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Evaluation of Degree of Coordination between Chinese Investment in Basic Research and Economic Growth

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Abstract

Based on the theory of complex systems science and synergetics, a model for the coordination degree of complex system "investment in basic research and economic growth" was built in this paper for the quantitative evaluation of the degree of coordination between investment in basic research and economic growth in China in recent 2 decades from a macro perspective. Results show that the subsystem of investment in basic research and the subsystem of economic growth and the whole complete system are showing a good momentum of steady growth. Although the subsystem of investment in basic research is slightly inferior to the subsystem of economic growth in order degree, it more matches the coordination of China's economic growth on the whole. In order to further promote and strengthen the basic research efforts in China, a number of policy recommendations were raised in this paper with a view to advancing the proper operation of the investment in basic research system in China in the new normal of economy and its long-term coordinate development with the complex system of economic growth.

Keywords: investment in basic research, economic growth, complex system, coordination degree

1 Introduction

Given the conversion of factor- and investment-driven competitions in the global market to innovation-drive ones, the practice of "implementing innovation-driven development strategy–enhancing the capability of independent innovation--promoting economic transformation and upgrading," seems to be sought after by the countries of the world. It has been a consensus to increase investment in science and technology research and firmly committed to the path of innovative development for the sustainable and sound development in the countries in the world. The successful development experience of the European countries shows that, innovation is an important source of sustainable economic and social development, of which the forerunner is basic research.

Basic research, as an essential strategic resource, acts as the foundation of innovation and the fresh ideas of the whole technological progress. All outcomes or major breakthroughs always have a profound impact on science and technology innovation and industrial development, and cause major economic and social changes. Vannevar Bush (1945), a founder of science and technology policy, has noted that: "The dependence of a nation on other nations in basic science knowledge will lead to its slow industrial progress and a weak position in the competition in world trade."

China's economic development presents the new normal at the present stage and an optimizing and upgrading economic structure, and China will attach more importance to encouraging and strengthening innovation to provide power to the economic engine in the future. During this stage, the new impetus for China's economic growth depends more heavily on enhancing "internal strength", and it is more urgent to give priority to the development of basic research. In order to better adapt to and lead the new normal, the coordination between the investment in basic research and economic growth in China were quantitatively investigated and studied from the macro level, and a number of policies and recommendations were raised according to the analysis of the empirical results with a view to increasing the overall level of basic research in China, while advancing the

coordinate development of basic research and economic and social development.

2. Description of Complex System and Synergetics

As for the study on the connotation of complex system, Bai Hua and Han Wenxiu (2000) gave more authoritative definition: complex system is a large-scale system with a new specific structure and functions and consists of a number of intertwining, interacting and inter-penetrating subsystems of different properties and it is always accompanied by some complex, dynamic and open basic attributes. The coordinate operation of each subsystem in a complex system is essential for the benign development of the whole system, thus it is necessary to make in-depth and systematic study on the coordination of complex systems.

From the perspective of synergetics, the compatibility between various constituent elements of a system in their development suggests the coordination, of which the degree is manifested in the degree of coordination or correlation between different subsystems. The degree and role of coordination determine to a large extent what order and structure of the system will go after it reaches critical areas, in other words, they determine the evolution of the system from disorder to order. In synergetics, the internal variables of phase transition points in system are divided into fast and slow relaxing variables, and the law and features of the constant evolution development of the whole system is mainly determined by the slow relaxing variables, that is, the synergy between order parameters, and the coordination degree is the measurement that reflects this synergy.

The thoughts and empirical analysis method of the complex systems theory and synergetics provide a new way of thinking for the study on the coordination degree of the complex system "the investment in basic research and economic growth in China". Taking a long-term perspective, a relationship featuring mutual coordination, restraint and collaboration always exists between the subsystem of research investment and the subsystem of economic growth in the complex system "the investment in basic research and economic growth in China", and the interaction promotes the disorder-order and low-high evolution of the complex system, which indicates that the complex system "the investment in basic research and economic growth in China" has the basic conditions for the application of coordination degree model. Simple qualitative analysis may not grasp or analyze the behavior or function features of the complex system on the whole, thus, a model for the scientific and objective measurement of the coordination degree of the investment in basic research and economic growth in China was built in this paper through reading literature and digesting and absorbing the theory of the coupling degree of system science and the synergetics, and applied to the measurement of the coordination degree of the system coordination and internal coordination.

3. Model for Coordination Degree of Complex System

3.1 Model Setting

The researchers of the theory of system science, represented by Cheng Siwei (1999), firstly proposed an analysis model for the coordination degree of complex system based on complex science and system engineering. Since this model is able to overcome the shortfalls of previous quantitative research methods and thus provides a new tool for the research on the measurement of coordination degree, it is widely applied to the analysis and calculation of the coordination degree of some complex systems in the academia. A model for the measurement of the coordination degree of the investment in basic research and economic growth in China was built in this paper within the synergetics theory analysis framework and in conjunction with some basic principles, such as instability, order parameters and slaving. Model build processes are as follows:

Let complex system "investment in basic research -economic growth in China" be S_j, where $j \in [1,2]$ Order parameters e_j $e_{j1}, e_{j2}, e_{j3}, \ldots, e_{jn}$ are several indicators describing the complex system "investment in basic research-economic growth in China". Then the order parameters of the complex system $e_j = \left(e_{j1}, e_{j2}, e_{j3}, \ldots, e_{jn}\right)$, where $n \geq 2, \beta_{ji} \leq e_{ji} \leq \alpha_{ji}, i \in [1,n]$. Assuming that the greater the value of the order parameter $e_{j1}, e_{j2}, e_{j3}, \ldots, e_{jn}$, then the higher the order degree of the system, and vice versa.

In conjunction with the above assumption and definition analysis, in this paper, the order degree of order

parameter of the complex system "investment in basic research and economic growth in China" $S_j\ (j=1,2)$

$e_j\ u_j(e_{ji})$ is defined as follows:

$$u_j(e_{ji})=\begin{cases}\dfrac{e_{ji}-\beta_{ji}}{\alpha_{ji}-\beta_{ji}}, i\in[1,k]\\ \dfrac{e_{ji}-\alpha_{ji}}{\alpha_{ji}-\beta_{ji}}, i\in[k+1,m]\end{cases} \tag{1}$$

In formula (1), α_{ji}, and β_{ji} are the higher and lower limit of the i th indicator in the j th subsystem. Thus, $u_j(e_{ji})\in[0,1]$, the closer the value is to 1, the greater the contribution of the order parameter to the corresponding subsystem or even the entire system. Of course, in addition to the size of each order parameter, parameter combinations also have effects to a large extent on the overall performance of a complex system. Geometric mean was employed to determine the function of order degree of the subsystem of basic research and the subsystem of economic growth, see formula (2):

$$u_j(e_j)=\sqrt[m]{\prod_{i=1}^{m}u_j(e_{ji})} \tag{2}$$

Formula (2) shows that $u_j(e_{ji})\in[0,1]$, and similarly, the closer the value is to 1, the higher the order degree of order parameter of the corresponding subsystem, and vice versa.

Assuming that the order degree of the subsystems of a complex system is $u_j^0(e_j)$ at the initial time T_0, then the order degree of the subsystems is $u_j^i(e_j)$ when the system evolutes at the time T_i. The coordination evolution degree of the complex system is:

$$syn=\theta\cdot\sqrt[k]{\left|\prod_{i=1}^{k}\left[u_j^i(e_j)-u_j^0(e_j)\right]\right|} \tag{3}$$

where θ meets the following conditions:

$$\theta=\frac{\min\limits_j\left[u_j^i(e_j)-u_j^0(e_j)\neq 0\right]}{\left|\min\limits_j\left[u_j^i(e_j)-u_j^0(e_j)\neq 0\right]\right|}, j=1,2,\cdots k \tag{4}$$

Moreover, it is worth noting that, if the calculation of θneeds the consideration of time period, the value of θ can be adjusted to be the difference between period i and period $i-1$ in specific solution processes. In this case, the coordination degree of the complex system syn is continuously changing. The solution formula of the value of θ is:

$$\theta=\frac{\min\limits_j\left[u_j^i(e_j)-u_j^{i-1}(e_j)\neq 0\right]}{\left|\min\limits_j\left[u_j^i(e_j)-u_j^{i-1}(e_j)\neq 0\right]\right|}, j=1,2,\cdots k \tag{5}$$

The formula (5) shows that $syn\in[-1,1]$, and the greater the value of syn, the more coordinate development between the subsystems, and vice versa. Because the measurement of the coordination degree of a complex

system needs to integrate the operational conditions of each subsystem; if the order degree of a subsystem is higher, while that of the other is relatively lower, or order degree varies greatly between the subsystems, the whole complex system will present lower coordination, that is $syn \in [-1, 0]$.

3.2 Order Parameter Selection

Definition and selection of order parameters of subsystems are particularly important during building and analyzing the model for the coordination degree of complex system. In the complex system "the investment in basic research and economic growth in China", the validity and applicability of the selection of order parameters will directly affect the accuracy of empirical results, as well as the detection of coordination evolution of the whole system. Therefore, it is necessary to interpret and describe the order parameters involved in the model for the coordination degree of the complex system "the investment in basic research and economic growth in China" in conjunction with the requirements for completeness, effectiveness and comparability of indicators.

In order to facilitate the research and analysis of the features and law of the coordination development of complex system and taking account of the multi-dimension and complexity of the coupling of the two subsystems (the investment in basic research and economic growth), the selection of order parameters should particularly comply with the following principles: principle of integrated and systematic, that is, order parameters should be selected based on an overall analysis of the correlation between the two subsystems and can fully reflect all aspects of the development of each subsystem; the principle of scientific, that is, order parameters must be able to reflect the objective situation of the two subsystem; the data sources reflecting order parameters should be reliable and accurate, and data calculation should be made in a scientific manner; the principle of accessible, which emphasizes that order parameters must be defined precisely and have practical significance, concentrated information and collectable data.

The existing literature shows that the subsystem of investment in basic research is generally measured by the input of human, material and financial resources in basic research activities. Therefore, the indicator of the total amount invested and the number of researchers in basic research are usually used to reflect the order parameters of the subsystem of investment. The four order parameters of the subsystem of economic growth are selected based on the theories related to macro-economics, and the modern market economy theory emphasizes that investment, consumption and export are the "Three-in-hand" of economic growth. Thus, as for the specific indicators of order parameters of the subsystem of economic growth, in addition to GDP, three indicators, that is, cross fixed capital formation, social retail goods, and gross export trade of merchandise and service, are selected for investment, consumption and export. Table 1 clearly reflects the indicators for the complex system "the investment in basic research and economic growth in China" built in this paper.

Finally, it is to be noted that, in order to eliminate the impacts of price changes on different annual values of indicators, the indicators that are measured with monetary units in the study were treated in a uniform manner, that is, they were converted to constant prices in 2005 before calculation and measurement.

Table 1. Order parameter of the complex system "investment in basic research and economic growth"

Complex system	Subsystem	Order parameter
Complex system "investment in basic research and economic growth"	Subsystem of investment in basic research	Amount of expenditure in basic research
		Number of researchers in basic research
	Subsystem of economic growth	GDP
		Cross fixed capital formation
		Social retail goods
		Gross export trade of merchandise and service

4. Empirical Analysis

4.1 Data Sources

In the measurement of the coordination degree of the complex system "the investment in basic research and economic growth" in China, the data were collected from two sources: finding and personnel data of the subsystem of basic research were from China Technology Statistics Yearbook; data of the subsystem of

economic growth were from World Bank database; World Bank, as a provider of global macroeconomic analysis reports, has scientific and authoritative macroeconomic data. The above data sources have laid the foundation for and support this study and also provide the explanatory power and persuasiveness for the conclusions of this study.

4.2 Coordination Degree Calculation and Result Analysis

According to the model for the coordination degree of complex system, in order to eliminate the dimensional effect on results, the raw data (the missing data were made up with evaluation) were standardized after the order parameters of the subsystems were selected and determined. In the analysis, the value in 1994 was taken as the lower limit and that in 2013 as the upper limit, then the processed data were substituted in formula (1), and the order parameters of the two subsystems (investment in basic research and economic growth) can be calculated, and the detailed results are shown in Table 2.

Table 2. Order parameters of the two subsystems (investment in basic research and economic growth)

	Subsystem of investment in basic research		Subsystem of economic growth			
Year	Amount of expenditure in basic research	Number of researchers in basic research	GDP	Cross fixed capital formation	Social retail goods	Gross export trade of merchandise and service
1995	0.0038	0.0151	0.0163	0.0217	0.0079	0.0230
1996	0.0078	0.0340	0.0333	0.0512	0.0096	0.0460
1997	0.0212	0.0472	0.0478	0.0696	0.0361	0.0695
1998	0.0240	0.0912	0.0693	0.0956	0.0519	0.0914
1999	0.0332	0.0742	0.0832	0.1319	0.0652	0.1142
2000	0.0570	0.0969	0.1068	0.1696	0.0962	0.1415
2001	0.0734	0.0918	0.1301	0.2006	0.1146	0.1705
2002	0.1071	0.1245	0.1664	0.2328	0.1542	0.2050
2003	0.1329	0.1604	0.2186	0.2643	0.1997	0.2465
2004	0.1877	0.2925	0.2624	0.3024	0.2498	0.2924
2005	0.2137	0.3220	0.3118	0.3493	0.3308	0.3493
2006	0.2593	0.4220	0.3699	0.4099	0.4722	0.4201
2007	0.2941	0.4648	0.4397	0.4848	0.5933	0.5094
2008	0.3800	0.5648	0.4963	0.5497	0.6565	0.5786
2009	0.4718	0.6314	0.6424	0.6264	0.5818	0.6513
2010	0.5724	0.6887	0.7335	0.7082	0.7633	0.7427
2011	0.7344	0.8113	0.8138	0.8141	0.8497	0.8330
2012	0.8958	0.9308	0.9017	0.9075	0.9144	0.9137
Mean value	0.2483	0.3258	0.3246	0.3550	0.3415	0.3555

The calculation result in Table 2 shows that, as for the subsystem of investment in basic research, the mean value of order parameters of the number of researchers in basic research is 0.3258, which is 0.0775 higher than that of the amount of expenditure in basic research (0.2483). This indicates that personnel input was higher than funding input in the resource investment in basic research in China at the present stage. Therefore, in the future investment in basic research resources subject to the existing resource, the funding for basic research may be moderately increased to optimize the investment structure and match the growing personnel input.

As for the subsystem of economic growth, the order degree of GDP order parameters is continued to improve, and the systematic order degree of the "Three-in-hand" is increasing annually with the changes that are the same as GDP order degree. This is mainly because, in the subsystem of economic growth, the cross fixed capital formation, social retail goods and gross export trade of merchandise and service were highly correlated with GDP itself, and the order degree of GDP order parameter to a large extent directly affected that of the other three order parameters.

The order degree of the order parameters of both investment in basic research and total GDP maintained increase at a certain percentage. The mean value of the order degree of the order parameter of investment in basic research was 0.2871 between 1995-2012, and that of GDP was 0.3246, and the large gap between them suggests that the mean order degree of the investment in basic research in China fell behind total GDP at this stage, which

means that the investment in basic research failed to better match the demands of economic growth. Moreover, as can be seen, although the order degree of the order parameter of investment in basic research was always below that of total GDP, presenting that the order degree of investment in basic research was lower that of total GDP in China that at this stage, the order degree of the parameter of personnel input has seen a significant increase or even a moderate lead trend compared with that of GDP of the same period since 2003, indicating a good momentum in the coordinate development.

Then, the data in Table 2 were substituted in formula (2) to calculate the order degree of the subsystem of investment in basic research and the subsystem of economic growth, as shown in Table 3.

Table 3. Degree of coordination between investment in basic research and economic growth in China

Year	Subsystem of investment in basic research	Subsystem of economic growth	Coordination degree of complex system
1995	0.0075	0.0159	0.0110
1996	0.0163	0.0294	0.0219
1997	0.0316	0.0537	0.0412
1998	0.0468	0.0749	0.0592
1999	0.0496	0.0951	0.0687
2000	0.0743	0.1253	0.0965
2001	0.0821	0.1503	0.1111
2002	0.1155	0.1871	0.1470
2003	0.1460	0.2309	0.1836
2004	0.2343	0.2759	0.2543
2005	0.2623	0.3349	0.2964
2006	0.3308	0.4165	0.3712
2007	0.3697	0.5038	0.4316
2008	0.4633	0.5674	0.5127
2009	0.5458	0.6249	0.5840
2010	0.6278	0.7367	0.6801
2011	0.7719	0.8275	0.7992
2012	0.9132	0.9093	0.9112
Average	0.2827	0.3422	0.3110

It is not difficult to see from Table 3 that the subsystem of investment in basic research and the subsystem of economic growth in China showed a steadily increasing coordination degree between 1995-2012. This means that the interaction and synergy between resource investment in basic research and economic growth have been increasingly being emphasized in the economic and social development in recent years: on one hand, economic development is promoted through the steady growth in the resource investment in basic research; on the other hand, the resource investment in basic research activities is improved in sustained economic growth. The order degree of the two subsystems shows that the order degree of the subsystem of economic growth was significantly higher than that of the subsystem of investment in basic research in recent years (other than 2012). This suggests that the growth rate of resource investment in basic research was much smaller than that of economic growth in China, but significant improvement has been made in basic research in recent years, and the gap has begun to narrow and the latter has even exceeded the former. According to the analysis in Table 3, generally speaking, the order degree of the subsystem of investment in basic research was lower than that of the subsystem of economic growth for a long time, and it mainly was attributable to the lack of researchers and particularly the lack of funding for basic research. With the increasing attention to and investment in basic research, the coordination degree of both of the subsystems and the whole complex system obviously improved. Therefore, the basic research work must not be ignored in the future. It is necessary to improve the coordination degree of the subsystem of resource investment in basic research by moderately increasing the funding and personnel investment in basic research to better match the coordination degree of the subsystem of economic growth.

Finally, taking the order degree of the subsystem of investment in basic research and the subsystem of economic growth as an intermediate variable and making 1995 as the base year, then $\theta = 1$; the order degree of the two subsystems in Table 3 were substituted in formula (3) and (4) to measure "the coordination degree of the complex system "investment in basic research and economic growth in China", and the finally result see the last column of Table 3. Meanwhile, in order to visually display the results, three incremental curves can be drawn

according to Table 3, as shown in Figure 1.

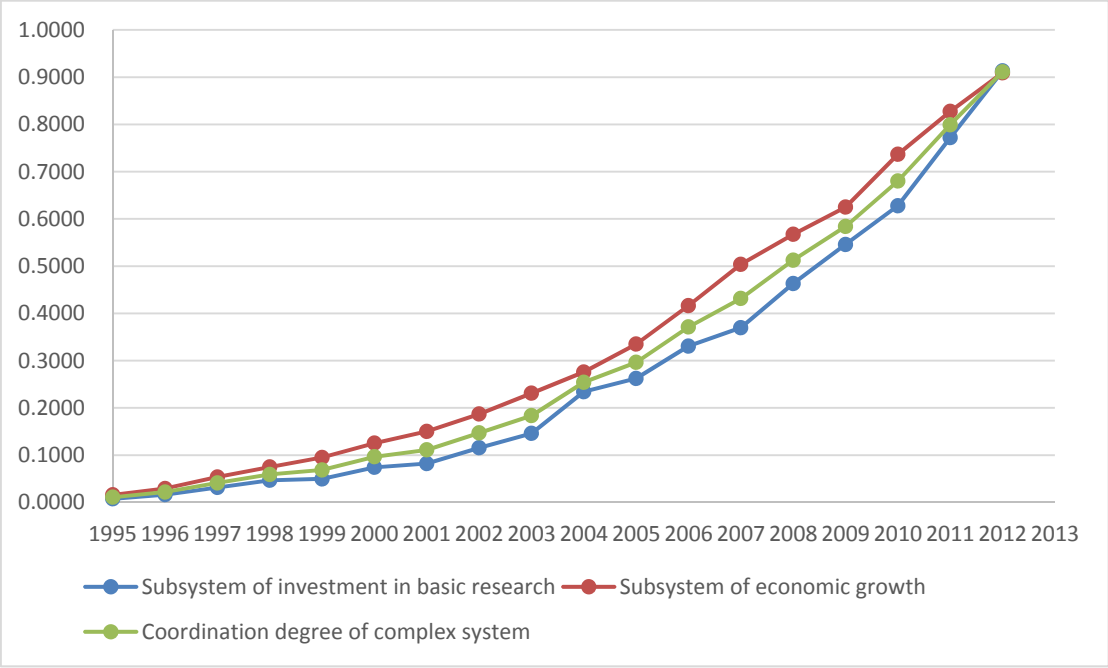

Figure 1. Degree of coordination between investment in basic research and economic growth in China between 1995-2012

The calculation of the coordination degree of the complex system "investment in basic research and economic growth in China" and Figure 1 show that the coordination degree of this complex system presented a solid increase between 1995-2012, which was mainly attributable to the continuous improvement in the order degree of the subsystem of investment in basic research and the subsystem of economic growth. The mean coordination degree of the complex system "investment in basic research and economic growth in China" in nearly 20 years was 0.3110, suggesting a generally lower degree of coordination between investment in basic research and economic growth. This was mainly attributable to the acute shortage of resource investment in basic research in China before 2002, of which the growth rate was much smaller than that of economic development, and this situation did not improve until 2002, since then the coordination degree of the whole complex system has been significantly improved. This was mainly the result of 2002-2005 National Program for Qualified Personnel Development, which was promulgated in 2002 and increased the staffing input in basic research and significantly improved the order degree of the order parameter of staffing input in basic research in 2002 (see Table 2). Subsequently, the Outline of the National Program for Long- and Medium- Term Scientific and Technological Development (2006-2020), which was promulgated by the State Council in early 2006, articulates the general requirements, implementation methods and measures to increase the efforts to support basic research and stresses the long-term perspective and advanced deployment of cutting-edge technology and basic research to create new market requirements, nurture emerging industries and lead the future economic and social development. Both the subsystems have developed in a coordinate manner afterwards. The gap between resource investment in basic research and economic growth in China is expected to get smaller and the degree coordination between them to be higher in the future under the guidance of the policies that pay more attention to and support basic research.

5. Conclusions and Discussions

To take the strategic height for the future economic and technological development, the leading countries in the world are strengthening the deployment of innovative strategies and attach unprecedented importance to basic research. Only through promoting the formation of innovation-driven development pattern and entering the fast lane of structural adjustment can China always nurture and maintain its comparative advantages for participating in a new round of international competition. Against this background and under the guidance of the research

thought of synergetics and complex science, the synergy between investment in basic research and economic growth in China was studied; by constructing the analysis model for the coordination degree of the complex system "investment in basic research and economic growth in China", the degree of coordination between the investment in basic research and economic growth in China in 1995-2012 was measured in this paper. It is of some significance in theoretical guidance and macroeconomic decision for basic research and the sound and harmonious economic and social development.

Results show that the investment in basic research in general highly coordinated with and matches economic growth and both of them maintained a steady growth, which indicates that resource investment in basic research in China has been able to adapt to the current economic and social development, and properly interacted and collaboratively developed with economy. But there are still some problems in the subsystem of resource investment in basic research, which are mainly manifested in inadequate funding input and mismatching staffing input within the system; the comparison of the order degree between systems shows that the order degree of the subsystem of resource invested in basic research was slightly lower than that of the subsystem of economic growth. The investment in basic research means the investment in the future. One of the most important challenges facing China's economic and social development in the next five years is how to promote the economic growth in an innovation-driven manner, so the basic research should be geared to China's current strategic demands and speed up the transformation of basic research results into applied technologies and product R&D to provide solid support for China's transformative economic and social development.

Against the new normal of Chinese economy, in order to further promote the proper operation of China's basic research system and its coordinate development with the economic growth system, it is necessary to vigorously expand the total space of basic research resource. In addition to the steady inputs from the central government, it also needs to actively mobilize and strive for the support from institutions, including local governments, universities and enterprises, and adjust and improve the input structure of institutions. In addition, it is necessary to strengthen the construction of the soft environment of scientific research, strive to create a good original innovative ecological environment that encourages and supports painstaking research, credit research and original results so as to provide backup guarantees for better identifying, developing and introducing more talented persons.

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