Hindawi
Mathematical Problems in Engineering
Volume 2021, Article ID 3176504, 12 pages
https://doi.org/10.1155/2021/3176504

Research Article

Research on the Prewarning Model of Relationship Risk Levels in Industry Collaborative Innovation Alliances across Provinces in China

Liufang Yu and Caiyun Chen

School of Management, Wuhan Polytechnic University, Wuhan 430031, China

Correspondence should be addressed to Liufang Yu; 12474@whpu.edu.cn

Received 20 August 2021; Accepted 30 September 2021; Published 21 October 2021

Academic Editor: Shianghau Wu

The governments need beforehand to perceive the innovative relationship risk because they are one of the innovation subjects in those industry collaborative innovation alliances. However, it is difficult for innovation subjects to quantify the risks for industry collaborative innovation alliances due to the complexity, nonlinear, and dynamic condition. This paper firstly constructs an ordered logistic model, uses the following as independent variables: the collaborative degree, the ratio of science technology expenditure to GDP, the ratio of education expenditure to GDP, the ratio of finances to GDP, and uses the levels of risk as the dependent variable. Then, this paper uses the panel data of 30 provinces in China (Hainan is not included) from 2010 to 2018 to fit the model. Based on the fitting results, the research has gained the relationship risk prewarning model in industry collaborative innovation alliances by using the collaborative degree as an independent variable. The governments at all levels can use this relationship risk prewarning model to percept risk levels and reckon the corresponding probability which exists in industry collaborative innovation alliances. Furthermore, there are regional influences existing in the prewarning relationship risk levels in industry collaborative alliances. The east and middle areas have significant regional influence, but it does not exist among west areas and others. The governments at all levels may consider the regional differences.

1. Introduction

The risk evaluation at the microlevel needs the professional knowledge and practical experience accumulation of core experts in the industry, and the basic data acquired is a real subjective cognition of innovation subject at the microlevel on the level of relationship risk to adapt to the decision-making at the microlevel. However, the internal participants of the industrial collaborative innovation alliance have been stratified, and the mesosubjects hope to have a direct prewarning of the level of relationship risk within the industry. In particular, under the major background of "the development of an innovation-driven economy", innovation has been a crucial driving force of the development of the local economy. Governments at all levels positively participate in collaborative innovation alliances and turn to be the important subjects of the alliances to lead other subjects to take part in the collaborative innovation alliance and connect one collaborative innovation alliance after another within the region. As the important subject of the collaborative innovation alliance and the node subject in the collaborative innovation network, the government should focus on the relationships between subjects in the alliance to have a prewarning of relationship risk to lead the new direction of collaborative innovation in the region in the future. The industries within regions and the provinces and cities across the country could predict the self-related relationship risk level of collaborative innovation alliances [1]. Therefore, it is necessary to have a prewarning of risk level and the probability of occurrence of each risk level in their respective regions with mesodata to help the practice community clearly realize and judge the relationship risk of the complicated organization and collaborative innovation alliance and make a scientific judgment and decision.

By far, there is less knowledge on the relationship risk of collaborative innovation alliance, and there has been no existing method for reference for the understanding of the field and the effective prevention of risk. The common risk prewarning models are as follows: univariate model, ZETA model, logistic model, probit model, neural network model, and entropy model (including system entropy, relative entropy, management entropy, and even risk entropy). These models have their own strengths and weakness. The entropy model is widely used in the study of alliance risk prewarning, but it still needs to acquire data with a subjective judgment which reduces its scientificity of conclusions. The logistics model does not need to satisfy the statistical assumptions such as normal distribution and homogeneity of variance as a linear model. There should be approximate treatment in the process of calculation, but the risk level prewarning does not need to be too precise, so it has been applied to much more fields [2]. Based on the comparison of the risk prewarning models, the study tries to simulate the panel data in recent 5 years with logistic regression to explore the influencing factors of the relationship risk level of industrial collaborative innovation alliance to form a risk prewarning model of industrial collaborative innovation alliance based on mesodata, so as to assist governments at all level to have a prewarning of the risk level of collaborative innovation alliance and the probability of occurrence of each level in the region.

2. Construction of the Relationship Risk Prewarning Model for Industrial Collaborative Innovation Alliances

2.1. Building Up the Ordered Logistic Model. The binary logistic regression could be built as a risk prewarming model for risk prewarming because the dependent variable values are taken as 0 and 1 to show the two situations, having risk and having no risk, so that it could be applied to the field of risk management. The relationship risk of industrial collaborative innovation alliance is at five levels: 1 (very low), 2 (low), 3 (general), 4 (high), and 5 (very high). The binary logistic regression is not suitable for the risk prewarning of industrial collaborative innovation alliance because the dependent variable values are only taken as 0 and 1; however, in the ordered logistic model, there are multiple observed values of dependent variables with sorting results, so the ordered logistic regression model could be built as a model for relationship prewarning of the industrial collaborative innovation alliance. The general expression of ordered logistics is as follows:

$$y^* = X\beta + \varepsilon, \varepsilon \mid X \sim \text{Logit}(0, 1). \tag{1}$$

y^* is the latent variable of dependent variable Y, and X means the vector of an independent variable x_i. β is an estimated parameter vector and ε is the random error term. When $w_i, i = 1, 2, 3, 4, 5$, is set as critical value (threshold) and the value y depends on the comparison result between y^* and critical value, the expression of value y is

$$y = \begin{cases} 1. y^* \leq \omega_1 \\ 2. \omega_1 < y^* \leq \omega_2 \\ 3. \omega_2 < y^* \leq \omega_3 \\ 4. \omega_3 < y^* \leq \omega_4 \\ 5. \omega_4 < y^* \leq \omega_5 \end{cases}. \tag{2}$$

In expression (2), $y = 1$, 2, 3, 4, 5 means the very low relationship risk of collaborative innovation alliance (harmonious partnership among members), the low relationship risk of collaborative innovation alliance (having difficulty in the cooperation and communication among members but it is apt to be overcome), general relationship risk of collaborative innovation alliance (general cooperation and communication among members), high relationship risk of collaborative innovation alliance (needing a long-term communication and negotiation), and very high relationship risk of collaborative innovation alliance (bad partnership among members and being on the verge of disintegration). According to the conditional probability knowledge in Mathematics, the corresponding equations of y to X are as follows:

$$\begin{cases} P(y = 1 \mid X) = P(y^* \leq \omega_1 \mid X) = \varphi(\omega_1 - X\beta) \\ P(y = i \mid X) = P(\omega_{i-1} < y^* \leq \omega_i \mid X) = \varphi(\omega i - X\beta) - \varphi(\omega_{i-1} - X\beta) \quad i = 2, 3, 4. \\ P(y = 5 \mid X) = P(y^* > \omega_5 \mid X) = 1 - \varphi(\omega_5 - X\beta) \end{cases} \tag{3}$$

The distribution function is the logistic one.

2.2. The Independent Variables in the Ordered Logistic Model

2.2.1. Collaborative Degree. Collaborative innovation alliance is a strategic behavior to achieve certain objectives with a plan, so it is a "social collaboration." It needs the alliance subject to achieve the organization from being disorder to order, from lowly order degree to the high order degree through the application of their advantages. The process of alliance subject to use their advantages is a collaborative one, so the degree of collaborative highly affects the efficiency of collaborative and the entire relationship between the subjects. Generally speaking, the subjects would have a high cognition and higher trust with each other when the degree of collaborative is higher, so there would be less opportunistic behavior of the subjects. The higher collaborative degree means the stronger resource integration ability of the entire innovation alliance. There are much more resources to be combined and a higher collaborative effect, so the total benefits of collaborative innovation that can be shared by all innovation subjects should be large to relatively reduce the economic interest conflict between innovation subjects. In system theory, a collaborative degree means the degree of collaborative and consistency of subsystems or system elements in the development process of the system, which describes the collaborative degree among subsystems or system elements in the system. In the collaboration, the ordered parameter would be transformed from one phase-transformation state to another state by describing the subsystems or system elements in the evolution process of the system, and it could be used to represent the order structure and type of system. The collaborative degree of the ordered variable "set" could display the overall collaborative degree of the evolving new structure. Therefore, the collaborative degree could be used to evaluate the degree of collaborative from both perspectives of system theory or the synergetic. The evaluation of collaborative degree could be deemed as a measuring instrument for synergetic innovation of industry-university-research (IUR). The measurement of the collaborative ability in the synergetic innovation system of IUR in a certain period could reflect the degree of the collaborative of synergetic innovation of IUR [3]. The collaborative degree is used for measuring the degree of collaborative among the alliance subjects while the degree of collaborative would affect the relationship between subjects. Therefore, the collaborative degree could be deemed as one of the variables of risk level prewarming. In this research, the collaborative degree is an independent variable as shown in Table 1.

2.2.2. Other Independent Variables. In the collaborative innovation alliance, the government is a leading subject since it affects the entire innovation environment and provides new factors for innovation alliance through innovation policy. The government could effectively gather resources to coordinate all innovation subjects through leading to effectively control the relationship between the subjects of collaborative innovation alliance. Generally speaking, governments could achieve their role in innovation alliance through the buildup of innovation environment, such as financial capital investment, innovative talent policy, and financial policy for local innovation. When the innovation factors of a collaborative innovation alliance are sufficient and there are much more resources with high quality to be collaborated by innovation subject, the effect of mutual collaborative would be better and the innovation subjects would get along well with each other because the effect of mutual collaborative would be higher than that of independent innovation. Hence, the influencing factors of the relationship risk level of collaborative innovation alliance are as follows: science and technology expenditure ratio, education expenditure ratio, and financial loan balance ratio. The science and technology expenditure ratio is calculated by the ratio of science and technology expenditure to the GDP of each region in the current year, and the factor affects the supply of innovation capital. The education expenditure ratio is calculated by the ratio of the absolute number of local face-to-face education expenditures to the GDP of each region in that year, and the factor affects the supply of innovation talents. The financial loan balance ratio is calculated by the ratio of the balance of bank loans in various regions to the GDP of various regions in the current year, and the factor would affect the supply of innovation funds and social support for innovation activities. In this research, the ratio of science and technology to GDP, the ratio of education to GDP, and the ratio of finance to GDP are other independent variables as shown in Table 1.

Table 1: Variables in the relationship risk prewarning model.

Variables	Sign	Unit	Type
Collaborative degree	X1	Decimal	—
Ratio of science and technology to GDP	X2	Decimal	—
Ratio of education to GDP	X3	Decimal	—
Ratio of finance to GDP	X4	Decimal	—

2.2.3. Standardized for Independent Variables. As seen from the entire industrial collaborative innovation alliance, the interaction among colleges and universities, scientific research institutions, and agencies and the direct interaction between government and these subjects would be shown in the collaborative degree of independent variables, which would be seen from the index selection in subsequent collaborative measurement while the interaction between the innovation subject, government, and other subjects would be shown through other independent variables. There are different value dimensions of all influencing factors, so the variables above should be standardized. The standardization method in the research is adopted with the range method. The first part in equation (4) is the positive index and the second part of equation (4) is the negative one.

$$S_j\left(x_{ji}\right) = \begin{cases} \dfrac{x_{ji} - \beta_{ji}}{\alpha_{ji} - \beta_{ji}}, & i \in \left[1, l_1\right] \\ \\ \dfrac{\alpha_{ji} - x_{ji}}{\alpha_{ji} - \beta_{ji}}, & i \in \left[l_1, n\right] \end{cases}. \tag{4}$$

The source of data is the *Statistical Yearbook of Chinese Science and Technology, the Statistical Yearbook of Chinese High-Tech Industry, the Compilation of Scientific and Technological Statistical Data of Colleges and Universities*, *the Statistical Yearbook of Chinese Torch*, and the statistical yearbooks of relevant provinces from 2010 to 2018. However, in the process of model verification, the data of collaborative degree of some independent variables and the data of relationship risk level need to be acquired through a certain approach. Here is an introduction to the acquisition process of the fitting data of the two variables.

2.3. Acquisition of Collaborative Degree Data

2.3.1. Evaluation Method of the Collaborative Degree. As for the evaluation tools of the interaction degree for the subjects of collaborative innovation, many scholars have mentioned the collaborative degree many times. The collaborative degree is one of the effective tools to measure the cross-organizational collaborative innovation effect and it could be used to represent the degree of collaborative and consistency of various innovation elements in the compound system [3]. In the study of the collaborative innovation mechanism, the collaborative degree of collaborative innovation system means the degree of consistency of interaction between collaborative subjects in the process of cooperation and the degree of a behavioral collaborative of subjects in the system; the evaluation of collaborative degree could be deemed as a measuring instrument for synergetic innovation [4–6]. With reference to the outcomes of subsequent research on the expansion of the compound system in different studies, this paper builds up a collaborative degree model suitable for the compound system of the collaborative innovation alliance. It is supposed that the compound system of the collaborative innovation alliance is S, and the subsystem of the collaborative innovation alliance is S_j $(j = 1, 2, 3, 4)$. S_1 is a subsystem of technology intermediary service; S_2 is a subsystem of colleges and universities; S_3 is a subsystem of the scientific research institution; S_4 is a subsystem of industry. The ordered variable is needed in the entire collaborative process of innovation alliance to describe that x_{ji} basis could be divided into two types for the impact of dependent variables: the positive influencing factor and the negative one. When x_{ji} is the positive influencing factor, the larger its value is taken, the higher the order degree of the system would be. When x_{ji} is the negative influencing factor, the larger its value is taken, the lower the order degree of the system would be. The subvariable of the ordered variable is $S_j(x_{ji}) = \begin{cases} (x_{ji} - \beta_{ji})/(\alpha_{ji} - \beta_{ji}), & i \in [1, l_1] \\ (\alpha_{ji} - x_{ji})/(\alpha_{ji} - \beta_{ji}), & i \in [l_1, n] \end{cases}$. The influencing factors built in the compound system of collaborative innovation alliance are positive and negative. With the consideration that the subvariable of the ordered variable would be positive after the processing to not affect the following processing, it should be $S_j(x_{ji}) = (x_{ji} - \beta_{ji})/(\alpha_{ji} - \beta_{ji}) \times 0.9 + 0.1$, $S_j(x_{ji}) \in [0.1, 1]$. The measurement of the order degree of the ordered parameter of a general subsystem could be used with the geometric average method and the linear weighted average method. The subjectivity could not be overcome when the weight is confirmed with a linear weighted average method, so the geometric average method is used to measure the order degree of subsystem integration fitting subsystem: $s_j(x_j) = \sqrt[4]{\prod_{i=1}^{4} s_j(x_{ji})}$. According to the evolution of the compound system from disorder to order, it is set with an initial moment as t_0. If the time setting t_0 of data acquisition was set to be 2009, the order degree of t_0 in all subsystems would be $d_j^0(x_j)$, $j = 1, 2, 3, 4$, the next time of evolution process of the compound system is t_1, and the order degree of time t_1 is $d_j^1(x_j)$, $j = 1, 2, 3, 4$, so t_1 is set to be 2010. Similarly, in the next round calculation, t_1 would be 2011 when t_0 is taken as 2010, so as to conclude the order degree of the compound system from 2010 to 2018. The collaborative degree of collaborative innovation alliance is $S(X) = \theta \sqrt[4]{|\prod_{j=1}^{4} [d_j^1(x_j) - d_j^0(x_j)|}$. The parameter θ is to tune the negative and the positive.

$\theta = \min[d_j^1(x_j) - d_j^0(x_j) \neq 0 / |\min[d_j^1(x_j) - d_j^0(x_j) \neq 0_j|$, $j = 1, 2, 3, 4$. If the value of $S(X)$ was bigger, it would mean the optimal collaborative degree of the compound system of collaborative innovation alliance. As the order degree of each subsystem fluctuates differently and exchanges information, materials, and energy with each other, the overall collaborative degree can be positive or negative.

2.3.2. Selection of the Subsystems. One collaborative innovation alliance is a complicated system with diversified subjects and protruding heterogeneity, but the majority of the industry agree that the collaborative innovation alliance is a network innovation organization with collaborative and interaction between diversified subjects, including the core subjects of colleges and universities, incorporations, and research institutions and the auxiliary subjects of governments, financial organizations, intermediary organizations, and innovation platforms. However, the study thinks that collaborative innovation should be a self-organizing system that all innovation subjects keep cooperating with each other and all innovation factors are recycling ceaselessly, and it would attract the exit or entry of all innovation subjects for the open characteristics of the system. The subject of collaborative innovation alliance would not be constant forever, so it would be impossible to focus on the entire microsubject when describing the collaborative process of the entire system. In the practice, it should be described with the subsystem according to the major classification. For example, some researchers divide the IUR technology allocation into three subsystems: subsystem of industry, a subsystem of colleges and universities, and subsystem of research and development [7, 8]. However, along with the profound carryout of collaborative innovation, all innovation subjects have refined and professional distribution in collaborative innovation alliances, so the collaborative innovation system is attracting the participation of various innovation subjects with open characteristics. The subsystem of technology service shows its talent as a crucial bridge to connect all innovation subjects and makes innovation alliance focus on it gradually. Scholars start to have a study on the subsystem of technology serving as a newly born subsystem, and they find that the subsystem has a finer lower-level subsystem composition, such as subsystem of talents and a subsystem of venues [9, 10].

Based on it, the study chooses the following subsystems as the ones for the compound system of collaborative innovation alliance: a subsystem of industry, a subsystem of technology intermediary service, a subsystem of colleges and universities, and a subsystem of the scientific research institution. The study does not deem government as a subsystem since it is the dominant leader of collaborative innovation. In China, the government would interfere agency, such as financial institutions, by affecting the subjects of collaborative innovation alliance with the factor of innovation capital; it would also affect the subsystem of the industry with tax policy and intervene the factor of innovation talents resources with education policy. The subsystem of government is based on a mixed system, so it would be hard to clarify the boundary with others or analyze the interaction among subsystems if it was deemed as a subsystem. However, the subsystem of government does impose impact on the relationship risk level of collaborative innovation alliance, so the indirect interaction between government and other innovation subjects would be considered in other independent variables when building up the model for relationship risk prewarning of collaborative innovation alliance while the direct relationship between government and others subsystems would be considered in the index to measure the collaborative degree of subsystems [11, 12]. For the selection of indexes of all subsystems on the measurement of collaborative degree, it is shown as follows:

(a) The subsystem of technology service: collaborative innovation alliance has been developed to be a complicated subsystem with the core of knowledge increment and value creation. In the subsystem, it is included with technology trading market, productivity promotion center, and business incubator in the core layer; the technical consultation, scientific and technological novelty search, scientific and technological development, Information Research Institute, and property right exchange in the middle layer; and the technology novelty search, talent market, leasing company, and audit and accounting service organization in the peripheral layer. It has been a necessary bridge for knowledge increment and value creation.

(b) The subsystem of colleges and universities: as an important source to create and spread new knowledge and new technology, colleges, universities, and scientific research institutions could greatly push incorporations to carry out innovation activity. In general, applied colleges and universities could send all kinds of innovation talents for all innovation subjects in the industrial innovation alliance; on the other hand, they could have the cooperation of technical application with the subjects in the alliance with the button of human resources. Knowledge-based colleges and universities with higher innovation levels would work with scientific research institutions to have a breakthrough knowledge innovation for serving the national strategy and social development. All innovation subjects in the industrial alliance would coordinate with colleges and universities to gain the resources they lack to solve their insufficient innovation capability. It is the innovation factor of a collaborative innovation alliance: the supplier of talents, technology, and knowledge.

(c) The subsystem of scientific research institutions: also as an important source to create and spread new knowledge and new technology, scientific research institutions could also great push incorporations to carry out innovation activities. However, the role of scientific research institutions in the collaborative innovation alliance is different from that of the subsystem of colleges and universities. The role of colleges and universities is to provide vast innovation personnel for the subsystem of industry. The innovative knowledge and innovative technology that these personnel are equipped with would provide important innovation factors for the subsystem of industrial innovation; meanwhile, it would achieve the exchange of the materials, ability, and information among the subsystems to provide a crucial motivation for the evolution of the entire compound system. However, besides the scientific research and the creation of innovative knowledge, scientific research institutions would also participate in the formulation of relevant innovation policies or laws, provision of strategic planning, and so on with an identity of expert [6]. It would impose an impact on the evolution of the compound subsystem of the collaborative innovation alliance by affecting the peripheral environment of the alliance. It is the innovation factor of collaborative innovation alliance: the supplier of knowledge.

(d) The subsystem of the industry: economic profit-driving is an important motivator for a collaborative innovation alliance. The alliance is dominated by industry and oriented by market demand, but there are still so many restricting factors between the ability of industry and the demand of the market, so subsystem of the industry could not satisfy the market demand as an independent system and it needs the collaborative with other subsystems to acquire the resources and ability to satisfy the market demand to achieve the economic profit and undertake social responsibility [13, 14].

2.3.3. Selection of Index of Four Subsystems. The index system built in the previous evaluation process is based on the input-output index. Du Biyun et al. measured the collaborative degree of measures the collaborative degree of the IUR technology alliance innovation system in the six provinces of the middle region with a compound system of collaborative degree model, and the ordered parameter selected by them is still the index of the input-output index when confirming the ordered parameter of a subsystem of scientific technology alliance [8]. The compound system of collaborative innovation alliance is social collaborative, while social collaborative has a purpose. The behavior of the collaborative subject is directly controlled by the objectives of the subject, so the evaluation on the collaborative degree should try to begin from the subject behavior. Therefore, it is necessary to choose an ordered parameter of the subsystem in the index of collaborative behavior among the subjects. Some researches begin from a complex system theory and dissipative structure theory to suggest a measurement method of regional collaborative innovation based on collaborative degree-management entropy when studying the measurement of collaborative innovation ability in the region [9]. There are two index systems selected by them: order degree of innovation subject and knowledge transfer degree. The index of order degree of innovation subject is selected with a large number of indicators of interaction between innovation subjects. Through the empirical comparison of collaborative degree and management entropy, it is found that the result of the two models is basically consistent so as to prove the scientificity and effectiveness of measurement. It also provides an effective reference for the index selection to the quantitative measurement of collaborative innovation alliance. Based on these, the study selects the following indexes for all subsystems of collaborative innovation alliance when confirming the empirical data of collaborative degree. Above all, the whole index of collaborative innovation alliances is shown in Table 2, where (a) stands for the subsystem of technology service; (b) stands for the subsystem of colleges and universities; (c) stands for the subsystem of scientific research institutions; and (d) stands for the subsystem of industry.

The source of data is the *Statistical Yearbook of Chinese Science and Technology, the Statistical Yearbook of Chinese High-Tech Industry,* the *Compilation of Scientific and Technological Statistical Data of Colleges and Universities*, the *Statistical Yearbook of Chinese Torch*, and the statistical yearbooks of relevant provinces from 2010 to 2018. Given the inconsistent dimensions of the original data, there would be errors when directly participating in the calculation and processing, so the paper uses the level difference method to standardize the original data.

2.3.4. Measurement of the Collaborative Degree. There are four subsystems in the compound system of collaborative innovation alliance: the subsystem of technology service, the subsystem of colleges and universities, the subsystem of scientific research institutions, and the subsystem of industry. By describing the mutual roles of the four subsystems, the order degree of the four subsystems in 30 provinces (cities) around the country and then the collaborative degree of the compound system are "integrated" through the order degree of the four subsystems, as shown in Table 3, so as to get the data of independent variable collaborative degree for the model of relationship risk prewarning of the collaborative innovation alliances.

3. Acquisition of Relationship Risk Level

3.1. Selecting Original Data Indexes to Confirm Relationship Risk Level. The theoretical study of collaborative innovation alliance could be traced to the IUR cooperation. It is suggested by Etzkowit and Leydesdroff. They emphasize that knowledge could be an increasing factor of the economy, and they focus on the cognition of innovation subjects. Colleges and universities, industries, and governments are mutually independent and interactive to form a dynamic triple helix to push the sustainable growth of the economy. Later, Leydesdroff thought that the uncertainty, complication, and completion of the system could be presented by the mutual information among three subsystems based on the cognition of information entropy, so as to suggest the index to measure the relationship of the triple helix [10]. The "triple helix" means innovation subjects. Then, everybody studies the cooperation and interaction relationship between subjects with the mutual information of "triple helix". To explore the relationship between the IUR collaborative and innovation subject, domestic scholars start to integrate the "triple helix" and data mining technology to measure the relationship between innovation subjects. Cai Xiang and Liu Xiaozheng studied the cooperation relationship of government-university-research with the SCI scientific papers, national science and technology standards, and national scientific research fund as the data of the output structure of "triple helix" [15, 16]. Zhuang Tao made the patent data as the original data of "triple helix" output to study the international cooperation of IUR, and he extended the subject of "triple helix" to be four subjects of international cooperation to measure the partnership among subjects to study the interaction between the government-university-research and the international cooperation organization [16]. Hence, based on the previous literature, the paper refers to the study and extension outcomes of above on "triple helix" with the consideration on the availability of data to choose invention patent as basic data. The paper carries out the study among the collaborative innovation subjects through the algorithm of "triple helix" and information theory knowledge to acquire the original data of relationship risk level during the empirical process. There are three types of patents: invention patent, utility model patent, and appearance design. The reason why to choose invention patent as the original data of algorithm of "triple helix" is that invention patents mean the originality with the highest technical content, so it is more suitable for the study on innovation than that of design patent and utility model patent. Hence, in the collection of basic data, the study only adopts the data of invention patents. The invention patent could be divided into job invention patent and nonjob invention patent. The owners of job invention patents are incorporations, scientific research institutions, colleges and universities, and governments. These subjects are closer to that of the collaborative innovation alliance in the study. In the past few years, in the effective invention patents in China, the proportion of nonjob invention patents is decreasing while that of the job one has been increasing. It has increased from 70.1% in 2006 to be 90.0% in 2014, which is increased by nearly 20% in eight years while the foreign countries always keep the high position of 98% for the past five years with an increasing tendency. It ensures sufficient data. With the consideration of the factors mentioned above, the paper chooses the number of service invention patent applications granted as basic data for the calculation of "triple helix".

3.2. Acquiring the Original Data to Confirm Relationship Risk Level. It confirms to calculate the interaction of innovation alliance with job invention to finalize the basic data of relationship risk level in empirical analysis. The data of job invention is acquired by the website of China National

Table 2: List of the index of four subsystems of the compound system of collaborative innovation alliances.

Subsystem	Index	Symbol	Unit	Type
(a) Subsystem of technology service	Total number of incorporations served	X11	Tens of thousands of incorporations	+
	Total income of service	X12	Million yuan	+
	Increased sales for the incorporation	X13	Million yuan	+
	Input of government	X14	Million yuan	+
(b) Subsystem of colleges and universities	Full-time equivalent of *R* and *D* personnel in colleges and universities	X21	Tens of thousands of persons per year	+
	Internal expenditure of *R* and *D* funds in colleges and universities	X22	Million yuan	+
	Government funds for the internal expenditure of *R* and *D* funds of colleges and universities	X23	Million yuan	+
	Corporate funds internal expenditure of *R* and *D* funds of colleges and universities	X24	Million yuan	+
	External expenditure of *R* and *D* funds of colleges and universities	X25	Million yuan	+
	Expenditure of domestic colleges and universities for the external expenditure of *R* and *D* funds of colleges and universities	X26	Million yuan	+
	Expenditure of domestic incorporations for the external expenditure of *R* and *D* funds of colleges and universities	X27	Million yuan	+
	Expenditure of domestic scientific research institutions for the external expenditure of *R* and *D* funds of colleges and universities	X28	Million yuan	+
	Number of applications for *R* and *D* projects in colleges and universities	X29	Item	+
(c) Subsystem of scientific research institutions	Full-time equivalent of *R* and *D* personnel in scientific research institutions	X31	Tens of thousands of persons per year	+
	Internal expenditure of *R* and *D* funds in scientific research institutions	X32	Million yuan	+
	Government funds for the internal expenditure of *R* and *D* funds of scientific research institutions	X33	Million yuan	+
	Corporate funds internal expenditure of *R* and *D* funds of scientific research institutions	X34	Million yuan	+
	External expenditure of *R* and *D* funds of scientific research institutions	X35	Million yuan	+
	Expenditure of domestic colleges and universities for the external expenditure of *R* and *D* funds of scientific research institutions	X36	Million yuan	+
	Expenditure of domestic incorporations for the external expenditure of *R* and *D* funds of scientific research institutions	X37	Million yuan	+
	Expenditure of domestic scientific research institutions for external expenditure of *R* and *D* funds of scientific research institutions	X38	Million yuan	+
	Number of applications for *R* and *D* projects in scientific research institutions	X39	Item	+
(d) Subsystem of industry	Full-time equivalent of *R* and *D* personnel in large and medium-sized industrial incorporations	X41	Tens of thousands of persons per year	+
	Internal expenditure of *R* and *D* funds in large and medium-sized industrial incorporations	X42	Million yuan	+
	Government funds for the internal expenditure of *R* and *D* funds of large and medium-sized industrial incorporations	X43	Million yuan	+
	Corporate funds internal expenditure of *R* and *D* funds of large and medium-sized industrial incorporations	X44	Million yuan	+
	External expenditure of *R* and *D* funds of large and medium-sized industrial incorporations	X45	Million yuan	+
	Expenditure of research institutions for the external expenditure of *R* and *D* funds of large and medium-sized industrial incorporations	X46	Million yuan	+
	Expenditure of domestic colleges and universities for the external expenditure of *R* and *D* funds of large and medium-sized industrial incorporations	X47	Million yuan	+
	Number of projects for *R* and *D* projects in large and medium-sized industrial incorporations	X48	Item	+
	Expenditure for new product development	X49	Million yuan	+
	Proportion of incorporations with *R* and *D* activities	X50	%	+

Table 3: Relational risk level in industry collaborative innovation alliances from 2010 to 2018.

Area/year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Beijing	1	2	2	2	2	1	1	1	1
Tianjin	4	3	4	3	4	2	2	2	2
Hebei	4	3	4	3	4	2	2	2	2
Shanxi	4	3	4	3	4	1	3	3	3
Inner Mongolia	2	5	5	5	5	1	1	1	1
Liaoning	1	2	2	2	2	1	1	3	3
Jilin	1	2	2	2	1	3	4	3	3
Heilongjiang	1	2	2	2	1	4	3	3	3
Shanghai	3	4	3	4	5	1	2	2	2
Jiangsu	5	1	1	1	3	2	2	2	2
Zhejiang	3	4	3	4	4	5	5	4	4
Anhui	3	1	1	1	3	2	2	2	4
Fujian	5	1	1	1	3	2	5	4	4
Jiangxi	4	3	5	5	5	4	3	2	2
Shandong	3	4	3	4	5	2	2	2	1
Henan	3	4	3	4	5	2	1	1	1
Hubei	4	3	4	5	4	1	1	1	1
Hunan	3	3	4	5	4	1	1	1	1
Guangdong	5	1	1	1	3	5	5	5	4
Guangxi	3	3	3	5	5	4	4	3	5
Chongqing	3	4	3	4	5	2	2	2	1
Sichuan	3	4	3	4	4	2	2	1	1
Guizhou	4	3	4	3	4	1	1	1	3
Yunnan	1	2	2	2	2	1	1	1	3
Tibet	2	4	3	4	5	5	1	2	1
Shanxi	1	2	2	2	1	4	3	3	3
Gansu	1	2	2	2	2	3	4	3	5
Qinghai	2	4	5	4	5	2	2	2	1
Ningxia	5	1	1	1	3	2	5	4	2
Xinjiang	4	3	4	3	4	1	3	3	3

Intellectual Property Administration and the websites of Intellectual Property Administration of all provinces. Through the tools of patent searching and analysis in the websites, I set the searching keyword as follows: "patent applicant + application date + code of province" according to the existing searching method. The patent applicants are represented with "Government (G)," "Incorporation (I)," "University (U)," and "Research Institution (R)" (repeated measurement is allowed). According to the appellation of state-owned incorporations and institutions, it would be categorized into the range of "government" if the "ministry," "bureau," "department," or the name of the organization directly under the government were included in the name of the applicant; it would be classified into the range of "incorporation" if the "company," "plant," "incorporation," and "group" were contained in the name; the name of institutions included with "university" and "college" would be classified into the range of "university" and those with the "academy," "lab," and "institute" would be classified into the range of "research institution." The discrimination of "university" and "research institution" is for the methods of the existing IUR studies because there is an obvious distinction in the functions of middle schools and universities and research institutions in the collaborative innovation alliance. The applied university is mainly for the innovation of talent cultivation while the knowledge-based university is to engage in basic innovation activity for the breakthrough innovation to serve for a national strategy. The applied scientific institution is mainly engaged in technical application, but it would be combined with the demand of governments in all places to be the "think tank" of government to advise the government on policies as an expert while the research institution engaging in basic major innovation activity mainly serves for the national strategy. Hence, there would be a distinction between "university" and "research institution" in the text. Besides, there would be respective reports on technical innovation in the statistical yearbook and annual report. As for the cooperation of innovation subjects, if there were two or three names, the name of the patent would be classified to be eight categories as follows: "University–Incorporation (UI)," "University–Government (UG)," "Incorporation–Government (IG)," and "Research Institution–Incorporation (RI)," "Research Institution–University (RU)," "Research Institution–Government (RG)," "University–Incorporation–Government (UIG)," "University–Research Institution–Incorporation–Government (URIG)." Meanwhile, if it was searched by year according to the application date, the province will be given by number. For example, the number of Guangdong is 44, and the frequency of occurrence is counted in each category so that the data after the statistics would be composed of the original database of cooperative patent application research [17]. The original data acquired by the forms is applied for the triple helix model to gain the marginal probability of each innovation subject. Then, the data of the correspondent triple helix system could be gained by calculating mutual information. The calculation of mutual information of diversified subjects is in need of knowledge of information theory. The collaborative innovation alliance is involved with diversified subjects, and there is a cross-relationship between multiple subjects. The innovation subjects have a collaborative innovation and apply for invention patent for the innovation outcome together so that the mutual information could reflect the cooperation among innovation subjects specifically. According to the information theory, Leydesdorff thinks the data provided by the network would produce a relevant frequency distribution. The relevant frequency distribution could generate one probability distribution: $P_i = f_i/\sum_i f_i$. The average information volume of the probability distribution is defined by scholars to be an information entropy: $E_i = -\sum_i P_i \log_2 (p_i)$.

Under the one-dimensional situation, the information entropy means the product of distribution probability and its negative logarithm. Under the multidimensional situation, we have a measurement by adding substitution. In the study, there are 4 subsystems of the collaborative innovation system and 4 job invention subjects, so the calculation of the information entropy of invention application of subjects in collaborative innovation alliance is adopted with four dimensions. According to the information theory, the calculation formula of E under multi-dimensions is as follows:

$$E(X_1, X_2, \ldots, X_n) = \sum_{\substack{x_1 \in X_1 \\ x_2 \in X_2 \\ \cdots \\ x_n \in X_n}} p(x_1, x_2, \ldots, x_n) \log_2 \frac{p(x_1, x_2 \cdots x_n)}{\prod_{i=1}^{n} p(x_i)}. \tag{5}$$

Referring to the calculation formula in the mutual information of information theory, the calculation formula of the mutual information of innovation subject in the collaborative innovation alliance is as follows:

$$\begin{aligned} T_{urig} = {} & E_u + E_r + E_i + E_g - E_{ur} - E_{ui} - E_{ug} - E_{ri} - E_{rg} \\ & - E_{ig} + E_{urg} + E_{uig} + E_{rig} + E_{uri} - E_{ruig}. \end{aligned} \tag{6}$$

Among these, the evidence of the two-dimensional mutual information is

$$T_{ij} = E_i + E_j - E_{ij}, \quad i, j \in \{u, r, i, g\}. \tag{7}$$

The evidence of the three-dimensional mutual information is

$$\begin{aligned} T_{ijk} = E_i + E_j + E_k - E_{ij} - E_{ik} - E_{jk} + E_{ijk}, \\ i, j, k \in \{u, r, i, g\}. \end{aligned} \tag{8}$$

Besides, in the calculation of information entropy, the value is directly taken as zero when $p = 0$is encountered, so the value is directly taken as zero when there is 0 in the study. The entire value calculation process is carried out according to different provinces so as to gain the measurement sheets of cooperation relationship of triple helix subject listed according to province (city) (there are a total of 30 provinces and cities, excluding Hainan Province).

According to the cluster analysis method, the K-mean cluster analysis in the SPSS software is used to classify the relationship of collaborative subjects into five levels, and the five levels correspond to the five levels of relationship risk of collaborative innovation alliance. The correspondent value would be taken as 1, 2, 3, 4, and 5. The K-mean cluster analysis of SPSS19.0 is applied to gain the panel data of the relationship risk level shown in Table 3.

4. Verification of the Model for Relationship Risk Prewarning

With the use of the STATA metrological analysis software, the variable Y means the relationship risk level of collaborative innovation alliance, and the variables X1, X2, X3, and X4 are the collaborative degree, science and technology expenditure ratio, education expenditure ratio, and financial loan balance ratio. The control variables are region and degree. Furthermore, the models in Table 4 are added control variables to the mode through “region”, “year”, X2, X3, and X4 step by step. The results are shown in Table 4.

Seen from the p value of independent variables, only the collaborative degree of the independent variable passes the significance test. The collaborative degree could pass the significance test among multiple influencing factors directly related to the relationship risk level of collaborative innovation alliance, so it means that the relationship risk level of collaborative innovation alliance could be predicted with the collaborative degree from the perspective of management and statistical metrology. But other variables which are science and technology expenditure ratio, education expenditure ratio, and financial loan balance ratio are not reasonable to prewarning relationship risk levels in those collaborative innovation alliances. Even the variables “region” and “year” are as a controlled variable put in model (5), model (6), and model (7), and the degree of X1 significance reduces on the contrary. Whether the variables “region” and “year” are controlled or not, the p values of X2, X3, and X4 are still not significant.

And then, seen from the model calculation and tests, the X1, independent variable of collaborative degree, is more reasonable when building up the model for the relationship risk level of collaborative innovation alliance, so STATA is used to fit the equation containing only the degree of the collaborative as an independent variable. The fitting result shows that the whole p value is 0.0001 and the p value of the independent variable, collaborative degree, is 0.068, so both of them pass the significance test. From model (2) in Table 4, the test adds a control variable: region; the results are still significant. It shows that the relationship risk prewarning contains region influence. According to the *Statistical Yearbook of Chinese Science and Technology*, the east area is Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the middle area is Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan; the west area is Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shanxi, Gansu, Qinghai, Ningxia,

TABLE 4: Regression results.

Variables	(1) y	(2) y	(3) y	(4) y	(5) y	(6) y	(7) y
$x1$	0.9122**	0.7733*	−1.6618**	−1.9144*	−1.8741*	−1.8642*	−1.8838*
	(2.40)	(1.67)	(−2.08)	(−1.92)	(−1.87)	(−1.86)	(−1.87)
$x2$					−0.2615	0.5764	0.5028
					(−0.78)	(0.54)	(0.43)
$x3$						−0.4799	−0.4583
						(−0.83)	(−0.77)
$x4$							0.1894
							(0.16)
Region	No	Yes	No	Yes	Yes	Yes	Yes
Year	No	No	Yes	Yes	Yes	Yes	Yes
Pseudo R2	0.0068	0.1230	0.0383	0.1528	0.1535	0.1543	0.1544
Observations	270	270	270	270	270	270	270

z-statistics in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

TABLE 5: Region influence.

Variables	(1) y	(2) y	(3) y	(4) y	(5) y	(6) y	(7) y
$x1$	−2.2626	−4.1602**	−2.8947**	3.9414	−4.1187	−3.7985**	−2.8947**
	(−0.83)	(−2.42)	(−2.15)	(0.65)	(−1.54)	(−2.34)	(−2.15)
Region	West	East	Middle	Northeast	West	East	Middle
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R2	0.0547	0.0661	0.2271	0.3745	0.0350	0.0536	0.2271
Observations	117	76	54	23	131	85	54

z-statistics in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

and Xinjiang; the east-north area is Liaoning, Jilin, and Heilongjiang. According to Economic Research Journal, the east area is Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, and Liaoning; the middle area is Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan; the west area is Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shanxi, Gansu, Qinghai, Ningxia and Xinjiang, Jilin, and Heilongjiang [18, 19]. Comparatively, It shows that the region influence takes place in the east area and middle area, but it does not take place in the west area and northeast area in model (1), model (2), and model (3) from Table 5 according to the classification of the *Statistical Yearbook of Chinese Science and Technology*. It shows that the region's influence takes place in the east area and middle area, but it does not take place in the west area in model (5), model (6), and model (7) from Table 5 according to the classification of *Economic Research Journal*. That means the coordinative degree is more relative to the innovation risk level in the east and middle areas. This research is more suitable for east and middle governments to prewarning innovation levels.

If the time variable is controlled, the correspondent cumulative ratio of ordered results in the east area is as follows:

$$\begin{cases} y^* = -4.1602x \\ Y = \begin{cases} 1, y^* \leq -5.8412 \\ 2, -5.8412 < y^* \leq -4.3095 \\ 3, -4.3095 < y^* \leq -3.6397. \\ 4, -3.6397 < y^* \leq -2.4402 \\ 5, y^* > -2.4402 \end{cases} \end{cases} \quad (9)$$

Meanwhile, the odds ratio value in the ordered logistic model means that every increase in the collaborative degree by one unit will lead to an increase of corresponding times of the probability that the relationship risk level will decrease by one level. So, it could be seen from the odds ratio value of the model for relationship risk prewarning that the probability of reducing the risk level by one or more levels will increase by times when the collaborative degree changes by one unit. The probability of the occurrence of each risk level would be predicted from the cumulative ratio of ordered results. The odds ratio is 0.0156 if the time variable is controlled in the east area. So, the probability of reducing the risk level by one or more levels will increase by 0.9844 times. It should be noted that the significant meaning of coefficient in the ordered logistic model is bigger than the meaning of coefficient itself. The significance of the coefficient is relevant to the value of the independent variable and the value of β. Hence, the governments at all levels could predict the relationship risk level of industry collaborative innovation alliance in the region.

5. Conclusions

The paper studies the governments at all levels and how to prewarn the innovation risk levels as they are one of the innovation subjects in industry collaborative innovation alliances. This paper makes some contributions about this point which are as follows: (i) the science and technology expenditure ratio, the education expenditure ratio, and the financial loan balance ratio are not reasonable to prewarning relationship risk grades in those collaborative innovation alliances; (ii) the relationship risk prewarning contains region influence. Furthermore, region influence is different among different areas. It is fit for using the collaborative degree to prewarding the risk degree in the east area and middle area, but it is not fit for the west area or northeast area. Using the collaborative degree to predict the risk levels can be suitable for governments which are indicative innovation subjects in industry innovation alliances, but they need to consider the differences among provinces; (iii) the odds ratio value in ordered logistic regression means that every increase in the collaborative degree by one unit will lead to an increase of corresponding times of the probability that the relationship risk level will decrease by one level. The probability of the occurrence of each risk level would be predicted from the cumulative ratio of ordered results.

Certainly, if any industry in the cross-region could refine all subsystems within the industry, it could also refer to the model of the prewarning to predict the level of relationship risk of internal collaborative innovation in the industry. In the future, along with the dynamic change of collaborative innovation alliances, the number of innovative subjects would be increased or decreased. These changes add the complication and risk of a collaborative innovation alliance. However, only the new subsystem is confirmed through the complicated system of collaborative innovation alliance to predict the relationship risk level of prewarning and the probability of occurrence of each level through the collaborative degree.

Data Availability

The data used to support the findings of this research are included within the article. The source of data is from the Statistical Yearbook of Chinese Science and Technology (2010–2018), the Statistical Yearbook of Chinese High-Tech Industry (2010–2018), the Statistical Yearbook of Chinese Torch from 2010 to 2018, and the Chinese National Intellectual Property Reports from 2010 to 2018. The data of job invention are acquired by the website of China National Intellectual Property Administration and the websites of Intellectual Property Administration of all provinces.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by the Hubei Province Education Science and Technology Foundation (Grant no. D20201605) and Wuhan Polytechnic University Outstanding Young Teachers Scientific Research Project (Grant no. 2020J07).

References

[1] H. Yan, S. P. Qin, and J. Shi, “Dynamic evaluation regional industry-university-research collaboration,” *Systems Engineering*, vol. 38, no. 5, pp. 66–74, 2020.

[2] H. Y. He, Z. W. Wang, and J. J. Cai, “A research on influencing factors of collaborative innovation of enterprises, universities and research institutes in China—an empirical analysis base on ordered logistic model,” *East China Economic Management*, vol. 28, no. 9, pp. 106–110, 2014.

[3] X. Wu, Q. F. Wei, and X. Gu, “Research on the collaborative degree measurement in collaborative innovation,” *Soft Science*, vol. 29, no. 7, pp. 45–50, 2015.

[4] S. Wei and S. Zhao, “The research of regional collaborative innovation mode in China: based on principal component analysis,” *Canadian Social Science*, vol. 8, no. 3, pp. 145–150, 2012.

[5] H. Dong, J. Q. Zeng, and M. R. Shen, “Research on construction and collaborative degree of composite system of industrial innovation—base on ICT industry,” *Studies in Science of Science*, vol. 34, no. 8, pp. 1166–1160, 2016.

[6] Y. J. Liu and J. D. Yin, “Comparison research on the level of collaboration innovation across provinces under the strategy of innovation-driven,” *Science and Technology Progress and Policy*, vol. 34, no. 16, pp. 33–41, 2015.

[7] L. F. Yu, J. D. Yin, and S. P. Xu, “Heterogeneity characteristics of innovation subject and relationship risk in innovation alliances under supply-side reform,” *Science and Technology Progress and Policy*, vol. 34, no. 5, pp. 6–13, 2017.

[8] B. Y. Du, C. H. Niu, and T. Niu, “Comparison research on system coordination degree among IUR alliances in Chinese six provinces,” *Modern Management*, vol. 36, no. 2, pp. 175-176, 2015.

[9] F. M. Deng, J. G. Zhang, and X. D. Liang, “Measurement on the capacity of regional collaborative innovation based on coordination degree-management entropy,” *Science and Technology Progress and Policy*, vol. 31, no. 5, pp. 113–117, 2014.

[10] L. Leydesdorff and G. Zawdie, “The triple helix perspective of innovation systems,” *Technology Analysis and Strategic Management*, vol. 22, no. 7, pp. 789–804, 2010.

[11] K. Nakwa and G. Zawdie, “Structure holes, knowledge intermediaries and evolution of the triple helix system with references to the hard disk drive industry in Thailand,” *International Journal of Technology Management and Sustainable Development*, vol. 14, no. 1, pp. 20–47, 2015.

[12] X. Cai and J. Zhao, “Research on the efficiency and influencing factors of university-industry-government synergistic innovation,” *Soft Science*, vol. 33, no. 2, pp. 56–60, 2019.

[13] Y. D. Wang and L. Lin, “Measuring the relationship of industry-university-research collaborative innovation in

Central China based on mutual information," *Journal of Intelligence*, vol. 37, no. 12, pp. 195–201, 2018.
[14] N. Hewitt-Dundas, "The role of proximity in university-business cooperation for innovation," *The Journal of Technology Transfer*, vol. 38, no. 2, pp. 195–201, 2013.
[15] X. Cai and X. Z. Liu, "Relationship among university, industry and government based on the perspective of SCI," *China Science and Technology Form*, vol. 22, no. 7, pp. 789–804, 2012.
[16] T. Zhuang and H. Wu, "Based on the number of Patents, Research on how to measure the triple helix among Governments-Industry-University-Research in China—the function of Governments in IUR," *Management World*, vol. 8, no. 8, pp. 175-176, 2013.
[17] H. Y. Chen and Z. L. Feng, "The statistical analysis of the application and the authorization of the service invention in China," *Science and Technology, Industry*, vol. 16, no. 3, pp. 81–86, 2016.
[18] L. Y. Han and C. Y. Du, "Regional difference of the impact of urban households' consumer finance," *Journal of economics research*, vol. 1, pp. 30–42, 2011.
[19] X. Cai and H. J. Zhang, "Research on the spatial effect of industry-university synergetic innovation in China and its influencing mechanism," *Journal of Technical Economics and Management*, vol. 10, pp. 26–32, 2019.