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Exploring the Triple Helix Synergy in Chinese National System of Innovation

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Abstract: Sustainable economic growth is closely linked to synergy in a national system of innovation. Although the dynamic synergy mechanism of the triple helix relations is essential to technology innovation, there are limited research methodologies to study or estimate the synergy effect accurately. This paper introduces a new approach in non-linear complex systems theory to offer steps towards a possible solution to this conundrum. Based on the pattern formation of the Belousov-Zhabotinsky's reaction, the paper constructs a simulation equation to explore the evolution mechanism by comparing the ideal state with the current state in China. The research finds that (1) under the ideal balanced condition of industrial absorptive capacity and academic knowledge transfer capability, the stronger incentive policies would play much more important roles than weak policies; (2) the performance of collaborative innovation is not optimal under current situation in China, but the industrial absorptive capacity, especially in private enterprises, has exceeded the capability of knowledge transfer in academia, and it has become the main driving force to promote future innovation. If the innovation policy can be focused on the high-level balance between the knowledge network and innovation network to promote synergy in China, the innovation performance will be accelerated more efficiently.

Keywords: triple helix; synergy mechanism; national system of innovation; China

1. Introduction

The sustainability of China's hitherto economic miracle is in question. As may come to pass for some developing nations, China also stands at a critical juncture between its catch-up phase that has relied on technology adaptation and one that springs from its capacity for knowledge generation and technology innovation. The national system of innovation (NSI) of a country in catch-up mode is different from one at the technology frontier. Different domestic economic and social contexts also mean that what works in the national system of innovation, synergy mechanism among university-industry-government in one country may not work in another. Sustainable economic growth is closely linked to the adaptability of NIS and the synergy of Triple Helix (TH) in NSI.

According to *the National Science and Technology Investment Statistics Bulletin 2018* issued by the National Bureau of Statistics of China on August 30 in 2019, the total national R&D expenditure in 2018 reached 19,666.7 billion yuan RMB, ranking the second in the world after the United States, which accounted for 2.19% of GDP with a total of 4.18 million R&D personnel, exceeding the average level of EU-15 countries. Among them, the expenditure of research institutions affiliated to the government is 269.17 billion yuan (accounting for 13.7%), the expenditure of colleges and universities is 145.79 billion yuan (accounting for 7.4%), the expenditure of state-owned and private enterprises is 1523.37 billion yuan (accounting for 77.4%); meanwhile, the expenditure of basic research is 109.04 billion yuan (accounting for 5.5%), the expenditure of applied research is 219.09 billion yuan (accounting for

11.1%), and the expenditure of experimental development is 163.96 billion yuan (accounting for 83.3%). Although the financial expenditure on science and technology in 2018 reached 951.8 billion yuan, considering the tax preferential policies such as additional deduction of firm's R&D expenditure and reduction of income tax of high-tech enterprises, the proportion of the government's actual investment in science and technology in the whole society has far exceeded 50% in China.

Driven by the continuous R&D investment mainly dominated by government, the number of international scientific papers and citations ranked second in the world and 244.75 million patents were authorized in 2018, however, private enterprises with less government funding have contributed 70% of the innovation outcomes. According to the latest global innovation ranking released by the World Intellectual Property Organization and Cornell University, China's innovation index in 2019, despite rising three places, still ranks 14th in the comprehensive ranking. This innovation index ranking of China is roughly in the same range as which published by China Academy of science and technology strategy, or Lausanne International School of management in Switzerland. The overall quality of NSI in China is far from meeting the requirements of building an innovative national strategy. The announcement of the 2019 National Conference on Science and Technology points out that there are some shortcomings of Chinese NSI, such as the research mechanism of key core technologies, the construction of innovation capacity, the cultivation of high-end talents, the allocation of resources, and refinement of the innovation ecology. As can be seen from the announcement, there are still some serious problems of asymmetric structure between the knowledge network and innovation network in the NSI in China. How to break down asymmetry between knowledge network and innovation network to realize higher-level equilibrium, it becomes the key point of sequential 2021–2035 National Medium and Long-Term Science and Technology Development Plan.

The synergy of NSI is closely linked to the function of TH in NSI, which is essential to knowledge generation and technology innovation of a country. Although building on the evolutionary theorizing by Nelson and Winter [1], the metaphor of NSI emerged in the late 1980s. Knowledge-Based Economy (KBE) has elaborated on NSI from an evolutionary perspective [2] since the mid-1990s, whereas TH can only be considered as an institutional elaboration [3], Due to limited research methodology to study the TH dynamic evolution mechanism of academic-industry-government relations, or to estimate accurately the synergy effect among them. This paper introduces a new approach in non-linear complex systems theory to offer steps towards a possible solution to this conundrum. Based on the pattern formation of the Belousov-Zhabotinsky (BZ) reaction, the paper constructs a simulation equation to explore the synergistic evolution mechanisms by comparing the ideal state with the current state of TH in China.

The simulation results demonstrate that (1) under the ideal balanced condition of industrial absorptive capacity and academic knowledge transfer capability, the stronger incentive policies would play much more important roles than weak policies; (2) current situation in China, the performance of collaborative innovation remains dismal at best, but the industrial absorptive capacity, especially in private enterprises, has exceeded the capability of knowledge transfer in academia, and it has become the main driving force to promote international merger and acquisition and global open innovation. If the innovation policy can be focused on the high-level balance between the domestic knowledge network and innovation network in NSI of China, the innovation performance will be accelerated more efficiently.

The subsequent parts of the paper are organized as follows. Section 2 reviews the literature on the TH in NSI. Research methods and variable refinement are discussed in Section 3, followed by Section 4 that presents the findings and their analysis. The conclusion is proposed in Section 5. The main contribution of this paper is to introduce a simulation method in non-linear complex systems theory into the research field of TH synergy in NSI, by which reveals the dynamic evolutional mechanism among TH in Chinese NSI.

2. Literature Review

Since the 1980s, market competition has become increasingly fierce, uncertainty has increased significantly, and product innovation and process innovation have shown a trend of systematization and complexity. Sahal distinguished among (i) material innovations “which are necessitated in an attempt to meet the requisite changes in the criteria of technological construction as a consequence of changes in the scale of the object”, (ii) structural innovations “that arise out of the process of differential growth whereby the parts and the whole of a system do not grow at the same rate”, and (iii) systemic innovations “that arise from integration of two or more symbiotic technologies” [4]. The resources and capabilities owned by a single enterprise are often unable to meet the minimum threshold requirements of complex product system. Open innovation at the micro-level and collaborative innovation at the macro level have gradually replaced the traditional closed standalone model.

After a visit to Japan, Freeman noted that Japan could be considered as NSI [5]. Lundvall further argued that interactions within national contexts might be more effective than cooperation within industry or standalone within one firm [6]. NSI combines the claims that innovation is systemic [6], that innovation systems are evolving [7] and organized institutionally, and therefore influenced by and susceptible to government policies at national or regional levels [8,9]. NSI thus seeks to combine the perspectives of policy analysis, institutional analysis, and (neo-) evolutionary theorizing [10]. In a national system of innovation, redundancy plus uncertainty (information) constitutes its maximum entropy. Redundancy can be considered as options that have not (yet) been realized, whereas uncertainty provides a measure of the options that have already been realized [11]. Increased redundancy reduces relative uncertainty [12]. Redundancy is generated in triple-helix relations because of partial overlaps in providing different meanings to the events from political, managerial, and technological perspectives [13].

The TH was first defined by Etzkowitz & Leydesdorff, in terms of links among universities, industries, and government(s) as institutional relations [3]. Etzkowitz argued that systems are innovative insofar as they generate new options from synergies among geographical, technological, and organizational factors [10]. The relations among academia, industry and government can be redefined in the light of new technological options, and institutions can substitute for each other’s functions to a certain extent. Universities can take on entrepreneurial roles to engage in the wider society on all scales in order to contribute to social and economic development [14], industry can organize academic education and research, The resulting overlay of relations and communications can develop a dynamic of its own [15]. The TH perspective becomes functional because it makes the synergetic pattern of university-industry-government relations in NSI clear.

Regarding the application of TH model in China, a large number of studies have emerged for analyzing the innovation system since Zhou introduced the concept of the TH relations in NSI into China [16]. These studies include, for example, the development of the Triple Helix model in a specific industrial field [17] or a specific region [18], the technology transfer between university and industry [19]. However, few of them have tried to provide a systematic evaluation of the implementation of the Triple Helix model in China [20], hitherto, the research methodologies to study or estimate accurately the synergy effect is still limited. Leydesdorff pointed out that the three main functionalities in the TH-triangle can be considered as (i) knowledge production (carried primarily by academia), (ii) wealth generation (industry), and (iii) normative control (governance) [21]. In order to build TH indicators of synergy, academic knowledge transfer capacity, industrial knowledge absorption capacity and innovation policy are reviewed as below.

2.1. Academic Knowledge Transfer Capabilities

Knowledge transfer between academia and industry is considered an important driver of innovation and economic growth as it eases the commercialization of new scientific knowledge within firms [22]. Bloedon and Stokes defined the concept of knowledge transfer as a process, by which knowledge concerning the making or doing of useful things contained within one organized setting is brought into use within another organizational context [23]. The capabilities of knowledge generation and transfer capabilities in academia, are progressively being recognized as an important factor for structural economic growth especially in contemporary knowledge economies, and higher education institutions (HEIs) and public research institution (PRIs) are generally accepted as places for science and knowledge creation [24], as a society improves its knowledge base by creating more efficient and effective ways of functioning. The flow of information and knowledge from researchers to the wider practice community through lectures, papers, patenting, licensing, joint ventures, spin-offs and other forms of knowledge dissemination and transfer, is often ineffective and problematic, therefore leaving what is commonly referred to as the research-practice gap [25].

The gap occurs when the research undertaken by academia is thought to have little or no relevance (usefulness) to the practice or profession it is portrayed to be assisting. Issues surrounding the 'appliedness' of research have been discussed over a long period of time [26]. Biglan categorized academic fields into 'applied' disciplines, which are generally linked to theory and knowledge being applied in a practical sense, as opposed to 'basic' or 'pure' research fields, which focus on developing theoretical and conceptual understanding [27]. In an empirical investigation on maintenance management models, Fraser et al. found that a leading engineering journal had empirical evidence rates as low as 1.5%, or put another way, out of 100 published articles on the topic, only 1.5 articles presented any form of links to practice [28].

Another issue which is believed to be intertwined with the increasing problems associated with the transfer of knowledge and the research-practice gap is the ambiguity of knowledge that transferred by academics. Tacitness and explicitness (related to knowledge ambiguity) moderated knowledge transfer negatively [29]. Although most researchers feel their work has clear relevance to decision-makers, but most decisionmakers think the research community is not helpful to them [30]. Fraser et al. discuss how the manufacturing and engineering literature is saturated with sophisticated mathematical/theoretical models [31]. While the criticism is mainly anecdotal, it is argued the many academics lack practical, industry-based experience, and are training engineering students and researching innovation problems, having never worked in the industry themselves [32]. The poor-level relevance of academic research to make a difference in solving societal problems and suggest some changes which need to occur, such as the closeness of a partnership relationship, consensus of goals, tolerance of cultural differences, and so on. Therefore, this paper characterizes academic knowledge transfer capabilities with three indicators, which are useful knowledge generation ability, knowledge interpretation ability and knowledge dissemination ability.

2.2. Industrial Knowledge Absorbing Capabilities

Grant confirms the importance of knowledge as the most strategically important resources of the firm [33], Kogut and Zander maintain knowledge is the main determinant of competitive advantage [34]. Accordingly, the strategic importance of knowledge strongly reinforces the relevance of absorptive capacity as a key resource in developing and increasing a firm's knowledge [35]. The knowledge-based view of absorptive capacity is an outgrowth of the resource-based view of the firm proposed by Barney which highlights the impact of partner contributions and outward knowledge transfer to absorptive capacity. According to Barney, firm resources are all capabilities, processes, attributes, assets, information, and knowledge controlled by a firm, which can be strategically manipulated to gain competitive advantage [36]. Organizational level absorptive capacity was introduced by economists Cohen and Levinthal seminal work explaining why organizations invest in research and development [37]. Building on the concept of dynamic capability proposed by Barney, Zahra and George furthered the theoretical base of absorptive capacity as a dynamic capability related to the management and successful exploitation of knowledge [38]. The knowledge-based view of absorptive capacity stresses the importance of promoting organizational learning, developing knowledge, enhancing open innovation, managing alliances, creating strategic variety, and impacting financial performance.

The relevance of ambiguity and absorptive capacity in the context of the research-practice collaboration was confirmed by Santoro and Bierly [29]. They showed that technological relatedness and technological capability (which increases absorptive capacity) were the most important facilitators of knowledge transfer in the process of collaborations. Volberda et al. highlight the impact other factors such as a dynamic environment have on the level of absorptive capacity [35].

Absorptive capacity conceptualized an organization's ability to exploit external knowledge through a sequential process to recognize the value of external knowledge, assimilate this new knowledge through exploratory learning, and apply assimilated knowledge to create new knowledge and value. Thus, this paper uses three indicators of "knowledge exploratory learning ability, knowledge-sharing ability and knowledge application ability" to characterize the industrial absorption ability.

2.3. Innovation Policy in China

The knowledge emanating from research is often seen as resulting in positive externalities [39], thus exhibiting some characteristics of a public good. A public good can be defined as a good that is non-rival in its usage and is non-exclusive [40]. These properties of knowledge imply that an economy may benefit extensively from investments in knowledge development, as it tends to spill over into the economy [41]. This characteristic of knowledge as a public good does imply that markets are likely to under-supply it. The theoretical motivation for public investments stems from the notion that if the benefits of new knowledge are distributed beyond those who developed it, a market economy may generate a sub-optimal amount of research and innovation [42].

While promulgated *Outline* of the National Medium-and Long-Term Science and Technology Development Plan (2006–2020), the strategy of building an innovative country, which focused on improving triple helixes relations in NSI, was officially launched in China. Since the implementation of the plan, the R&D expenditure has been steadily improved. 94.4% of R&D funds were invested in applied research projects nowadays, but policy environments are evidently far from optimal because the technology neck problem of enterprises in various industries is still quite common, and the efficiency and effectiveness of technology transformation are still far from expected. For example, by the end of 2016 only 5034 patents and 2461 authorized patents had been transferred or licensed by 38 Central Universities in Beijing and 42 research institutes of Chinese Academy of Sciences in Beijing, accounting for only 7.8% and 9.2% of the total number of authorized patents [43].

Efforts to promote synergy of TH in NIS have been the focus of public innovation policy which concerned with fine-tuning an established system, exploring best practices of policy interventions and enabling factors of commercialization or specific transfer mechanisms. Especially in recent years, China has promoted the revision of the Law on the Promotion of the Transformation of Scientific and Technological Achievements and promulgated Several Provisions on the Implementation of the Law of the People's Republic of China on the Promotion of the Transformation of Scientific and Technological Achievements, and formulated the Action Plan for the Promotion of the Transformation of Scientific and Technological Achievements, which constitutes a "trilogy" for the promotion of the transformation of scientific and technological outcomes. At the same time, the State Council has also issued Notice of the State Council on Printing and Distributing the Construction Plan of the National Technology Transfer System and Notice of the State Council on Measures to Optimize Scientific Research Management and Improve Scientific Research Performance. In general, the optimization measures of innovation policy mainly include increasing investment in industrial R&D, improving the quality of academic research, optimizing the innovation environment and strengthening the transformation of scientific and technological achievements. Therefore, this paper uses three dimensions of "academic incentive policy, industrial incentive policy and environmental incentive policy" to characterize the current innovation policy indicators.

Based on the above literature analysis, the research framework of this paper is as Figure 1.

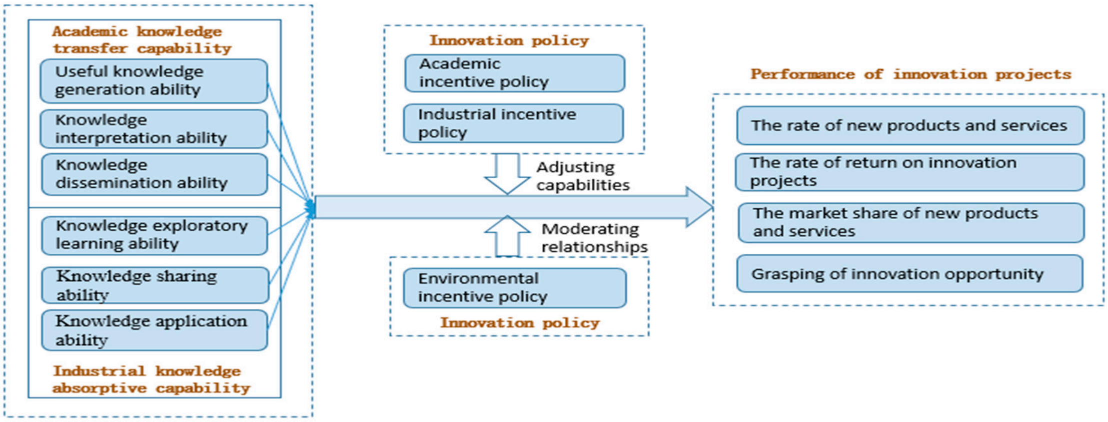

Figure 1. The research framework and relationship between main variables.

3. Simulation Model Building

In accordance with the research objectives and framework of this work, the variables and parameters should be measured to build the simulation model for exploring the dynamic evolutional mechanism of triple helix relations in NSI. Therefore, the questionnaire that uses a Likert 7-point scale to reflect the states of academic knowledge transfer capability, industrial absorptive capability and performance of collaborative innovation is constructed. Academic knowledge transfer capability is represented by three variables of useful knowledge generation ability, knowledge interpretation ability and knowledge dissemination ability; industrial absorptive capability is included by three variables of knowledge exploratory learning ability, knowledge sharing ability and knowledge application ability; the performance of collaborative innovation, is represented by four variables of the number of new products and services, the rate of return on innovation project, market share of new products and services, and grasping of innovation opportunity. Innovation policy as the intermediary variables affecting research-practice relations and innovation collaboration is represented by academic incentive policy, industrial incentive policy and environment incentive policy. Finally, the regression analysis method will be mainly used to estimate parameters (See Table 1 for details).

Table 1. Variables and parameters.

Variable	Variable Name	Variable Explanation
State variable: x_1	Industrial knowledge absorptive capacity level	To describe the level of absorbing capability in industry
State variable: x_2	Academic knowledge transfer capacity level	To describe the spill over the level of knowledge transfer in academia
State variable: x_3	Performance level of collaborative innovation	To describe the performance state of collaborative innovation
Control variable: θ	Innovation policy	General proficiency to motivate capability and relationship of TH in NSI
parameter: α	Contribution of industrial absorptive capacity	The influence coefficient of industrial absorptive capacity on the performance
parameter: β	Contribution of academic knowledge transfer capacity	The influence coefficient of academic knowledge transfer capacity on the collaborative innovation performance
parameter: γ	Innovation performance	The changing coefficient of collaborative innovation performance

3.1. Variable Measurement

A survey of the 512 industry-academic linkage projects was implemented from July 2018 to December 2018, which collected 467 answers from relative technical managers of firms in 17 high-tech industries in China. 398 effective questionnaires were obtained, with a recovery rate of 77.7%. The Cronbach α internal consistency coefficient values of the four main variables are all over 0.8, indicating that the four indicators have high internal consistency, and the questionnaire design meets the reliability requirements (See Table 2 for details).

Table 2. Result of variables measurement.

Variable	Observation Index	Mean Value	Variance	Cronbach α
Industrial knowledge absorptive capacity	knowledge exploratory learning ability	5.2377	2.4230	0.812
	knowledge sharing ability	2.6275	1.3536	
	knowledge application ability	3.6533	3.2462	
Academic knowledge transfer capacity	useful knowledge generation ability	4.1454	3.3574	0.803
	knowledge interpretation ability	2.9957	2.6548	
	knowledge dissemination ability	3.1557	3.1372	
Innovation policy	academic incentive policy	4.9643	1.3533	0.824
	industrial incentive policy	3.3455	1.3762	
	environment incentive policy	4.1532	1.5722	
Innovation performance	the number of new products and services	3.7836	3.2351	0.807
	the rate of return on innovation project	3.0354	3.1372	
	market share of new products	3.3532	3.4735	
	grasping of innovation opportunity	3.5123	4.1749	

Descriptive statistical findings that (1) the overall level of knowledge exploratory learning ability in industry has reached a high level, but there are still significant differences between individuals. Meanwhile, the level of knowledge sharing ability is generally quite low; (2) although the level of the useful knowledge generation ability in academia is relatively high, the knowledge interpretation ability and knowledge dissemination ability are still very low; (3) compared with academic incentive policy and environmental incentive policy, industrial incentive policy has not been highly recognized; (4) the overall performance of collaborative innovation projects is low, and the differences between individuals are quite large.

3.2. Estimation of Parameters

The regression model was established to estimate the coefficient parameters of variables under the influence of current innovation policies. Innovation performance is a dependent variable, and industrial knowledge absorptive capacity and academic knowledge transfer capacity are independent variables. In this paper, the average number of observation indicators is taken as a comprehensive level of relevant variables.

The regression result shows that the influence coefficient of industrial absorptive capacity on the performance of collaborative innovation is 0.675, meanwhile, the influence coefficient of academic knowledge transferability is only 0.356. Under current innovation policy, it seems certain that industrial absorptive capacity plays a more important role than the academic knowledge transfer capability during the process of collaboration between industry and academia (0.675 > 0.356) (See Table 3 for details). Considering the survey that the industrial incentive policy is lower than the enterprise's expectation, it seems to get a hypothesis that the future innovation policy should focus more on the industrial incentive policy in China. Therefore, we further explore the evolutional mechanism when innovation policy changed using the simulation model to test this hypothesis.

Table 3. Result of regression analysis.

Model	
Academic knowledge transfer ability	0.675 ** (0.102)
Industrial knowledge absorptive capacity	0.356 ** (0.097)
Constant	−12.374 **
F	78.464 **
R^2	0.823

Note: the figures in the table are estimated values of parameters, and the values in brackets are estimated standard errors. *** means significant at the level of 0.01, ** means significant at the level of 0.05, * means significant at the level of 0.10 (bilateral test).

3.3. Model Selection

Model selection. The Belousov-Zhabotinsky's (BZ) reaction is an experimentally accessible example of chemical self-organization [44,45]. In the 1970s, nonlinear oscillations and bifurcations were discovered first by modelling and then by experiments for the autocatalytic Brusselators and the BZ chemical reaction [46]. The autocatalytic chemical reaction phenomenon plays a vital role in the breakdown of the stability of the thermodynamics. Self-organization phenomena, leading to ordered behavior, can arise in an initially uniform and time-independent system far from equilibrium. Their interest arises primarily from the fact that the emergence of order is often accompanied by the appearance of spatially asymmetric patterns. Such symmetry breaking phenomena are therefore of special interest in modeling the behavior of complex objects, where both order and asymmetry are ubiquitous [47].

The self-organized pattern formation of non-linear complex systems has very useful applications in many fields of social science as well. In China, Brusselator model was firstly taken by Li as the judgment tool of dissipative structure threshold [48], Li et al. studied the evolutionary mechanism of industry and university alliance based on 2-D system dynamic equation [49], Zhang et al. built the 3-D variable model to introduce "BZ" reaction for studying the evolutional mechanism of the enterprise system [50]. In this work, we use the 3-D variable model to explore university-industry-government relations in the national system of innovation.

A class of problems for which system self-organizing has been particularly well studied is described by the so-called BZ reaction equations [51]. BZ reaction is the typical system with self-organization property. It specifically refers that the chemical oscillation phenomenon occurs when citric acid is oxidized by potassium bromate under the acidic conditions with metal cerium ion as catalyst, and furthermore, certain rhythmicity in time also exists there, namely, color rectilinear oscillation occurs in the solution between achromatic color and faint yellow. According to Prigogine's explanation of the oscillating reaction: when the system is far away from the equilibrium state, namely, nonequilibrium nonlinear region, unordered even state is not always stable [52]. Under the specific dynamic conditions, unordered even stationary state can be out of stability and generates time-space ordered new status. At the microscopic scale, it seems unordered that microscopic particles of various reacting matters make random motions and collisions, but at the macro level, the reaction is ordered in both space and time.

The system variables can be divided into fast and slow variables, and the slaving principle is found by the synergistic theory [52], namely, slow variable dominates the progress and result of the system evolution and development, under the condition of threshold value, such slow variable becomes the dominant variable, and other variable becomes slaving variable. The slaving principle in the self-organization synergy theory provides the possibility for the establishment of the simulation equation to study the dynamical mechanism of the TH synergy in national system of innovation.

Feasibility analysis. The innovative dynamics are endogenized and the relations among the agents reconstructed by the dynamics of innovations [10]. In other words, the innovation system is a self-organizing system. Prigogine noted that a synergistic self-organizing system must also possess four general conditions: far from equilibrium, openness, nonlinear interactions and fluctuation [53]. Using self-organizing synergy theory as a research fulcrum, it should be confirmed that national system of innovation meets all prerequisites of a synergetic self-organizing system.

The national innovation system has the attributes of synergetic self-organizing system: (1) Open innovation theory proposed by Chesbrough shows that openness is the important prerequisite and approach to improve innovation performance, the opening degree between system innovative actors directly decides the effect of performance of innovation [54]. In the network-based and knowledge-based economy, the innovation system has evolved into an open era from the traditional closed standalone pattern, and furthermore, the university-industry-government linkage becomes the core of the national open innovation system. The process of industry-university collaborative innovation is the knowledge-core value innovation process for information sharing, knowledge production, knowledge spread and application [55]. Therefore, Haken points out that it is more suitable for replacing thermodynamic entropy into information entropy for understanding the nonequilibrium social systems [56]. (2) Christensen considers that innovation is divided into incremental innovation and disruptive innovation, and the different fluctuation rules are revealed in the innovation process [57]. (3) The concept of knowledge transfer has been proposed by many scholars while studying asymmetric knowledge distribution [58]. Cohen and Levinthal reveal the vital role of the absorptive capacity in knowledge transfer [59], and subsequently explorative and exploitive organizational study are proposed by March [60] to deepen the connotation of organizational absorptive capacity. Above all, it is obvious that NSI meets all the preconditions of the self-organizing synergistic system to apply B-Z reaction for the simulation study.

3.4. Model Building

The synergistic theory, namely system variable, is divided into fast and slow variables [29]. It is referenced to explore the slaving principle that slow variable dominates the development course and result of the system evolution. Following literature reviews and empirical research above, three key variables of national system of innovation had been refined which are: the academic knowledge transfer capability, the industrial knowledge absorptive capacity, and finally the performance of innovation. However, how the national system of innovation will gradually progress was still unknown when innovation policy context or capabilities change. This paper builds a three-D equation set based on BZ reaction, to explore the dynamic mechanism of TH when innovation variables change over time.

Dynamic evolution equation of industrial knowledge absorptive capacity. Under the original state of academia and industry linkage, explicit knowledge transfer is given priority. While the proportion of the tacit knowledge increases overtime, firms may fail to improve absorptive capacity synchronously and academic researchers may be limited by their knowledge interpretation and dissemination abilities, the knowledge transfer becomes more difficult. In addition, it is obvious that innovation performance is always influenced by incentive policy. Therefore, under the certain condition of incentive policy θ, logistic evolution equation of state variable of industrial knowledge absorptive capacity is as follows:

$$\frac{1}{\alpha}\frac{dx_1}{dt} = \theta x_1 + \theta\frac{\beta}{\alpha}x_2 + \gamma x_1 x_3 \tag{1}$$

In which, θx_1 is the autocatalytic factor under the incentive policy context, θ reflects the role of innovation policy to x_1. $\theta\frac{\beta}{\alpha}x_2$ is the impact factor of x_2 on x_1 under incentive policy context θ, $\frac{\beta}{\alpha}$ is influence coefficient. HEIs and PRIs' knowledge transfer promotes the enhancement of firms' absorptive capacity. $\gamma x_1 x_3$ shows the feedback influence of innovation performance x_3 on x_1, the endogenous promotion of enterprises' innovation performance will act on more research input of enterprises and enhance their technology capabilities, which weakly depends on whether it is driven by policy.

Dynamic evolution equations of academic knowledge transfer capability. In an initial state, HEIs and PRIs are the important knowledge sources for the industry to improve technology capabilities and innovation performance in the knowledge-based economy. Academic knowledge transfer capability is influenced by both industrial absorptive capability and innovation performance in the evolutional process. Therefore, under the certain condition of incentive policy θ, logistic evolution equation of academic knowledge transferability is as follows:

$$\frac{1}{\beta}\frac{dx_2}{dt} = -\theta x_2 - \alpha x_1 x_2 + \frac{\gamma}{\beta} x_3 \quad (2)$$

In which, $-\theta x_2$ means the autocatalytic factor of x_2 under incentive policy. Its coefficient is negative, showing that with the constant improvement of academic knowledge transfer capability in HEIs and PRIs, marginal income decreases progressively because HEIs or PRIs fall into the dilemma situation: focusing on knowledge production or knowledge commercialization under their limited resource conditions and time. $-\alpha x_1 x_2$ shows the influence factor of x_1 on x_2, under assured incentive policy θ. The enterprise is also faced up with the difficult choices: enhancement of R&D or improvement of absorptive capability. $\frac{\gamma}{\beta}x_3$ is the influence factor of collaborative innovation performance on academic knowledge transfer capability there exists positive incentive effect of the promotion of innovation performance on academic knowledge transfer capability, and $\frac{\gamma}{\beta}$ is the influence coefficient.

Dynamic evolution equation of collaborative innovation performance. The purpose of innovation in the industry is to finally achieve commercial successes by means of open absorption and utilization of heterogeneity knowledge. So collaborative innovation performance is essentially only related to its own state level of absorptive capability of firms. Therefore, under the certain condition of incentive policy θ, logistic evolution equation of state variable is as follows:

$$\frac{1}{\gamma}\frac{dx_3}{dt} = \eta_1 x_3 + \eta_2 \theta \frac{\alpha}{\gamma} x_1 \quad (3)$$

In which, $\eta_1 x_3$ is the autocatalytic factor of collaborative innovation performance, the pressure of market competition and endogenous innovation dynamics make the state of innovation performance in the rising trend. η_1 is constant normally. $\eta_2 \theta \frac{\alpha}{\gamma} x_1$ is the impact factor of absorptive capability on the performance of collaborative innovation. The external incentive policy acts on the collaborative innovation performance via absorptive capability finally, embodying that with the improvement of absorbing ability, collaborative innovation performance promotes. $\frac{\alpha}{\gamma}$ is the influence coefficient, η_2 is constant. Generally, η_2 is normally more than 1, embodying the synergistic effect of industry-university linkage. The reason why the knowledge transfer variable x_2 is not included in the equation is that the collaborative innovation performance is finally reflected in the enterprise's innovation performance. The direct impact mechanism of academic knowledge transfer on innovation performance is not clear. $\eta_1 = 2$ is supposed in this paper, which reflects that the endogenous power of industry-university linkage promotes the innovation performance, showing the Matthew Effect. If $\eta_1 = 2$, it reflects that the innovation performance is multiplied by the synergistic effect of TH under the condition that innovation performance is promoted by absorbing capability.

Dynamic evolution equations of TH synergy. Combining the above three equations, this paper constructs the following dynamic evolution equations of TH synergy:

$$\begin{cases} \frac{1}{\alpha}\frac{dx_1}{dt} = \theta x_1 + \theta \frac{\beta}{\alpha} x_2 + \gamma x_1 x_3 \\ \frac{1}{\beta}\frac{dx_2}{dt} = -\theta x_2 - \alpha x_1 x_2 + \frac{\gamma}{\beta} x_3 \\ \frac{1}{\gamma}\frac{dx_3}{dt} = \eta_1 x_3 + \eta_2 \theta \frac{\alpha}{\gamma} x_1 \end{cases} \quad (4)$$

4. Simulation Results

In this paper, it is set that in the differential equation, the initial state of the three variables of industrial absorptive capacity, academic knowledge transfer and collaborative innovation performance is $X_0 = [x_1, x_2, x_3]$. The x_1, x_2, x_3 respectively represent the input condition of the three factors of TH statuses before collaboration. At the same time, being specific to the incentive effect generated by external policy environment, there are two conditions divided in this paper: (1) Set the control variable incentive policy $\theta = 1$, it reflects normal support of the country and regional government to the collaborative innovation, the implementation of collaborative innovation under spontaneous condition; (2) set control variable incentive policy $\theta = 2$, it reflects that the country and region give stronger policy support to collaborative innovation, by means of offering necessary infrastructure input, talent input, innovation service support and other incentive mechanism to carry out collaborative innovation, so as to push the implementation of collaborative innovation activities.

It is also specific in this paper to two states of Triple Helix, based on MATLAB simulation analysis software, the studies will be respectively implemented: (1) The ideal status when absorptive capacity and transfer ability are at higher level symmetry, the TH synergy mechanism under two different incentive policy contexts are simulated. (2) The second status is under the current condition in China based on empirical statistical data studied ahead.

4.1. Simulation When Capabilities Balance between Industry and Academia

Under the balanced condition of absorptive capacity in industry and knowledge transfer capability in academica, we suppose that the performance of collaborative innovation relies on the further implementation of collaborative linkage. Therefore, it is respectively defined that industrial absorptive capacity is 1, academic knowledge transfer ability of is 1 and collaborative innovation performance is 0 (due to certain time delay) for the initial state of the simulation. Namely, under initial state $X_0 = [1, 1, 0]$, the study is respectively implemented according to the two conditions of normal incentive policy ($\theta = 1$) and strong incentive policy ($\theta = 2$).

Normal incentive policy context. The simulation result of dynamic mechanism in NSI under normal incentive environment ($\theta = 1$) is shown in Figure 2, y_1 is industrial absorptive capacity, y_2 is academic knowledge transfer capability and y_3 is collaborative innovation performance.

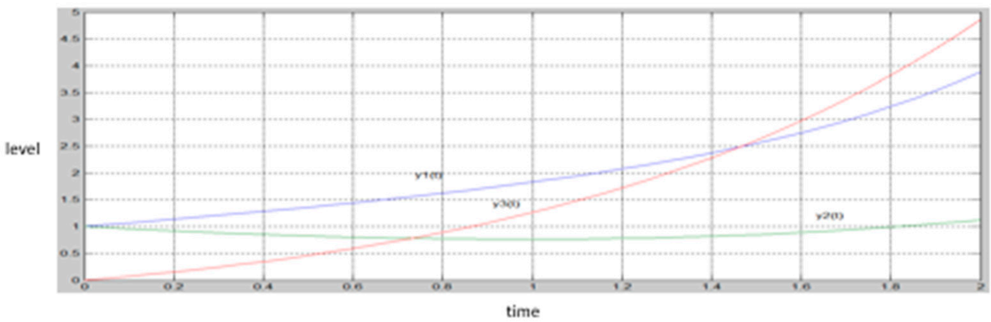

Figure 2. Dynamic evolution mechanism under the normal incentive policy.

Simulation results: Under the condition of normal external incentive policy context, when x rises to 2, innovation performance is close to 5. The rapid promotion of collaborative innovation performance appears, and absorptive capability is improved rapidly at the same time, and the academic knowledge transfer ability of colleges and universities maintains stable and rises slowly.

Result analysis: (1) Under the condition of weak external incentive policy, because of the comparative matching of knowledge supply capability and knowledge absorptive capability, heterogeneous knowledge accumulated by universities has become the main target for enterprises to absorb, which has rapidly improved the innovation ability and innovation performance of enterprises.

(2) In the initial stage, the participation of agents in HEIs and PRIs in collaborative innovation projects has spent a lot of energy, and academic productivity has been affected to a certain extent. (3) The result of long-term interaction between university and enterprises respectively promote their technology capabilities from collaboration.

Stroger incentive policy context. The simulation results of the collaborative innovation mechanism under a strong incentive environment ($\theta = 2$) is shown in Figure 3.

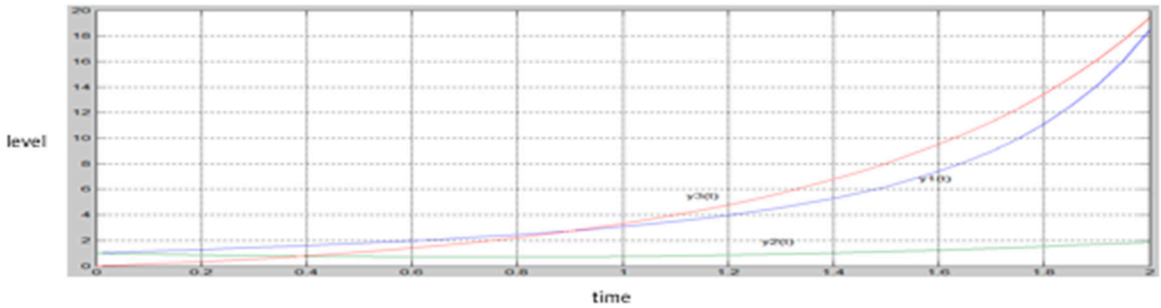

Figure 3. Ideal dynamic mechanism of NSI with stronger incentive policy.

Research results: Under the ideal condition of stronger incentive policy, industrial absorptive capacity, academic knowledge transfer ability and collaborative innovation performance show the same variation trend with the normal incentive policy, but collaborative innovation performance gets the rapid promotion. Under the condition of x = 2, innovation performance is 19, which is 4 times of the normal incentive policy. At the same time, the absorptive ability is improved synchronously, and knowledge transfer capability shows the secular change trend of firstly dropping and then rising.

Result analysis: The result proves that national or regional innovation policy has the positive effect of promoting absorbing ability and innovation performance when the capabilities of agents match in NSI. It might be four reasons: (1) Innovation policy fosters consensus of synergistic innovation, which reduces the cost of technology transaction. (2) Innovation policy increases investment in innovation infrastructure and enterprise innovation resources, which promote the motive force and capability of synergistic innovation in industry. (3) Innovation policies have increased investment in innovative resources such as university human resources and research funds, which better balance the relationship between innovative services and scientific research. (4) HEIs and PRIs learned heterogeneous knowledge from the industry which promoted the continuous improvement of academic research abilities over time, also strengthened their motivation to participate in collaborative innovation activities for knowledge commercialization.

4.2. Simulation Based on Current Situation in China

According to the empirical results ahead the influence coefficient of industrial absorptive capability on innovation performance is 0.675, while the influence coefficient of unit knowledge transfer ability to innovation performance is 0.356. Based on the results of the questionnaire, the evaluation of innovation policy by the industry is in the middle level. Therefore, this paper sets the influence coefficient of incentive policy on the performance of collaborative innovation is 1.166. It is confirmed that initial state X_0 = [0.675, 0.356, 0] to obtain simulation result of Figure 4. In which, y_1 is industrial absorptive capacity, y_2 is knowledge transfer ability of HEIs and y_3 is collaborative innovation performance.

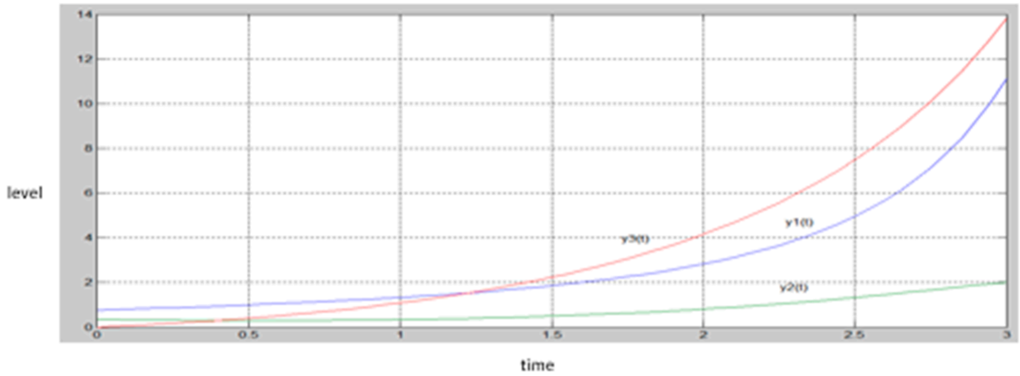

Figure 4. Dynamic mechanism of TH synergy in China.

Simulation results: Under the current situation of NSI in china, the synergy of TH is still far from optimal. However, innovation performance is slightly higher than 4 if x = 2, and innovation performance starts to show rapid growth trend, may up to 14, if x = 3. Absorptive capability in industry is in high correlation with innovation performance with system evolution and time advance. Knowledge transfer ability of HEIs and PRIs slowly rises, while the evolutionary trend is stable. The result shows that China's national system of innovation has good prospects for development, and innovation performance will face a significant growth trend over time. (1) In the current situation, the absorptive capacity in industry has exceeded the ability of knowledge transfer of HEIs and PRIs, and it has become the main driving force to promote innovation and development. (2) At present, the level of absorptive capacity has been higher than the level of innovation performance. From the analysis of the evolution progress viewpoint, the role of absorptive capacity and innovative capacity in industry will be gradually revealed, which will sustainably and rapidly improve the innovation performance of national innovation system in future.

Results analysis: (1) while the breadth and depth of open innovation have been continuously expanded, industrial absorptive capacity has become the core competence of collaborative innovation. This result elaborates that industrial absorptive capacity is highly correlated with TH synergy. If the absorptive capacity in industry is insufficient, the efficiency of knowledge transfer will also be affected prominently. Not only the cooperation cycle between university and industry becomes long and tough, but also the important and limited resources may be exhausted. When the industrial absorptive capacity matches the academic knowledge transfer capability, the performance of collaborative innovation and the quality of national innovative ecology can be significantly improved. Above all, the industrial absorptive capability plays an important role in TH synergy in NSI. However, while the improvement of industrial capability, the problem of knowledge sharing within the organization is particularly prominent. On the one hand, with the increase of the mobility of enterprises' technical personnel, setting up technical firewalls has become the main strategy of personnel which limits the sharing of knowledge; On the other hand, enterprises still do not pay much attention to knowledge management, which also greatly affects knowledge sharing in the team and organization level. (2) Knowledge transfer capability of HEIs and PRIs shows relative stability. Based on the synergistic theory, the evolution of the system is dominated by slow variables. The knowledge transfer capability of HEIs and PRIs has obviously become the dominant variable that affects triple helix's synergy. In other words, the capabilities of useful knowledge generation, knowledge interpretation and dissemination, already become a bottleneck problem in NSI of China. Evidence also found that with the enhancement of the industrial absorptive capacity, Chinese enterprises are more willing to acquire technology through international merger or global cooperation than local collaborations, which affects the cooperation of domestic universities negatively [61]. With the continuous support of national scientific research investment, universities and scientific research institutions have published many high-quality papers and applied for a large number of patents, but obviously there is a gap between the knowledge demand of real innovation context and supply from the HEIs and PRIs.

5. Conclusions

Based on BZ reaction model in non-linear complex systems and MATLAB simulation analysis software, this work introduces a new simulating method to explore the synergistic mechanisms of TH in NSI, and obtained an important conclusions: The hypothesis that the future innovation policy should mainly focus more on the industrial incentive policy in China might not be comprehensive. Innovation policy plays a positive role in promoting the collaborative innovation capability and performance in NSI, and policy objectives need to be targeted at solving bottleneck problem at priority. At present, innovation policy in China faces a dilemma, that is, to continuously increase governmental direct investment in basic and applied research to improve knowledge supply capacity, or to incentive industrial investment to improve knowledge integration and application capacity.

Based on the results of empirical research and simulation research, this paper considers that the domestic academic knowledge capacity is the order variable which dominant the evolution of TH in Chinese NSI. Optimizing governmental direct R&D investment mechanism should be the top priority, especially the application research project funding which accounts for a very high proportion. Although the main goal of applied research projects funding is to promote technology commercialization, the current criteria for competition are mainly composed of published papers, applied patents and previous project experience. Therefore, in order to obtain more governmental funding supports, researchers both in academia and in industry inevitably spend much more time and energy in publishing papers or applying for patents, and ultimately have no energy and motivation to implement commercialization.

Additionally, the incentive policies to encourage industrial innovation investment also need to be further subdivided. In addition to increasing the R&D investment efficiency of state-owned enterprises, how to eliminate the barriers between knowledge production and knowledge circulation may be the key issue of industrial innovation policy. Although the construction of intellectual property regimes has been paid more and more attention to for a long time, and the intellectual property courts also be constructed as a policy innovation pilot, the implementation process of intellectual property regimes is plagued by problems, such as difficult to obtain infringement evidence and the lack of enough supervisors, etc. Most private enterprises prefer to choose management measures to avoid R&D investment or to acquire oversea knowledge by means of strict internal prevention of knowledge sharing, in order to reduce the externality of knowledge spillover. So, optimizing the enforcement mechanism of the intellectual property regimes may also be the key link to eliminate the bottleneck of collaborative innovation.

In summary, if the innovation policy can be more targeted at the upgrading of the domestic supply capacity of useful knowledge in HEIs and PRIs as optimization objectives, at the same time continue to strengthen the implementation of the intellectual property protection regimes, the synergy quality of national innovation system in China would be continually improved, and the endogenous innovation performance would be accelerated rapidly.

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