for each indicator.
$\alpha = \sqrt[i]{\prod_{i=1}^{n} \frac{\alpha_i}{\bar{\alpha}_i} k_{a_i}}$	Adjustment parameter 1	Measure the level of knowledge production capability of university system through a comprehensive evaluation index system	According to the China statistical yearbook of science and technology of colleges and universities, α_i（i=1,2,3,4,5）reflect "Personnel number for R&D", "Published papers in international conference" "Science and Technology Achievement Award", "Published Academic papers". $\bar{\alpha}_i$ reflects Average standard for all university systems, k_{a_i} reflect weight coefficient for each indicator.
$\beta = \sqrt[i]{\prod_{i=1}^{n} \frac{\beta_i}{\bar{\beta}_i} k_{\beta_i}}$	Adjustment parameter 2	Measure the level of knowledge dissemination capability of university system through a comprehensive evaluation index system	According to the China statistical yearbook of science and technology of colleges and universities, β_i（i=1,2,3,4,5）reflect "Published works of science and technology", "Number of teaching staff", "Number of graduate students". $\bar{\beta}_i$ reflect Average standard for all university systems, k_{β_i} reflect weight coefficient for each indicator
$\lambda = \sqrt[i]{\prod_{i=1}^{n} \frac{\lambda_i}{\bar{\lambda}_i} k_{\lambda_i}}$	Adjustment parameter 3	Measure the level of knowledge transfer capability of university system through a comprehensive evaluation index system	According to the China statistical yearbook of science and technology of colleges and universities, λ_i（i=1,2,3,4,5）reflect "Personnel number of Science and technology service", "The real incomes for technology transfer ", "Actual incomes for R&D application (TRMB)", "Actual incomes for technology services (TRMB)", $\bar{\lambda}_i$ reflect Average standard for all university systems, k_{λ_i} reflect weight coefficient for each indicator;;