Synergy Degree Model Between Sci-tech Finance and Sci-tech Innovation Based on Correlation Matrix Weight in Guangdong

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***Abstract*—Science and technology are known as the first productive force in the modern society, and they are the core elements to motivate the innovative progress of the whole social economy. The mutual cooperation and progress of sci-tech finance (STF) and sci-tech innovation (STI) can realize the innovation transformation of the national economy and simultaneously enhance the comprehensive competitiveness of the country. Through comparative analysis of theoretical mechanism of synergetic development between STF and STI, we take the synergetic degree of STF and STI in Guangdong Province in China as object of research to construct the order degree model and the synergy degree model. In the calculation of the weight of each index in the system, three different weight calculation methods, namely the correlation matrix weighting method, the entropy weighting method and the standard deviation method, are used from different perspectives. An empirical study is presented based on the above different methods by using the data of twelve years of Guangdong province. By a comparative and comprehensive analysis, the results show that using different methods to calculate the weight of each index can avoid deviations. Therefore, more reasonable and more convincing results than those by some single methods can be obtained in practice.**

***Index Terms*—Sci-tech finance, Sci-tech innovation, Weight, Index system, Synergy degree model**

I. Introduction

Synergetics is an emerging discipline with a wide range of elements that integrates knowledge of various subjects. It was proposed by German physics H. Haken [1] in the 1970s. In response to the sustainable development strategy, Z.L. Chen [2] et al. did some researches on the synergy degree between above-ground and underground space along urban mass transit, simultaneously, Y.L. Su [3] et al. built a collaborative degree model of producer services and equipment manufacturing industry based on entropy weight method. Q.X. Kong [4] et al. observed the coordinated variation of Chinese nonferrous metal futures and stock prices on the basis of the synergy degree in complex system, and L.B. Bai [5] et al. constructed the project portfolio model on the foundation of the synergy degree in the composite system. X. Deng et al. [6] and researchers [7-10] conducted in-depth studies in the financial field but without considering problems in the context of scientific and technological innovation. D. Liu [11] et al. did some researches on the relationship between technological innovation and institutional innovation in the developing process of resource-based city to construct a measure model for synergy degree in the compound system. Francisco [12] studied interactions between science, technology and innovation, and R.Y. He [13] presented a structure vector auto-regressive (SVAR) model to measure the effects of financial capital integration and sci-tech innovation. Q.Z. Deng [14] et al. utilized attribute hierarchical model and entropy weighting method to obtain index weight on the fundamental of setting up coupling system model for sci-tech finance (STF) and sci-tech innovation (STI). D.F. Qiu [15] et al. proposed a model to analyze the coupling coordination level of STF and STI in Jiangsu Province in China.

Based on the above studies, this paper considers STF and STI as a complex system, in which STF and STI are two subsystems, respectively. According to the theory of synergy, the two disordered subsystems are integrated into an orderly composite system.

Recently, many authors have used the theory of synergy to study the synergy degree model of complex systems composed of STF and STI. L.X. Xu [16] et al. studied the efficiency of regionally technological and scientific innovation in China from the perspective of synergy. B.F. Xu [17] et al. studied the synergy in the evolution of the regionally technological innovation system in the Yangtze River Delta of China from the perspective of the technological innovation chain. X.F. Lin [18] et al. studied the synergy model of the sci-tech economic system in Hebei Province, Q.S. Meng [19] et al. studied the characteristics of composite system coordination to improve the theoretical basis of composite system coordination, and H.Q. Wang [20] et al. studied the national STF and STI synergy model.

However, we have noticed that researches on and applications analysis of the synergy degree of STF and STI in Guangdong Province are too few. Moreover, when

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determining the weight of indicators, scholars usually utilize a certain method only, which will inevitably leave the reader unable to fully understand the model, and there may be some deviations in the outcomes. With the purpose of avoiding the bias of a single method, this paper utilizes the synergetic theory to construct a compound system for STF and STI, and scientifically calculates the synergetic degree of the compound system. In the calculation of the weight of each index in the system, a variety of weight calculation methods are used, namely the correlation matrix weighting method, the entropy weighting method and the standard deviation method, and based on different weight results, the data of STF and STI development in Guangdong Province from 2002 to 2013 were analyzed empirically.

II. Building the Model

Through the preliminary analysis, we know that the scientific and technological advancement in a certain area is inseparable from the mutual promotion of STF and STI. Therefore, we combine the synergy theory and the synergy degree model of composite systems proposed by Q.S. Meng [19] et al. to build a model of the synergetic development degree of STF and STI.

A. Ordering Degree Model of Subsystem

The composite system of STF and STI is set to be $S=\{S_1,S_2\}$. S_1 represents the sci-tech innovation subsystem, and S_2 represents the sci-tech finance subsystem. Let the parameters of the two subsystems be $e_j=(e_{j1},e_{j2},\cdots,e_{jn})$, where $n\ge 1$. Let α_{ji} and β_{ji} be the upper and lower limits of the order parameter component e_{ji} at the system stability critical point respectively, then, $\beta_{ji}\le e_{ji}\le \alpha_{ji}$,where $i=1,2,\cdots,n$.

Definition 1[19]: Ordering degree of the subsystem of the order parameter component e_{ji} can be expressed as the following.

$$u_j\left(e_{ji}\right)=\begin{cases}\dfrac{e_{ji}-\beta_{ji}}{\alpha_{ji}-\beta_{ji}}, \text{when } e_{ji} \text{ is a positive indicator,}\\[2ex] \dfrac{\alpha_{ji}-e_{ji}}{\alpha_{ji}-\beta_{ji}}, \text{when } e_{ji} \text{ is the reverse indicator,}\end{cases} \tag{1}$$

where the value of $u_j\left(e_{ji}\right)$ indicates the importance of the order parameter component e_{ji} in the system. The larger the value, the greater the effect of e_{ji} on the ordering degree of the subsystem. $u_j\left(e_{ji}\right)\in[0,1]$.

The total contribution of all components to the ordering degree of the subsystem can be calculated by integrating the $u_j\left(e_{ji}\right)$. This paper adopts linear weighted summation method to integrate calculation:

$$\mu_j\left(e_j\right)=\sum_{i=1}^{n}\lambda_i\mu_j\left(e_{ji}\right),\lambda_i\ge 0,\ \sum_{i=1}^{n}\lambda_i=1 \tag{2}$$

Among them, λ_i is the weight of each e_{ji} in the subsystem, and reflects the importance of the component e_{ji} in maintaining the ordering degree of the system.

B. Synergy Degree Model of Composite System

Definition 2[19]: At the assumed starting time t_0, $u_1^0\left(e_1\right)$ represents the ordering degree of the sci-tech finance subsystem, and $u_2^0\left(e_2\right)$ represents the ordering degree of the sci-tech innovation subsystem. At another moment t_1 in the evolution of the composite system, $u_1^1\left(e_1\right)$ and $u_2^1\left(e_2\right)$ represent the ordering degree of the subsystems for the STF and STI system respectively. The synergy degree of the sci-tech financial and innovational composite system can be defined as:

$$C=sig\left(\bullet\right)\times\sqrt{\left|u_1^1\left(e_1\right)-u_1^0\left(e_1\right)\right|\times\left|u_2^1\left(e_2\right)-u_2^0\left(e_2\right)\right|}. \tag{3}$$

Where

$$sig\left(\bullet\right)=\begin{cases}1,\ u_1^1\left(e_1\right)-u_1^0\left(e_1\right)>0 \text{ and } u_2^1\left(e_2\right)-u_2^0\left(e_2\right)>0,\\ -1, \qquad\qquad \text{other situations.}\end{cases}$$

It can be seen from (3) that the calculation of the synergy degree in the composite system is non-static and follows the chronological order, and this synergy degree also needs known conditions such as the ordering degree of the subsystems of the STF and STI. The synergy degree of the composite system *C* is actually a state where two subsystems forming the composite system can cooperate and develop. The greater the *C*, the greater the synergy effect of the composite system, and vice versa.

III. Empirical Research

A. Indicator Selection

There is no systematic research on the selection criteria of order parameter components and the index system of synergy degree measurement in China or other countries. In line with the principles of science, system, hierarchy, adaptability and operability, this paper, based on the actual situation of Guangdong Province, and by referring to the relatively typical index system of synergetic degree measurement constructed by scholars such as H.Q. Wang [20] et al., scientifically builds the index system for measuring the synergetic degree, as shown in Table I.

B. Data Sources

This paper selects the relevant statistical data of STF and STI in Guangdong Province from 2002 to 2013. The sources include the websites of Guangdong Provincial Bureau of Statistics, Guangdong Provincial Department of Science and Technology, Guangdong Science and Technology Statistics Network and Guangdong Science and Technology Yearbook from 2003 to 2013. Because some indicators are difficult to obtain directly or find the original data cannot be found, we make reasonable substitution for these indicators, or use similar indicators to replace the original indicators [20], as follows.

1) Innovation tax revenue: there is no data on innovation tax revenue in Guangdong Province at present, therefore, high-tech industry profits and taxes with strong correlation and similarity are used as replacement.

2) Number of technology-based listed companies: there is no data on the number of technology-based listed companies in Guangdong Province, and technology-based listed

companies must firstly be high-tech enterprises. The more high-tech enterprises there are, the more technology-based listed companies there are. Therefore, we use high-tech companies to replace technology-based listed companies.

According to the above data collection sources and replacement methods, the original data are shown in Tables II and III. The counting unit of S13, S21, S22 and S31 is 100 million yuan.

C. Data Processing

The use of the dimensionless processing of index data is a necessary process for the two systems to perform synergy testing, because the nature of the direct influencing factors of STF and STI are different. In this paper, mean-standard deviation method is used for centralization and standardization. The specific method is as follows.

$$X'_{ij} = \frac{X_{ij} - \overline{X}_j}{S_j}(i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m) \quad (4)$$

Where X'_{ij} and $\overline{X}_j$ represent standardized data and the average value of X_{ij} respectively. S_j is the standard deviation of X_{ij}. When there are *m* samples and *n* items of indicator data, the original index data matrix $B = (X_{ij})_{n\times m}$ is formed, where X_{ij} represents the value of the *j*-th sample of the *i*-th index. $B' = (X'_{ij})_{n\times m}$ is the form of standardization.

TABLE I
INDEX SYSTEM OF COORDINATION DEGREE MEASUREMENT

Order parameter	First-level indicators	Second-level indicators
S (Sci-tech innovation subsystem)	S1 (R & D capabilities)	S11 (Number of the top three retrieved papers)
		S12 (Number of invention patent applications)
		S13 (Number of granted invention patents)
	S2 (Achievement transformation ability)	S21 (Output value of high-tech products)
		S22 (Sales revenue of high-tech products)
	S3 (Industrial capacity)	S31 (Added value of high-tech industry)
	S4 (Technology diffusion capability)	S41 (Amount of contract concluded in technology market)
F (Sci-tech finance subsystem)	F1 (Public sci-tech Finance)	F11 (Local financial science and technology funding)
		F12 (Innovation tax revenue)
	F2 (Market sci-tech Finance)	F21 (Bank Technology Credit Amount)
		F22 (Number of technology listed companies)
		F23 (Total venture capital)

TABLE II
RAW DATA OF SCI-TECH INNOVATION SUBSYSTEM

Years	S11	S12	S13	S21	S22	S31	S41
2002	1 996	34 339	22 760	4 532. 33	4 359. 79	998. 68	68. 45
2003	2 847	43 186	29 235	6 611. 18	6 394. 46	1 560. 68	80. 57
2004	3 442	52 201	31 446	8 963. 53	8 857. 65	1 794. 33	57 .27
2005	5 777	72 220	36 894	10 300. 27	10 119. 60	2 249. 59	112. 47
2006	6 966	90 886	43 516	13 121. 43	12 961. 88	2 849. 42	107. 03
2007	8 363	102 449	56 451	14 853. 76	16 756. 93	2 883. 08	133. 86
2008	10 044	103 882	62 031	17 175. 65	16 537. 62	3 663. 62	184. 78
2009	11 312	125 673	83 621	17 161. 94	16 758. 08	3 852. 74	247. 93
2010	14 779	152 907	119 346	21 050. 20	20 952. 80	4 850. 59	242. 50
2011	14 331	196 275	128 415	23 609. 35	23 257. 81	4 741. 14	286. 62
2012	13 232	229 514	153 598	25 253. 28	24 607. 63	5 478. 80	369 75
2013	14 952	264 265	170 430	29 283. 54	27 999. 37	6 654. 38	535. 68

TABLE III
RAW DATA OF SCI-TECH FINANCE SUBSYSTEM

Years	F11	F12	F21	F22	F23
2002	57. 70	255. 72	26. 58	3 238	150. 00
2003	56. 58	400. 53	39 .23	3 961	164. 00
2004	65. 37	434. 43	45. 53	4 651	170. 00
2005	83. 77	533. 26	35. 11	4 998	200. 00
2006	104. 10	721. 19	40. 69	5 968	310. 00
2007	119. 26	841. 65	37. 13	7 636	214. 42
2008	132. 52	899. 76	43. 19	8 580	250. 66
2009	168. 50	1 154. 84	48. 82	8 557	312. 79
2010	214. 44	1 684. 10	60. 89	5 574	349. 56
2011	203. 92	1 870. 72	73. 26	6 034	295. 37
2012	246. 71	1 908. 52	93. 01	7 166	209. 71
2013	344. 94	2 345. 08	107. 70	7 374	320. 86

D. Determination of Indicator Weights

1) Correlation matrix weighting method

Step 1: Assuming there are n indicators in the indicator system, then the correlation matrix A is $(a_{ij})_{n\times n}$, $a_{ii}=1$. $A_i=\sum_{j=1}^{n}\left|a_{ij}\right|-1$, where $i=1,2,3,\cdots,n$, denotes the total degree of influence of the i-th index on the other $n-1$ indexes,. The larger the value, the greater the influence of the i-th index, and the larger the corresponding weight.

Step 2: Calculating the weight of each indicator by $\lambda_i=\frac{A_i}{\sum_{i=1}^{n}A_i}$.

2) Entropy weighting method

Step 1: Assuming that the proportion of the j-th plan under the index i is $P_{ij}=\frac{X_{ij}}{\sum_{j=1}^{m}X_{ij}}\ (i=1,2,\cdots n)$.

Step 2: Calculating the entropy value of the i-th index by $e_i=-k*\sum_{j=1}^{m}P_{ij}\log(P_{ij})$, where $k>0$ and ln is the natural logarithms. k is constant and related to the number of samples m. Generally, $k=\frac{1}{\ln m}$.

Step 3: For the i-th index, the greater the difference between the indexes X_{ij}, the greater the effect on the solution evaluation, and the corresponding entropy value is naturally low. Let $g_i=1-e_i$, obviously the larger the g_i, the more important the index.

Step 4: Calculating the weight by $\lambda_i=\frac{g_i}{\sum_{i=1}^{n}g_i}(i=1,2\cdots n)$.

3) Standard deviation method

Step 1: Finding the mean of a random variable by

$$\overline{X_i'}=\frac{1}{m}\sum_{j=1}^{m}X_{ij}'. \tag{5}$$

Step 2: Finding the mean square error of indicator by

$$\sigma_i=\frac{1}{m}\sqrt{\sum_{j=1}^{m}\left(X_{ij}'-\overline{X_i'}\right)^2}. \tag{6}$$

Step 3: Calculating the weights of the indicator by

$$\lambda_i=\frac{\sigma_i}{\sum_{i=1}^{n}\sigma_i},\quad i=1,2,\cdots,n. \tag{7}$$

The weights of different indicators can be obtained by substituting standardized data into three weight methods, as shown in Table IV.

E. The Ordering Degree in the Subsystem and the Synergy Degree in the Composite System

From (1), (2) and the results in Table IV, the ordering degree of the subsystems under different methods can be obtained, as shown in Table V. By substituting the data in Table V into (3), we can get the synergy degree of the composite system with different weighting methods, as shown in Table VI. A line chart is drawn according to the data in Table VI, and intuitively makes the development trend of the synergy of STF and STI composite system, as shown in Fig 1.

IV. Result Analysis

The calculation results of the synergy degree of STF and STI in Guangdong Province in China from 2002 to 2013 demonstrate the following main characteristics.

1) From Fig 1, we can observe that the synergy degree of Guangdong Province fluctuates in the range of [-0.05,0.2] in recent years, indicating that in recent years, the STF and STI in Guangdong Province are in a low synergy state, and even the composite system in 2007 showed a non-synergistic evolution state. This also shows that the mechanism of collaborative development between STF and STI in Guangdong Province is not yet mature, and sometimes there may even be mutual constraints. In 2007, the synergies obtained by the standard deviation method and the correlation matrix method are both negative, while the entropy weighting method calculates a positive value, which indicates that the entropy weighting method has a certain degree of deviation in processing this data.

2) Although the synergetic degree of the composite system in Guangdong Province is low in recent years, it generally shows a rising trend on the whole, and the climbing speed is significantly accelerated in recent years, which indicates that STF and STI in Guangdong Province are gradually moving to a more coordinated development state.

3) After calculating the orderliness of the two subsystems, we conclude that regional sci-tech finance has generally not kept pace with regional innovation in science and technology, as shown in Fig 2, Fig 3, and Fig 4.

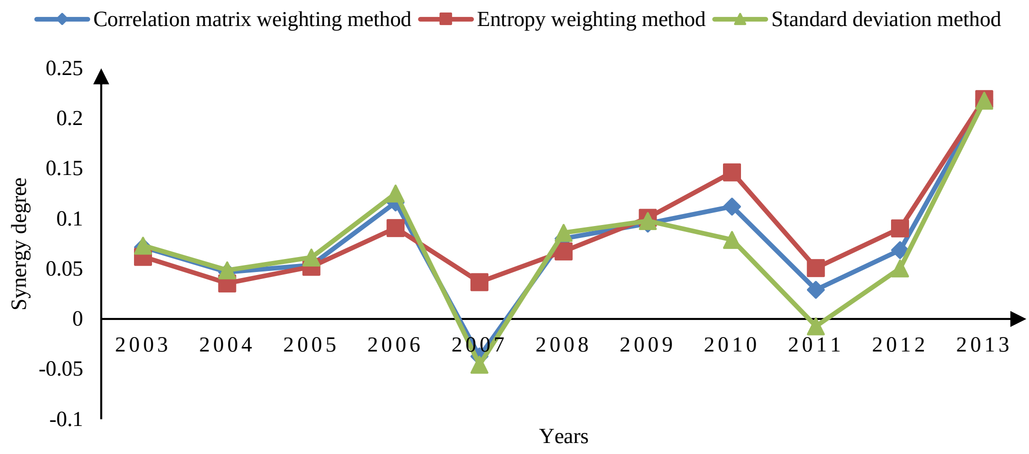

Fig 1. Trend of Synergy of Composite System under the Three Weighting Methods.

TABLE IV
THE WEIGHTS OF THE SYNERGY DEGREE UNDER THREE WEIGHTING METHODS

Methods		Indicators	Correlation matrix weighting	Entropy weighting	Standard deviation
Weights	Output index of sci-tech innovation	S11	0. 140 227 2	0. 137 463 1	0. 162 636 6
		S12	0. 143 008 8	0. 157 169 5	0. 142 170 3
		S13	0. 141 973 8	0. 186 018 6	0. 154 291 7
		S21	0. 145 506 9	0. 106 357 3	0. 137 086 9
		S22	0. 144 295 8	0. 104 205 5	0. 139 037 7
		S31	0. 145 895 2	0. 109 983 1	0. 133 512 5
		S41	0. 139 092 3	0. 198 803 0	0. 131 264 4
	Performance indicators of sci-tech financial investment	F11	0. 234 443 8	0. 303 220 9	0. 189 545 2
		F12	0. 235 327 3	0. 373 272 1	0. 205 379 2
		F21	0. 214 872 7	0. 173 536 3	0. 188 845 2
		F22	0. 147 089 1	0. 075 970 6	0. 201 360 5
		F23	0. 168 267 2	0. 074 000 2	0. 214 869 9

TABLE V
ORDERING DEGREE UNDER THREE WEIGHTING METHODS

Methods	Correlation matrix weighting		Entropy weighting		Standard deviation	
Years	Ordering degree of sci-tech innovation	Ordering degree of sci-tech finance	Ordering degree of sci-tech innovation	Ordering degree of sci-tech finance	Ordering degree of sci-tech innovation	Ordering degree of sci-tech finance
2002	0. 003 250 458	0. 000 910 588	0. 004 645 844	0. 001 177 72	0. 003 067 527	0. 000 736 200
2003	0. 066 850 881	0. 081 529 862	0. 061 746 241	0. 068 405 91	0. 066 059 200	0. 086 010 056
2004	0. 109 140 905	0. 133 240 073	0. 092 834 204	0. 109 220 22	0. 108 051 484	0. 142 255 496
2005	0. 195 456 681	0. 166 580 508	0. 181 253 977	0. 139 993 13	0. 196 152 046	0. 185 188 790
2006	0. 274 127 940	0. 338 515 972	0. 249 026 031	0. 261 466 90	0. 274 547 968	0. 385 017 346
2007	0. 350 893 874	0. 320 314 475	0. 324 022 973	0. 279 591 64	0. 352 820 899	0. 358 496 271
2008	0. 422 594 506	0. 410 241 840	0. 395 216 028	0. 343 743 83	0. 424 606 101	0. 461 635 209
2009	0. 495 133 002	0. 534 891 490	0. 481 594 357	0. 461 904 86	0. 499 567 543	0. 589 495 439
2010	0. 656 568 132	0. 612 693 182	0. 634 344 836	0. 601 800 09	0. 665 528 433	0. 626 966 646
2011	0. 726 530 814	0. 624 898 712	0. 708 023 705	0. 636 988 13	0. 733 449 006	0. 626 184 769
2012	0. 820 622 938	0. 675 201 066	0. 812 710 813	0. 715 321 13	0. 823 784 931	0. 654 442 418
2013	1. 000 000 000	0. 942 593 849	1. 000 000 000	0. 972 206 57	1. 000 000 000	0. 923 639 412

TABLE VI
SYNERGY DEGREE OF COMPLEX SYSTEMS UNDER THREE WEIGHTING METHODS

Years	Correlation matrix weighting method	Entropy weighting method	Standard deviation method
2003	0. 071 606	0. 061 958	0 073 291
2004	0. 046 764	0. 035 621	0. 048 599
2005	0. 053 645	0. 052 163	0. 061 502
2006	0. 116 303	0. 090 733	0. 125 163
2007	-0. 037 380	0. 036 869	-0. 045 562
2008	0. 080 299	0. 067 581	0. 086 046
2009	0. 095 089	0. 101 028	0. 097 901
2010	0. 112 071	0. 146 182	0. 078 859
2011	0. 029 222	0. 050 918	-0. 007 287
2012	0. 068 797	0. 090 556	0. 050 524
2013	0. 219 007	0. 219 344	0. 217 799

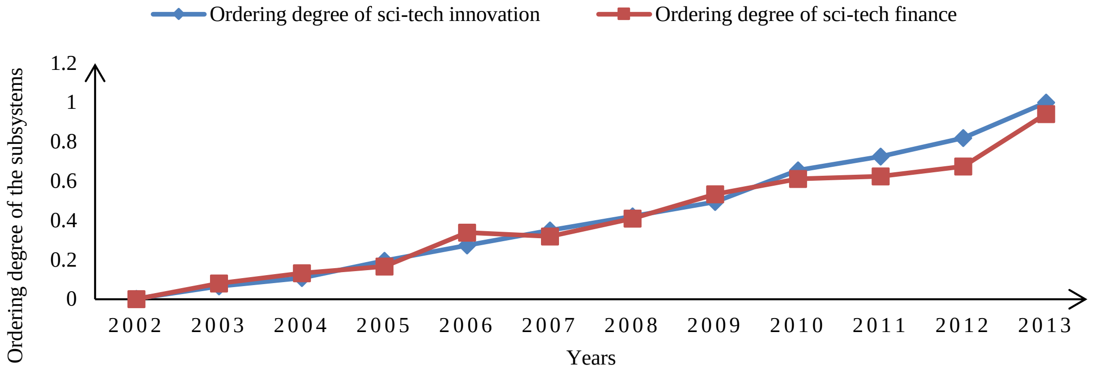

Fig 2. The development trend of ordering degree under the correlation matrix method.

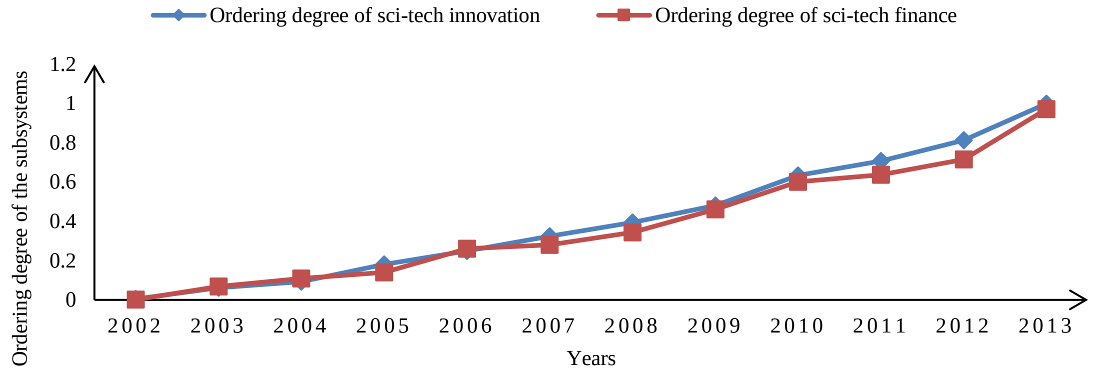

Fig 3. The development trend of ordering degree under the entropy weighting method.

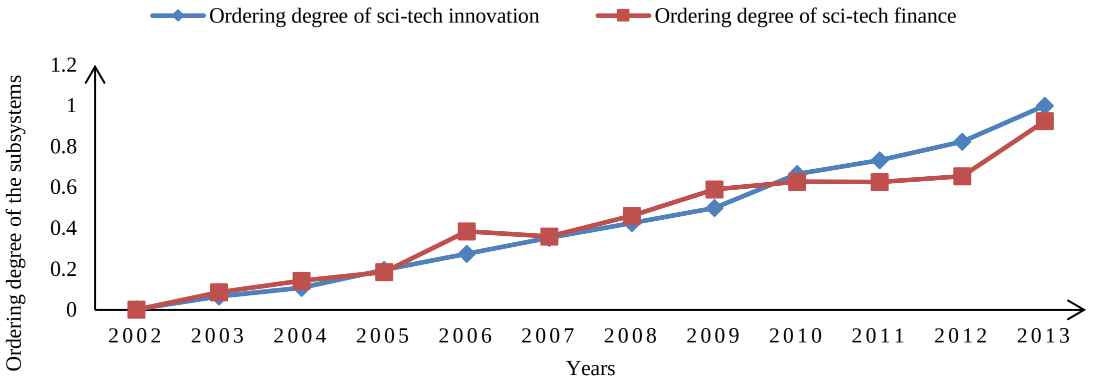

Fig 4. The development trend of ordering degree under the standard deviation method.

V. Conclusions

This paper, based on the synergetic analysis of sci-tech finance (STF) and sci-tech innovation (STI), constructs an index system that conforms to Guangdong, and establishes a model of the synergy degree of scientific and technological finance and innovation of Guangdong Province. When determining the weights of the order parameter components of the constructed subsystem, we use three different methods instead of using only one method, namely the correlation matrix weighting method, the entropy weighting method and the standard deviation method. Independent analysis was made on the synergy degree models of STF and STI, and finally a comprehensive comparison was made between them. The results show that using different weight calculation methods not only can avoid the inaccuracy of one method, but also make the results more reasonable and convincing. Moreover, the performance of the composite system in recent years is analyzed through the model we built and the development tendency of the system is determined. According to these development trends, corresponding strategies can be made by corresponding government departments to make the development of the composite system in this region move towards the direction of high coordination.

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