Research on the Four-Chain Synergy Degree of Venous Industry in China

Guofu Zhao(✉)

School of Economics & Trade, Zhengzhou University of Technology, Zhengzhou 450044, China
20201022@zzut.edu.cn

Abstract. -To measure the synergy degree of the four chains, namely the industrial chain, innovation chain, service chain, and capital chain in the development of China's venous industry, this research establishes an evaluation system for the synergy degree and carried out empirical research on two typical venous industrial parks. The results show that the degree of order of the industrial chain subsystem, innovation chain subsystem, service chain subsystem, and capital chain subsystem of Tianjin Ziya Venous Industrial Park and Xi'an High-Tech Industrial Parks became higher from 2006 to 2016. The synergy degree of the four-chain composite system is within the range of 0 to 0.2 and is still on the rise. And the capacity and the order degree of the certain chain will be greatly improved if it gets much more attention from the government or the park, which should attach importance to the synergized development of the four chains. The research reveals that there is still a long way to go before the four chains of the Chinese venous industry become fully synergized. The government may well strengthen the synergy management of the four chains and encourage the innovation of venous industries. What's more, the government and relevant enterprises should provide good services, straighten out the financing channels of small and medium-sized venous enterprises, and create a good business environment for China's venous industry.

Keywords: China's venous industry · multi-chain synergy · evolution analysis

1 Introduction

Developing the venous industry could be important for the construction of a two-oriented society, namely a resource-conserving society and an environment-friendly society. The venous industry mainly reuses the wastes or transforms waste into renewable resources to be reused [1] to make full use of developed resources, conserve the primary resources, and reduce pollutant emissions so that the environment can be protected. In recent years, the government has paid special attention to the development of venous industries and issued a series of policies as a boost, among which "park-based" development outweighs other measures. Under the guidance of this strategy, venous industrial parks and ecological industrial parks sprung up all over the country. In the construction and development of venous industrial parks, the three chains, innovation chain, service chain, and capital chain support the venous industrial chain [2], which in turn reinforces the three chains.

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The capital chain, financing the advancement of the innovation chain and service chain, is also fed back by these two chains. At the same time, the service chain also promotes the innovation chain. The two-way action of the four chains enhances the development of venous industries and the construction of a two-oriented society. Yet the synergy degree of the four chains of venous industries and the synergy evolution law still remained unknown from the previous studies and will be the research object of this paper. And suggestions for further improving the venous industries will also be provided.

2 Literature Review

In terms of the relationship between different chains, the integration and collaboration of industry and innovation chains were more widely studied previously. And the research objects mainly include: firstly, the stabilization effect on emerging industries [3] brought by the integration of innovation and industrial chains as well as the horizontal and vertical synergies between industry and innovation chains at a certain time [4]; secondly, the significance and path of integrated development of industry and innovation chains [5], and the coordinated development [4] and upgrading [7] of these two chains; thirdly, the integration strategy of industrial chain, innovation chain, and capital chain in emerging industries and health and smart industries [8]. It can be seen that the above research only focused on the relationship between the two or three of the chains and ignored the supporting role of the service chain in the development of the industrial chain. However, as the waste recycling, logistics and transportation, repair, maintenance, and trading of second-hand goods, productive services related to resource regenerative utilization, and park management of the venous industries are typical service ones. The service chain, which is composed of a series of service links, has a huge positive effect in supporting the development of the venous industries and enabling the innovation chain to be effective. In addition, the service chain of venous industries also needs financial support, which calls for more concern on the synergy between the service chain, industrial chain, and capital chain.

With regard to the studies on the synergy mechanism between different chains, Hacken (1989) held that in the objective world, various systems work together or influence or restrain each other, leading to changes in the structure and order degree of the system. For example, the old structure may evolve into a new one or there may be alternations between disorder and order. If the subsystems coordinate with each other and become synergized, the system will be in good order, which was defined as "synergetics" by Haken. The general principle of synergetics is that the orderly state of the system is decided by a set of time-dependent variables. The variables that change quickly are called fast parameters while the rest are slow ones. And the state of the system is mainly determined by the slow parameters which are also named order parameters.

Most of the studies on the synergy degree by domestic scholars are related to the evaluation of synergy innovation and are mainly reduced to four levels, the enterprise level, the industrial level, the regional level, and the national level. To be specific, the research at the enterprise level mainly focuses on the coordination between product innovation and process innovation [9], and the internal mechanism and process of coevolution of enterprise dynamic capabilities [10]. At the industrial level, the studies center on the coordination of the economic subsystem and environment subsystem of energy-intensive industries [11], the coordination of policies and measures of the photovoltaic industry [12], the coordination of knowledge-intensive manufacturing industry and knowledge-intensive service industry [13], and how the industrial policies improve the green total factor productivity (GTFP) of manufacturing industry [14]. The focuses of the research at the regional level include the reform and path from coordination to the synergy of cross-regional environmental governance [15], the synergistic effect and antagonistic effect between ecological compensation and poverty alleviation [16], the coordinated development of Beijing, Tianjin, and Hebei supported green finance [17], and the coordinated governance of high-quality development of China's dairy industry [18]. At the national level, the research mainly concentrates on the coordination between fiscal policy and monetary policy [19], the coordination between science and technology policies and industrial policies [20], and the coordination between anti-dumping and technological progress [21]. Most of the existing studies emphasize the evaluation of the synergy degree of the composite system composed of two subsystems, while the synergy of three subsystems is less investigated and that of four subsystems has not been found yet. In addition, the research at the industrial level outnumbers the other three yet was less involved with the coordination of different elements within the industry. In light of this problem, the specialty of this study is that it focalizes on the synergy of the industrial chain, innovation chain, service chain, and capital chain of the venous industry, which has a great significance for promoting the healthy and orderly development of the venous industry.

3 Establishment of Evaluation Indicators of Synergy Degree of Four Chains

With the *Standard for National Demonstration Eco-Industrial Parks* (hereinafter referred to as the "Standard"), the *List of Accepted National Demonstration Eco-Industrial Parks* (hereinafter referred to as the "List") issued by the Ministry of Ecology and Environment of People's Republic of China on December 24, 2015, the relevant information obtained in the process of research and interview [22], and the characteristics of the initial development of venous industry parks serving as a basis, the evaluation indicator system for the synergy of four chains, namely industrial chain, innovation chain, service chain, and capital chain of the venous industry were established and defined as S_1, S_2, S_3, S_4 respectively. Among these, the industrial chain subsystem S_1 starts from five dimensions, including the structure of the industrial chain, economic development, material reduction and recycling, pollution control, and park governance, to establish five first-level indicators. The innovation chain subsystem S_2 focuses on two dimensions, innovation input, and innovation output, to establish two first-grade indicators. Service chain subsystem S_3 has two first-grade indicators, that is the public service capacity and production and service capacity. The capital chain subsystem S_4 also picks two first-grade indicators, namely the fundraising capacity and fund turnover capacity. And each of these 11 first-grade indicators is set with two second-grade ones (22 in total), as shown in Table 1.

Table 1. Evaluation indicator of synergy degree of four chains of venous industry

Subsystem	First-Grade indicator	Second-Grade indicator	Code	Basis	Indicators and data sources
S_1 Industrial chain subsystem	Industrial chain structure	Number of ecological industrial chain	S_{11}	R	Established based on investigation and interview data
		Average length of ecological industrial chain	S_{12}	R	Established based on investigation and interview data, the number of nodes of the ecological industrial chain
	Economic development	Industrial added value for per capita	S_{13}	B	Industrial added value in park/ number of employees in par, survey data
		Industrial added value per unit area	S_{14}	B	Industrial added value in park/ land for industrial purposes in the park, survey data
	Material reduction and recycling	Amount of solid waste per industrial added value	S_{15}	B	Amount of solid waste in the park/ industrial added value, survey data
		Comprehensive utilization of industrial solid waste (%)	S_{16}	B	Comprehensive utilization amount/ inbound volume of solid waste inside and outside the park, survey data
	Pollution control	Waste collection and centralized treatment capacity	S_{17}	R	The annual capacity of solid waste collection and treatment, survey data

(*continued*)

Table 1. (*continued*)

Subsystem	First-Grade indicator	Second-Grade indicator	Code	Basis	Indicators and data sources
		Harmless treatment ratio for house refuse (%)	S_{18}	R	Harmless treatment amount/ amount of house refuse, investigation and interview
	Park governance	Perfection of ecological industrial information platform (%)	S_{19}	B	Survey data
		Cognitive rate of the ecological industry by the public (%)	S_{110}	B	Survey data
S_2 Innovation chain subsystem	Innovation input	Number of personnel in scientific research	S_{21}	R	Survey data
		Input in scientific activities	S_{22}	R	Survey data
	Innovation output	Number of scientific activities	S_{23}	R	Survey data
		Number of patent applications	S_{24}	R	Survey data
S_3 Service chain subsystem	Public service capacity	Perfection of public facilities	S_{31}	R	Investigation and survey data
		The convenience of public service	S_{32}	R	Investigation and survey data
	Production service capacity	Number of settled productive service industry	S_{33}	R	Survey data

(*continued*)

Table 1. (*continued*)

Subsystem	First-Grade indicator	Second-Grade indicator	Code	Basis	Indicators and data sources
		Number of personnel in the productive service industry	S_{34}	R	Survey data
S_4 Capital chain subsystem	Fundraising capacity	Average debt-asset ratio of park enterprise	S_{41}	R	Total debt/ total asset, survey data
		Average current ratio of park enterprises	S_{42}	R	Total current assets/ total current liability, survey data
	Fund turnover capacity	Number of turnover of current fund of park enterprises	S_{43}	R	Turnover/ average balance of current funds, survey data
		Capital turnover rate of park enterprises	S_{44}	R	Sales revenue/ average amount of stockholder's equity $\times$ 100%, survey data

Source: The "basis" column is designed to reveal the source of the data. To be specific, B indicates that the indicators are established according to the "Standard" and "List", and R indicates that the indicators are established based on the survey and interview data

4 Establishment of the Evaluation Mechanism of Synergy Degree of Four Chains of Venous Industry

The industrial chain, innovation chain, service chain, and capital chain of the venous industry constitute a complex system $S = f(S_1, S_2, S_3, S_4)$, which will be stable under the synergistic effect of the four chains, there are two kinds of variables, slow ones and fast ones, at the critical point when the system becomes stable. Of the two kinds of variables, the slow ones maintain the stableness of the system, also called the order parameter. The key mechanism of the venous industry transforming from disorder to order and from low efficiency to high efficiency lies in the synergy between order parameters.

The order parameter of the four-chain synergy system of the venous industry in the evolution process is $S_i^{(t)}$ (S_i is the function of t). i $\in [1, m]$ and m is the number of order parameters, m > 1. The subparameter of $S_i^{(t)}$ is $S_{ij}^{(t)}$. $j \in [1, n]$ and n is the number of sub-parameters of order ones, n > 1. In this research, the order parameter $S_i^{(t)}$ corresponds to the four capability subsystems. Therefore, $i = 1, 2, 3,$ and 4 correspondingly. $S_{ij}^{(t)}$ is the second-grade indicator of $S_i^{(t)}$ while j is the number of second-grade indicators. The first-grade indicators, as transition ones, will not be counted. The relationship between order parameter $S_i^{(t)}$ and its subparameter $S_{ij}^{(t)}$ is calculated as $S_i^{(t)} = f\left(S_{i1}^{(t)}, S_{i2}^{(t)}, \ldots, S_{in}^{(t)}\right)$. Since the synergy degree takes the evolution of the order parameters of the composite system within the time range t $\in [t_0, t_l]$ as the research object and the time range is the discrete series with each year serving as a separate node, the value of $S_{ij}^{(t)}$ can be expressed as a time sequential value $\{S_{ij}^{(t)}\}$. The evaluation process of the synergy degree of the four-chain system of the venous industry is specified in the next part.

4.1 Calculation of Order Degree of Order Subparameter

Assuming that α_{ij} and β_{ij} are the lower limit and upper limit of the order subparameter $S_{ij}^{(t)}$ respectively, then $\alpha_{ij} = min\left(S_{ij}^{(t)}\right)$, $\beta_{ij} = max\left(S_{ij}^{(t)}\right)$, and $\alpha_{ij} \le S_{ij}^{(t)} \le \beta_{ij}$ in this paper. There are positive indicators and negative ones in order subparameters. For example, in Table 1, the "amount of solid waste per industrial added value" is a negative indicator while others are all positive. The order degree increases along with growing positive indicators and decreases along with growing negative indicators. Generally, if $S_{i1}, S_{i2}, \ldots, S_{ih}$ are positive indicators and on the rise, the order degree of the system will be higher. On the contrary, if $S_{ih+1}, S_{ih+2}, \ldots, S_{in}$ are negative indicators and on the rise, the order degree of the system will be lower [23]. Based on the measurement method of order degree of order subparameters proposed by Xiaoya Wang (2017), the research defines the order degree of order subparameters of the four-chain synergized system of the venous industry as follows.

Definition 1. Formula (1) is the order degree of the order subparameter $S_{ij}^{(t)}$.

$$O_{ij}^{(t)}\left(S_{ij}^{(t)}\right) = \begin{cases} \frac{S_{ij}^{(t)} - \alpha_{ij}}{\beta_{ij} - \alpha_{ij}}, & j \in [1, h] \\ \frac{\beta_{ij} - S_{ij}^{(t)}}{\beta_{ij} - \alpha_{ij}}, & j \in [h+1, n], \end{cases} \tag{1}$$

It can be seen that $O_{ij}^{(t)}\left(S_{ij}^{(t)}\right) \in [0, 1]$, and the order parameters play a large part in determining the order degree.

4.2 Calculation of Order Degree of Order Parameter

(1) Order degree of the order parameter

The order degree of the order parameter can be achieved by integrating the order degrees $O_{ij}^{(t)}\left(S_{ij}^{(t)}\right)$ of subparameter. Based on the measurement method of the order degree of order parameter proposed by Jiliang Zheng and Ya Zhang (2017), the research adopts the linear weighted-sum method to measure the order degree of the order parameter of the four-chain synergized system of the venous industry. The formula is shown below.

Definition 2. The order degree of the order parameter $S_i^{(t)}$ is calculated according to the following Formula (2).

$$O_i^{(t)}\left(S_i^{(t)}\right) = \sum_{j=1}^{n} w_{ij} \cdot O_{ij}^{(t)}\left(S_{ij}^{(t)}\right) \tag{2}$$

In the formula,

$O_i^{(t)}\left(S_i^{(t)}\right)$ is the order degree of the order parameter $S_i^{(t)}$.

j is the number of subparameters $S_{ij}^{(t)}$ of order parameter $S_i^{(t)}$.

w_{ij} is the weight of the subparameter $S_{ij}^{(t)}$ of order parameter $S_i^{(t)}$. And the weight can be calculated by the entropy method (see below). $w_{ij} \geq 0$ and $\sum_{j=1}^{n} w_{ij} = 1$.

$O_{ij}^{(t)}\left(S_{ij}^{(t)}\right)$ is the order degree of $S_{ij}^{(t)}$, the subparameter of the order parameter $S_i^{(t)}$.

It can be seen from Formula (2) that $O_i^{(t)}\left(S_i^{(t)}\right) \in [0, 1]$, and the larger the value, the larger part $S_i^{(t)}$ playing in determining the order degree of the system, whereas it is effective.

(2) Weight

The entropy method is used in this paper to determine the weight. This method holds that the greater the discrete degree of sample observations of a certain index, the more information the index has. The smaller the uncertainty, the smaller the entropy will be. Therefore, the index will have greater weight [24]. Assuming that the research object X has m samples and is evaluated by n indicators, then x_{ij} (I = 1,2,…,m: j = 1,2,…,n) is the evaluated value of the j-th indicator, and its weight will be calculated according to the following process by adopting the entropy method [25].

The first step is establishing an evaluation matrix according to Formula (3).

$$X = \left(x_{ij}\right)_{m\times n} \tag{3}$$

In the formula,

m- the number of samples.

n- the number of indicators.

If the indicator value $x_j^T = \left(x_{ij}\right)_m$ (T means transposition) has greater dispersion, the information entropy will play a bigger role in the evaluation system and it should be given a higher weight, or otherwise.

The second step is standardizing the evaluation matrix according to Formula (4). And the Min-max standardization is used.

$$x_{ij}\prime = \frac{x_{ij} - \min\left(x_j\right)}{\max\left(x_j\right) - \min\left(x_j\right)} \tag{4}$$

The third step is calculating the weight of the ith sample under the jth indicator according to Formula (5) so that the indicator weight matrix P can be obtained.

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} X_{ij}} \quad (5)$$

$$P = (p_{ij})_{m \times n} \quad (6)$$

The fourth step is calculating the information entropy of the j-th indicator according to Formula (7).

$$e_j = -\frac{1}{lnm}\sum_{i=1}^{m} p_{ij} \cdot lnp_{ij} \quad (7)$$

The fifth step is calculating the coefficient of variability of the information entropy of the j-th indicator according to Formula (8) (namely the redundancy of information entropy).

$$\mathrm{d_j} = 1 - \mathrm{e_j} \quad (8)$$

The sixth step is calculating the weight of the j-th indicator according to Formula (9).

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (9)$$

4.3 Synergy Degree of Four-Chain Systems

The synergy degree of the industrial chain, innovation chain, service chain, and capital chain of the venous industry, namely the coordination degree of the four chains, manifests the trend and degree of the venous industry developing from a disordered state to an ordered state. Assuming that when the time is t_0, order degree of industrial chain subsystem is $O_1^{t_0}\left(S_1^{t_0}\right)$. And the order degree of the innovation chain subsystem is $O_2^{t_0}\left(S_2^{t_0}\right)$, and that of the service chain subsystem is $O_3^{t_0}\left(S_3^{t_0}\right)$, and that of the capital chain subsystem is $O_4^{t_0}\left(S_4^{t_0}\right)$. And when the time is t_1, the order degree of the industrial chain subsystem is $O_1^{t_1}\left(S_1^{t_1}\right)$, that of the innovation chain subsystem is $O_2^{t_1}\left(S_2^{t_1}\right)$, that of the service chain subsystem is $O_3^{t_1}\left(S_3^{t_1}\right)$, and that of the capital chain subsystem is $O_4^{t_1}\left(S_4^{t_1}\right)$. The synergy degree of the four-chain system of the venous industry is defined as follows.

Definition 3. Formula (10) is the synergy degree of venous industry in the range $[\mathrm{t_0,t_1}]$.

$$C = \lambda \cdot \sqrt[4]{\prod_{i=1}^{4}\left|O_i^{t_1}\left(S_i^{t_1}\right) - O_i^{t_0}\left(S_i^{t_0}\right)\right|} \quad (10)$$

In the formula, $\lambda = \frac{min_i\left[O_i^{t_1}\left(S_i^{t_1}\right)-O_i^{t_0}\left(S_i^{t_0}\right)\right]}{\left|min_i[O_i^{t_1}\left(S_i^{t_1}\right)-O_i^{t_0}\left(S_i^{t_0}\right)\right|}$ and $O_i^{t_1}\left(S_i^{t_1}\right) - O_i^{t_0}\left(S_i^{t_0}\right) \neq 0$. When $O_i^{t_1}\left(S_i^{t_1}\right) - O_i^{t_0}\left(S_i^{t_0}\right) > 0$, the development direction of all subsystems remained uniform in the range $[t_0,t_1]$, and the system is in an ordered state with $\lambda = 1$. When $O_i^{t_1}\left(S_i^{t_1}\right) - O_i^{t_0}\left(S_i^{t_0}\right) < 0$, the development directions of all subsystems are different in the range $[t_0,t_1]$, and the system is in a disordered state or uncoordinated state with $\lambda = -1$. Apparently, $C \in [-1, 1]$. And the greater the value is, the more synergized the four chains of venous industry would be, or otherwise.

5 Four-Chain Synergy Degree Evaluation of CHINa's Venous Industry

Taking Tianjin Ziya Economic and Technological Development Zone (hereinafter briefly referred to as "Tianjin Ziya") and Xi'an High-Tech Industrial Development Zone (hereinafter briefly referred to as "Xi'an High-tech") as examples, this research carries out an empirical analysis of the four-chain coevolution path of venous industry in the two zones with the help of the four-chain synergy evaluation system and the measurement mechanism of synergy degree established in the previous section.

5.1 Data Source

The sources of empirical data in this part are mainly mainly include: (1) the open data on the websites of the management committees of the two development zones; (2) the annual statements from industrial information department, environmental protection department, science and technology department, and commercial department, which are the subordinates of the Management Committee; (3) data verification and acceptance list of National Demonstration Eco-Industrial Parks on the website of the Ministry of Ecology and Environment of PRC; (4) information disclosure table of the annual evaluation report on the construction of National Demonstration Eco-Industrial Parks; (5) the indicator data, such as the perfection degree of the ecological industrial information platform, debt-to-asset ratio, current ratio, number of turnover of current fund, and capital turnover rate, which can not be found through the above channels, are obtained through field visits and in-depth interviews with typical enterprises in the park on the recommendation of the staff of the management committee.

5.2 Data Processing

5.2.1 Data Standardization

The standardization of the four chain synergy indicators of the venous industry in Tianjin Ziya and Xi'an High-Tech development zones are shown in Table 2 and Table 3.

Table 2. Standardization of four-chain synergy indicators of Tianjin Ziya venous industry

Year	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{110}	S_{21}
2006	0.000	0.000	0.026	0.016	0.118	0.139	0.000	0.100	0.000	0.173	0.042
2007	0.100	0.000	0.073	0.080	0.353	0.235	0.000	0.100	0.250	0.286	0.074
2008	0.100	0.333	0.162	0.086	0.412	0.281	0.133	0.200	0.250	0.529	0.147
2009	0.200	0.333	0.251	0.086	0.608	0.444	0.133	0.200	0.500	0.571	0.189
2010	0.200	0.333	0.309	0.179	0.608	0.549	0.267	0.300	0.500	0.571	0.242
2011	0.500	0.667	0.393	0.252	0.627	0.609	0.267	0.400	0.750	0.571	0.295
2012	0.600	0.667	0.576	0.279	0.627	0.677	0.333	0.500	0.750	0.629	0.368
2013	0.600	0.667	0.597	0.290	0.667	0.677	0.467	0.600	0.900	0.714	0.537
2014	0.700	1.000	0.764	0.327	0.765	0.925	0.667	0.800	0.900	0.714	0.632
2015	0.800	1.000	0.901	0.584	0.902	0.995	0.867	0.900	1.000	0.900	0.800
2016	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Year	S_{22}	S_{23}	S_{24}	S_{31}	S_{32}	S_{33}	S_{34}	S_{41}	S_{42}	S_{43}	S_{44}
2006	0.203	0.043	0.119	0.000	0.000	0.136	0.102	0.143	0.000	0.100	0.000
2007	0.264	0.106	0.143	0.182	0.154	0.182	0.193	0.143	0.200	0.300	0.125
2008	0.312	0.191	0.190	0.364	0.154	0.318	0.345	0.190	0.200	0.350	0.375
2009	0.351	0.340	0.333	0.364	0.308	0.364	0.447	0.238	0.300	0.400	0.500
2010	0.434	0.468	0.381	0.545	0.308	0.500	0.503	0.286	0.360	0.400	0.500
2011	0.486	0.511	0.429	0.673	0.462	0.500	0.621	0.286	0.600	0.500	0.625
2012	0.577	0.596	0.500	0.673	0.462	0.636	0.752	0.381	0.800	0.700	0.625
2013	0.654	0.660	0.619	0.727	0.615	0.682	0.783	0.524	0.800	0.800	0.750
2014	0.742	0.766	0.714	0.818	0.769	0.773	0.832	0.619	0.900	0.900	0.750
2015	0.857	0.809	0.881	0.909	0.923	0.773	0.907	0.762	0.960	0.900	0.875
2016	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

5.2.2 Weight of Four-Chain Synergy Degree

With the entropy method being used, the calculation results of the weight of the four-chain synergy degree of the venous industry are listed in Table 4.

5.2.3 Order Degree of Four-Chain Subsystems and Synergy Degree of Four-Chain Composite Systems

The order degree of four-chain subsystems and the synergy degree of four-chain composite systems of the venous industry in Tianjin Ziya and Xi'an High-Tech zones, which were calculated according to Formula (2) and Formula (10), are disclosed in Table 5 and Table 6.

Table 3. Standardization of four-chain synergy indicators of Xi'an High-Tech venous industry

Year	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{110}	S_{21}
2006	0.167	0.000	0.045	0.100	0.150	0.139	0.000	0.182	0.286	0.230	0.032
2007	0.167	0.200	0.111	0.152	0.333	0.235	0.067	0.182	0.429	0.286	0.086
2008	0.333	0.400	0.196	0.196	0.467	0.331	0.133	0.273	0.429	0.529	0.108
2009	0.333	0.400	0.281	0.302	0.583	0.444	0.133	0.273	0.571	0.571	0.151
2010	0.500	0.600	0.337	0.361	0.667	0.549	0.200	0.364	0.571	0.600	0.194
2011	0.500	0.600	0.497	0.429	0.683	0.609	0.267	0.455	0.714	0.614	0.280
2012	0.500	0.800	0.593	0.472	0.717	0.677	0.333	0.545	0.714	0.629	0.355
2013	0.833	0.600	0.613	0.491	0.767	0.771	0.467	0.636	0.857	0.714	0.527
2014	0.833	1.000	0.774	0.549	0.800	0.925	0.667	0.818	0.857	0.814	0.688
2015	1.000	1.000	0.905	0.694	0.917	0.995	0.867	0.909	1.000	0.900	0.828
2016	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
year	S_{22}	S_{23}	S_{24}	S_{31}	S_{32}	S_{33}	S_{34}	S_{41}	S_{42}	S_{43}	S_{44}
2006	0.101	0.041	0.091	0.091	0.077	0.069	0.038	0.143	0.500	0.125	0.111
2007	0.207	0.102	0.136	0.182	0.154	0.121	0.100	0.143	0.500	0.250	0.222
2008	0.279	0.143	0.227	0.273	0.231	0.190	0.156	0.190	0.667	0.313	0.333
2009	0.391	0.286	0.295	0.364	0.308	0.310	0.384	0.238	0.667	0.375	0.444
2010	0.503	0.408	0.364	0.545	0.308	0.379	0.446	0.286	0.700	0.375	0.556
2011	0.555	0.510	0.432	0.636	0.462	0.448	0.578	0.286	0.717	0.375	0.667
2012	0.648	0.592	0.545	0.727	0.538	0.569	0.647	0.381	0.750	0.625	0.667
2013	0.726	0.694	0.636	0.818	0.615	0.655	0.758	0.524	0.750	0.750	0.722
2014	0.785	0.776	0.773	0.818	0.846	0.724	0.813	0.619	0.800	0.875	0.778
2015	0.877	0.898	0.864	0.909	0.923	0.879	0.896	0.762	0.867	0.875	0.944
2016	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 4. Weight of four-chain synergy indicators of venous industry

S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{110}	$S_{21}S_{21}$
0.1230	0.1161	0.1095	0.1445	0.0540	0.0666	0.1533	0.0975	0.0845	0.0510	0.3352
S_{22}	S_{23}	S_{24}	S_{31}	S_{32}	S_{33}	S_{34}	S_{41}	S_{42}	S_{43}	S_{44}
0.1719	0.2581	0.2348	0.2578	0.3283	0.2034	0.2104	0.2561	0.2933	0.2008	0.2498

5.3 Evolution Analysis of Four-Chain Synergy Degree

The evolution diagram of the four-chain order degree of the venous industry in the two development zones is indicated in Fig. 1 and Fig. 2 based on the above calculation results.

Table 5. Order degree of Four-chain subsystems and synergy degree of the four-chain composite system of Tianjin Ziya venous industry

year	S_1 order degree	S_2 order degree	S_3 order degree	S_4 order degree	four-chain synergy degree
2006	0.0393	0.0880	0.0493	0.0567	0.0557
2007	0.1120	0.1310	0.1749	0.1867	0.0846
2008	0.2102	0.1972	0.2815	0.2714	0.0875
2009	0.2770	0.2899	0.3629	0.3542	0.0804
2010	0.3338	0.3660	0.4492	0.3840	0.0578
2011	0.4652	0.4147	0.5574	0.5057	0.0958
2012	0.5288	0.4938	0.6126	0.6289	0.0765
2013	0.5821	0.6079	0.6929	0.7168	0.0810
2014	0.7287	0.7046	0.7958	0.7906	0.1018
2015	0.8635	0.8310	0.8855	0.8760	0.1069
2016	1.0000	1.0000	1.0000	1.0000	0.1345

Table 6. Order degree of Four-chain subsystems and synergy degree of the four-chain composite system of Xi'an High-Tech venous industry

year	S_1 order degree	S_2 order degree	S_3 order degree	S_4 order degree	four-chain synergy degree
2006	0.1037	0.0599	0.0673	0.1757	0.0925
2007	0.1851	0.1233	0.1367	0.2388	0.0690
2008	0.2928	0.1744	0.2087	0.3220	0.0758
2009	0.3437	0.2612	0.3412	0.3838	0.0775
2010	0.4328	0.3430	0.4151	0.4325	0.0715
2011	0.4974	0.4231	0.5274	0.4630	0.0649
2012	0.5666	0.5116	0.6165	0.5691	0.0873
2013	0.6401	0.6306	0.7081	0.6664	0.0939
2014	0.7882	0.7470	0.7997	0.7540	0.1085
2015	0.9101	0.8629	0.9015	0.8534	0.1093
2016	1.0000	1.0000	1.0000	1.0000	0.1155

It can be seen that the four-chain order degrees of venous industry in Tianjin Ziya and Xi'an High-Tech zones were on the rise from 2006 to 2016.

As shown in Fig. 3, the synergy degree of the four-chain composite system is within the range of 0 ~ 0.2 and is still on a steady rise. Before 2012, the synergy degree of Tianjin Ziya rose and fell repeatedly in the range of 0.0557 ~ 0.1345, and that of Xi'an

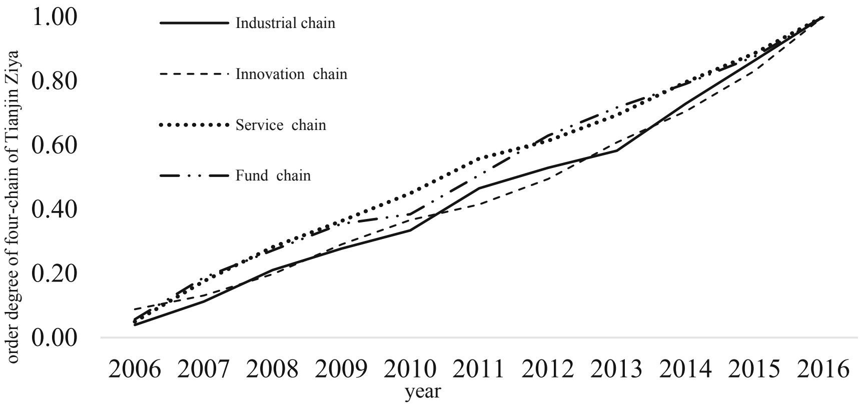

Fig. 1. Evolution diagram of the four-chain order degree of Tianjin Ziya

High-Tech showed the same trend but in the range of 0.0649 ~ 0.1155, of which the former zone has a higher fluctuation frequency and amplitude than the latter one. This indicates that before 2012, the four-chain synergy degree of Tianjin Ziya is less balanced than that of Xi'an High-Tech yet with a greater change rate. Since 2012, the synergy degrees of the venous industry in those two zones basically showed a steady upward trend. And from 2012 to 2015, the four-chain synergy degree of the emerging venous industry of Xi'an High-Tech was higher than that of Tianjin Ziya. And after 2015, the synergy degree of Tianjin Ziya improved rapidly, surpassing that of Xi'an High-Tech.

The reasons for the great difference in the synergy degree between two four-chain systems of venous industries can be examined from the order degree of four capabilities. For the order degree of the industrial chain, Fig. 4 reveals that from 2006 to 2016, although the order degrees of the industrial chain of the two zones increased in parallel, the value and stability of the order degree of the industrial chain of Xi'an High-Tech were higher than those of Tianjin Ziya. It may be because Xi'an High-Tech was founded in 1991, earlier than Tianjin Ziya, and possesses a mature leading industry. What's more, the remanufacturing industry in the park is dominated by waste automobile parts, engineering machinery, and machine tools, forming a venous industrial chain of "waste engines-remanufacturing- products", which is highly technological, promotes the cluster gathering of advanced manufacturing enterprises, and improves the industrial development capacity. Tianjin Ziya, founded in 2006 and having different orientations from Xi'an High-Tech, is the base of the chain "waste recycling- disassembly treatment- remanufacturing and deep processing- manufacturing industry", less technological than Xi'an High-tech. The order degree of the innovation chain, service chain, and capital chain of the two parks may overlap and change simultaneously sometimes.

From Fig. 5 below, it can be seen that the order degree of the innovation chain of Xi'an High-Tech tended to grow from 2006 to 2016, and that of Tianjin Ziya was higher than Xi'an High-Tech before 2011 and then decreased to be lower than that of Xi'an High-Tech until it caught up again in 2016. The research discovered that since Xi'an High-Tech was established, it has been relying on a series of innovation activities, including the technological development of venous industry carried out by high-quality talents resources from Xi'an Jiaotong University and other universities, to keep the innovation capacity of Xi'an High-Tech being improved steadily. Tianjin Ziya, located in the southwest of Tianjin, the intersection of Beijing, Tianjin, and Hebei, is pretty far from Beijing and Tianjin's downtown area and couldn't be so attractive to talents, especially after 2010 when Beijing's Siphon Effect was further enhanced, the talents were unwilling to work in remote counties and districts in Tianjin. All these caused the lower order degree of innovation chain in Tianjin Ziya with no talents being readily available. However, since 2015, as the Beijing-Tianjin-Hebei integration strategy was implemented, Tianjin Municipal Government encouraged talents to work in counties and districts in Tianjin with preferential treatment to balance the economic development of all districts and counties. Finally, the innovation capacity of Tianjin Ziya was greatly enhanced with the support of high-level personnel.

Figure 6 manifests that the order degree of the service chain of Xi'an High-Tech has been rising steadily from 2006 to 2016 while that of Tianjin Ziya was higher than Xi'an High-Tech before 2011 and then decreased and has remained as high as Xi'an High-Tech since 2012. The reason may be that Tianjin Ziya expanded quickly after 2012, which was way too ahead of the development speed of related supporting services, resulting in

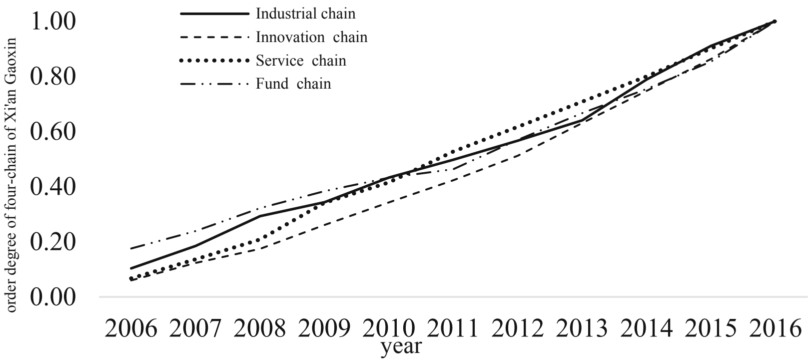

Fig. 2. Evolution diagram of four-chain order degree of Xi'an High-Tech

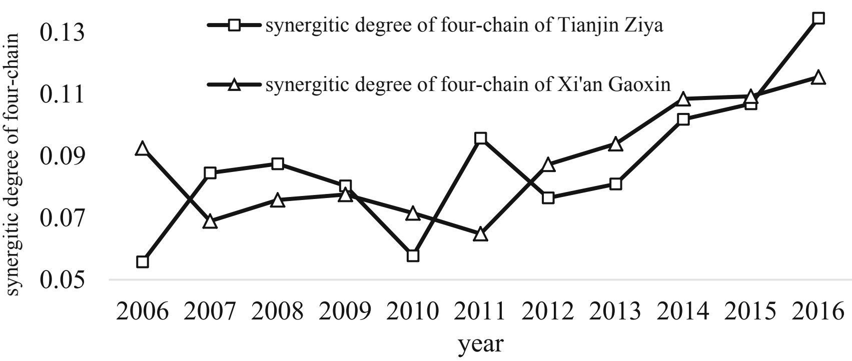

Fig. 3. Comparison of four-chain synergy degree between Tianjin Ziya and Xi'an High-Tech

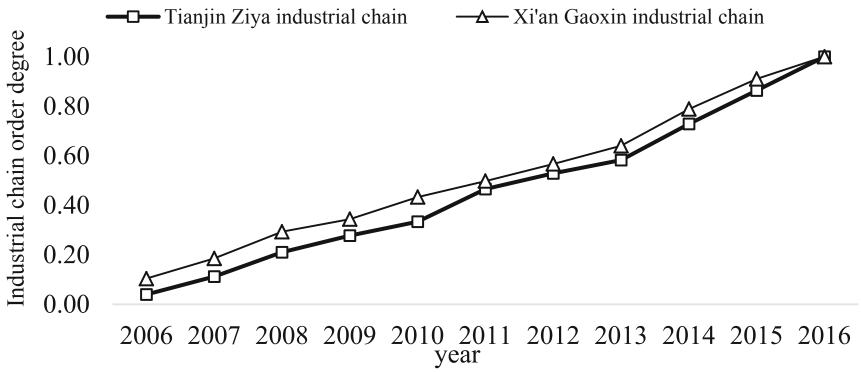

Fig. 4. Comparison of order degree of industrial chain between Tianjin Ziya and Xi'an High-Tech

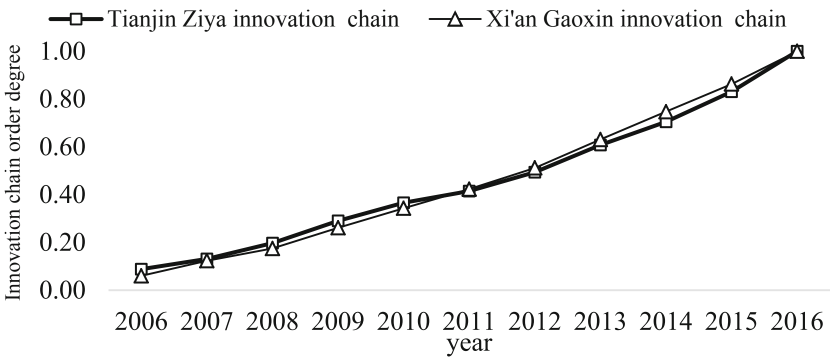

Fig. 5. Comparison of order degree of innovation chain of venous industry between Tianjin Ziya and Xi'an High-Tech

a relative decline in the order degree of the service chain. At the same time, in the process of expansion, the park pays too much attention to capital raising and the development of liquidity (see Fig. 7), while ignoring the improvement of service capacity.

In terms of order degree of capital chain, that of Xi'an High-Tech was better than that of Tianjin Ziya before 2010 and the situation reversed after 2010. Then the gaps of order degree between Tianjin Ziya and Xi'an High-Tech narrowed gradually after 2014 until the two basically kept equal in 2016. According to the websites of the two development zones and other materials, Tianjin Ziya expanded gradually after 2011. It introduced a large number of private capital into the park, paid enough attention to the difficulties in fundraising for enterprises in the park, tried to take measures to help enterprises in the park to raise low-cost funds, and strengthened the management of capital flow between enterprises in the park and industrial chains, which greatly improved capital raising capacity and liquidity of venous industry in Tianjin Ziya.

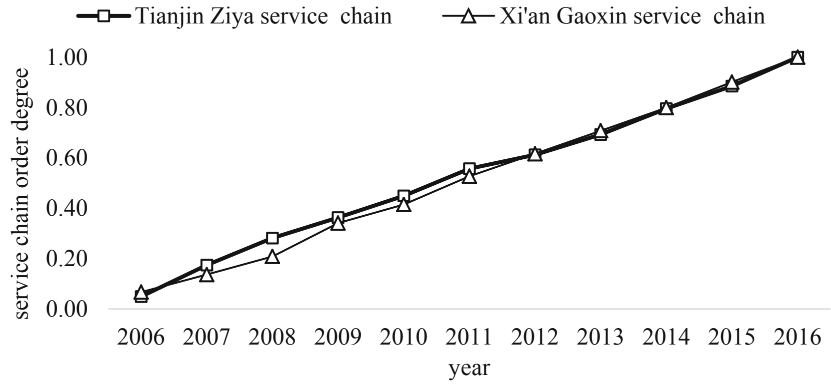

Fig. 6. Comparison of the order degree of service chain of venous industry between Tianjin Ziya and Xi'an High-Tech

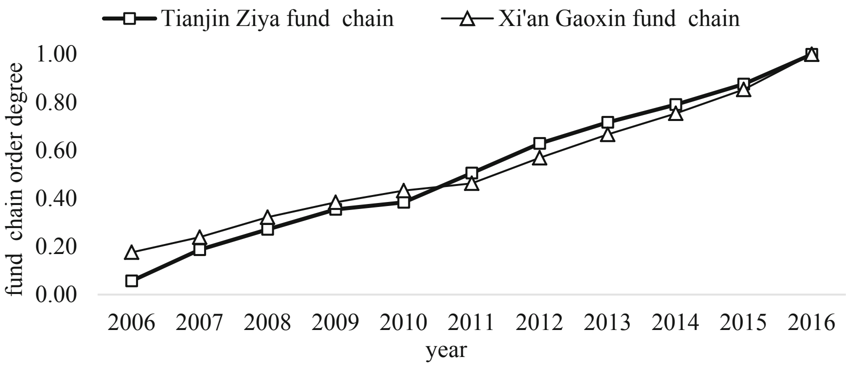

Fig. 7. Comparison of order degree of fund chain of venous industry between Tianjin Ziya and Xi'an High-Tech

6 Conclusion

The development of the venous industry needs the support of the industrial chain, innovation chain, service chain, and capital chain. And the synergy of the four chains guarantees the healthy development of the venous industry while the synergy degree is the measure of the synergistic effect of the four chains. The empirical results of the evaluation of the synergy degree of the four chains in Tianjin Ziya and Xi'an High-Tech indicate that from 2006 to 2016, the order degree of the industrial chain subsystem, innovation chain subsystem, service chain subsystem, and capital chain subsystem of the venous industry of the two zones has been rising and the synergy degree of the four-chain composite system is in the range of 0 to 0.2 and still on the steady rise. However, there are differences in the synergy degree of the four-chain composite systems of the two zones. To be specific, the synergy degree, before 2012, of Tianjin Ziya fluctuated in the range of 0.0557–0.1345 while that of Xi'an High-Tech fluctuated in the range of 0.0649–0.1155, of which the former had a higher frequency and amplitude than the latter. This phenomenon indicated that before 2012, the order degree of Tianjin Ziya was less balanced than that of Xi'an High-Tech yet with a greater change rate. And the synergy degree of the venous industry in the two development zones showed a steady upward trend since 2012. The reason for these differences was that the capacity and order degree of the certain chain will be greatly improved when it receives much attention from the government or the park management committee. And there is still room for further improvement of the synergy between the industrial chain, innovation chain, service chain, and capital chain of China's venous industry. The government should strengthen the coordination and management between the four chains and encourage venous enterprises to innovate. In the meanwhile, the government and relevant enterprises should better serve the venous enterprises, straighten out the financing channels of small and medium-sized venous enterprises, and create a good business environment for China's venous industry.

The policy implication of the above conclusions is that the development of the venous industry is the key to ensuring the synergy of the four chains. It is necessary to perfect the industrial chain through chain supplement, chain extension, and chain increase, achieve mutual support between different chains, and seek ways of reutilizing the waste and renewable products produced by enterprises within and outside the industry, which may achieve the mutual utilization of waste and renewable resources between different chains. And with the products supporting each other, the potential of the exchange of waste and renewable resources between industries can be tapped and the symbiotic relationship between industries can also be established. In the meanwhile, park managers and settled enterprises should attach importance to the improvement of innovation-driven capacity, improve service facilities and enhance service capacity, enhance fundraising and liquidity, and ensure the synergized development of the four chains of the venous industry.

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