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Xi Yu
Sichuan Agricultural University

Krishna P. Paudel
LSU Agricultural Center

Dongmei Li
Sichuan Agricultural University

Xiaolei Xiong
Guizhou University of Finance and Economics

Yanyu Gong
Sichuan Agricultural University

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Sustainable Collaborative Innovation between Research Institutions and Seed Enterprises in China

Xi Yu [1], Krishna P. Paudel [2], Dongmei Li [1,*], Xiaolei Xiong [3] and Yanyu Gong [1]

1 College of Management, Sichuan Agricultural University, Chengdu 611130, China; yuxi@stu.sicau.edu.cn (X.Y.); gongyanyu@live.com (Y.G.)
2 Department of Agricultural Economics and Agribusiness, Louisiana State University (LSU) and LSU Agricultural Center, Baton Rouge, LA 70803-5604, USA; kpaudel@agcenter.lsu.edu
3 College of Public Management, Guizhou University of Finance and Economics, Guiyang 550025, China; Yanlingde136196@163.com
* Correspondence: lidm@sicau.edu.cn; Tel.: +86-028-8629-3780

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Abstract: Public research institutions are encouraged to engage in industry sustainable collaboration in China. We develop an analytical framework based on the factor-process-outputs model and use a mechanism model by incorporating four elements (innovation climate, strategic partnership, collaborative mechanism, and the degree of participation) associated with the research institutions and industry collaboration. Using data collected from a face-to-face interview survey of 533 experts located at research institutions in seven Chinese provinces and one municipality who have collaborated with the seed industry, we use a structural equation model to identify important factors that affect innovation behavior. Results show that the innovation climate does not directly affect the participation of research institutions in research industry collaboration; however, it has a direct effect on strategic partnership and the collaborative mechanism. We find that an innovation climate could indirectly influence the participation of research institutions via collaborative mechanism and strategic partnership. Furthermore, strategic partnership and collaborative mechanism are found to moderate the participation behavior of research institutions. Moreover, we find that policy support, knowledge innovation strategies, and resource sharing mechanisms are essential factors for sustainable and effective collaboration.

Keywords: sustainable collaborative innovation; research institution; innovation climate; collaborative mechanism; strategic partnership; innovation behavior; China

1. Introduction

Research institutions (RI, including universities and research institutes) are vital in the sustainable innovation system for promoting the economic development of a nation. As the RI gradually become the center of society's knowledge production, their roles in innovation become more diverse [1,2]. The RI are implementing various mechanisms for encouraging researchers and students to engage in research institutions and industry collaboration (RIIC) [2]. The sustainable collaborative innovation (Sustainable collaborative innovation between research institutions and industry is to shift the whole seed industries toward social, environmental and economic sustainability) between the RI and enterprises can boost national economic development and enhance the competitive advantage of the enterprises. The ability of the RI to take part in collaborative innovation is influenced by their context, resource-based capability, and capacity [3]. Currently, 80% of China's plant breeding resources, talents and technologies are concentrated in RI (The data comes from the Seed Information Website in China [4]). Many seed enterprises (Seed enterprises refer to enterprises engaged in the research and development, production,

sales and promotion of crop breeding to produce primarily breeder and foundation seeds (in some cases also registered and certified seeds [5]) lack research and development (R&D) capabilities although they have management, capital and market resources. In a traditional management system, the entire seed production process, ranging from manufacture to promotion, is detached from R&D components. As each side has a different advantage but lacks effective collaboration, research has not been effectively utilized in the seed industry. Therefore, the Chinese government has put forward policies to support and encourage collaborative innovation between RI and seed enterprises in 2011.

Research increasingly views collaboration as a forceful driver of university-industry-government innovation. Collaborative innovation is not only a process wherein different stakeholders are interrelated with each other but is also a complex system that requires synergies among the various elements of innovation [6]. Collaborative innovation projects have produced benefits far beyond earlier concurrent and cooperative efforts [7]. Torfing [8] researches collaborative innovation in the public sector, and points out an argument that multi-actor collaboration is a key driver of public innovation. Prior studies have looked at how to promote the collaborative innovation of university-industry-government [9–16]. These studies paid more attention to the models of collaborative innovation. The "Triple Helix" model is often used to analyze the collaboration among university-industry-government [9,16–20]. The framework "Triple Helix" is set up by Etzkowitz and Leydesdorff (1995) [9], and focuses primarily on interactions between three parties to reach the same goal [21]. Bucic and Gudergan [22] established a collaborative innovation model, which specified the direct and mediating effects of explaining the innovation within the alliance, and showed that the creativity, learning and knowledge reserve of the alliance drove the innovation. From the spatial analysis of regional innovation performance, Xu et al. [23] found that R&D personnel and R&D capital among different regions could help to promote the spillover effect of regional innovation performance.

Several studies have been conducted to understand the research process of collaborative innovation [10,11,14,24–27]. Agger and Sørensen [27] develop a taxonomy of tasks related to managing collaborative innovation and highlight the importance of management for promoting collaborative innovation processes. Hartley et al. [28] compare three major public innovation strategies, namely new public management, the neo-Weberian state, and collaborative governance. They suggest that although collaborative innovation carries an unrealized potential for creating new public policies and service, it is not an institutional strategy that works in all contexts. Ketchen, Ireland and Snow [25] analyze the relationship between strategic entrepreneurship, collaborative innovation and wealth creation. They find that small and large firms that learn how to integrate strategic entrepreneurship and collaborative innovation are well-positioned to create profits. The firms' size and openness are the driving forces of university-industry collaboration. Moreover, R&D intensity affects both the propensity and the degree of participation in R&D projects during collaboration [10]. Researchers also analyze the process optimization of the University-Industry-Research collaborative innovation from the perspective of knowledge management and transfer [11,25]. Bommert [26] studies collaborative innovation in the public sector, suggesting that the government needs to introduce supportive policies to successfully carry out collaborative innovation. Liew, Shahdan and Lim [14] present strategic and tactical approaches to university and industry collaboration in a contemporary commercial setting to secure a win-win situation.

In light of collaborative innovation in different areas and countries, Bagheri Moghadam et al. [29] present the fact that there is a considerable gap in relationships between universities and the power industry in Iran that could be filled with nonprofit R&D management and institutions responsible for technology development. Huang and Chen [1] conclude that a formal university-industry collaboration management mechanism might be the most essential factor for enhancing collaborative innovation. They also add that the innovation climate can moderate the relationship between university and industry research. Zhao et al. [30] investigate how a collaborative innovation system in a knowledge-intensive competitive alliance evolves through an empirical study conducted in China, Korea, and Germany.

They indicate that as the most important external control mechanism, resource input mechanism could alter the collaborative innovation period.

This paper aims to contribute to the growing literature on collaborative innovation by identifying the factors that influence RI's decision to join the RIIC, as well as estimating the correlation in influencing factors. Prior studies have provided a theoretical basis for this study. Nevertheless, these studies emphasize the synergy between the RI and enterprises from a macro perspective but ignore the negotiability of collaborative factors among different parties [10,11,14,24–26]. These studies mainly build models of collaborative innovation processes or analyze the results of collaborative innovation without considering the factors' mobility as the basis of collaborative innovation. This study employs recent survey data of 533 interviewees of 67 agricultural research institutes and agricultural universities in seven provinces (Sichuan, Yunnan, Guizhou, Shanxi, Gansu, Hunan, and Henan) and one municipality (Chongqing) of China for empirical analysis.

This study uses structural equation modeling to analyze how the RIIC elements, including innovation climate, collaborative mechanism, and strategic partnership, influence the collaborative innovation behavior of the RI to create an effective collaborative innovation. Previous studies focus on the efficiency of collaborative innovation rather than considering interaction and causal effects among the innovation climate, innovation process, and innovation behavior [10,11,14,24–26]. Particularly, by constructing an analytical framework of "factor-process-behavior", based on the existing model developed by Barnes [31], we explore the correlation and causal relationships among the innovation climate, collaborative mechanism, strategic partnership, and collaborative innovation behavior in detail.

2. Materials and Methods

2.1. Theoretical Model

We introduce the theory and method of synergetic relationship and develop a dynamic collaborative innovation model to explain the complexity of collaborative innovation [1,2,32]. The RIIC is a synergistic relationship that helps achieve common goals by integrating the respective advantages of each organization to increase overall value from collaboration. By expanding the analytical model of "Factor-Process-Outputs" proposed by Barnes et al. [33], this study constructs a theoretical model of Factor-Process-Behavior" (Figure 1), which is the theoretical basis of our empirical study. From the theoretical model, there are four components related to collaborative innovation: innovation climate, strategic partnership, collaborative mechanism, and degree of participation. These are grounded under factor (innovation climate), process (strategic partnership and collaborative mechanism), and behavior (degree of participation).

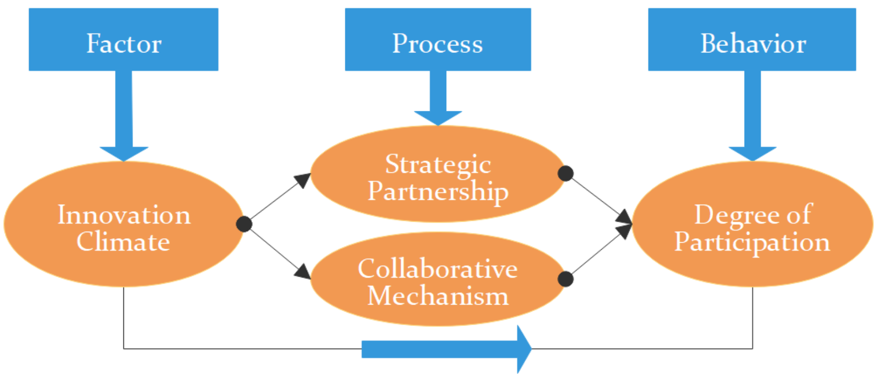

Figure 1. The Theoretical Model.

Innovation climate refers to the synthesis of uncertain social factors that influence collaborative innovation in seed enterprises and research institutes. Developing a positive innovation climate

in society could facilitate enterprise and benefit both entrepreneurs and research institutes. If the government agencies and industry have a positive attitude to support the collaborative innovation activities, collaborative innovation could be smoother and more successful. For instance, the marked innovation output of Israeli firms does not occur simply due to their more effective management of technology, but also due to the favorable environment for innovation [34]. In this study, support for an innovation climate was considered to include a series of initiatives and actions taken for providing a support service by the government, banks, and other financial companies. Therefore, an innovation climate is identified as one in which social factors have an effect on the participation of the RI, such as government policy support, intermediary services, financial support, and insurance support.

Strategic partnership designates to what degree and in what way a participant uses innovation to perform its innovation strategy and to develop its performance. Strategic partnership can determine the common research and development goals, reducing R&D risks and costs. Collaborative innovation should address the issues related to the planning and implementation of innovative projects [35]. Innovation strategy calls for the unification of engineering and investment policies. Thus, in this study, the strategic partnership means closely strategic cooperation in the RIIC, which includes development strategy, technology innovation, and knowledge innovation strategy.

Collaborative mechanisms are the extent to which the organization has instituted formal approaches and tools and provided resources to encourage meaningful behavior within the organization [36]. Furthermore, collaborative mechanisms refer to the relative operational principle and relevant system in the entire collaborative innovation process for each participant. In other words, collaborative mechanisms are the sum of the dynamics, rules, and procedures related to the interrelated elements within collaborative innovation. There are several internal sub-mechanisms, such as the incentive mechanism, communication mechanism, output sharing mechanism, profit distribution mechanism, risk-sharing mechanism, resource sharing mechanism, and organizational cultural mechanism.

Degree of participation reflects the degree of information and resource sharing, the degree of decision-making, and the level and scope of collaboration with each other. In order to analyze the characteristics of the degree of participation in collaboration, we use the three dimensions for distinguishing participation proposed by DiMaggio and Powell [37]: interactions, structures, and information flow. In addition, collaborations possessing a high degree of participation will be positively associated with the acquisition of distinctive resources from different collaborators [38]. Thus, the degree of participation is always highly relevant to the specific behaviors of collaborators. Here, it is mainly reflected in the mode and method of RI chosen, as well as the frequency of cooperation.

In summary, collaborative innovation is a network of non-linear complex systems, and the innovation climate is a prerequisite towards realizing collaborative innovation. Strategic partnership and collaborative mechanism are a concrete reflection of the cooperation process and degree of participation in the results of cooperation behavior. This study uses the degree of participation as the evaluation index of collaborative innovation behavior.

2.2. Research Hypothesis

2.2.1. Innovation Climate and Strategic Partnership

Successful collaborative innovation needs a strategic orientation, which is defined as how and to what degree an organization uses innovation to carry out its operations and develop its performance [39,40]. In this context, strategic partnership is used to integrate government guidance, enterprise demanding and the output of the RI to achieve the strategies associated with government-enterprises-research institutions collaboration. In the national innovation system, both enterprises and the RI have their own goals and comparative advantage, as well as shortcomings and lack of innovation resources. Only with the collaborative support of the government, can intermediaries,

such as seed industry associations, financial institutions, and other related institutions [41], improve the collaborative degree of innovation strategies [42]. Thus, this study proposes the following hypothesis:

Hypothesis 1 (H1). *The innovation climate has a significant positive effect on the strategic partnership in the RIIC.*

2.2.2. Innovation Climate and Collaborative Mechanism

Collaborative mechanism means that under the collaborative support of the government, intermediaries, financial organizations and other related institutions, as well as all basic actors, invest respective innovation resources into joint technology development in collaborative innovation activities [43]. The innovation climate and collaborative mechanism are the main factors that affect collaborative innovation [44]. The collaborative mechanism in risk-sharing and benefit sharing among all collaborators can lead them to maintain a long-term and stable relationship. The collaborative mechanism in the seed industry needs policy, technological and financial support. Under the guidance of collaborative strategies, each member has a similar value and behavioral orientation [45]. Therefore, the following proposition is advanced:

Hypothesis 2 (H2). *The innovation climate has a significant positive effect on the collaborative mechanism in the RIIC.*

2.2.3. Innovation Climate and the Degree of Participation of the RI

The collaborative innovation behavior of the RI is influenced by the external policy environment, intermediaries and financial institutions. The government plays an important and indirect role [46,47], which includes setting up a cooperation platform for cooperation and creating a favorable environment for innovation. Intermediaries and financial institutions also play an indirect role [48]. Venture capital intervention and collaborative innovation can not only lower the cooperative risk but also reduce the risk of the specialized value-added service provided by the venture capitalist. Furthermore, common cultural values can reduce conflicts with each other [49]. Therefore, we advance the following proposition:

Hypothesis 3 (H3). *The innovation climate has a significant positive effect on the degree of participation of the RI.*

2.2.4. Strategic Partnership and the Degree of Participation of the RI

Seed enterprises and the RI have different organizational cultures and standards of behavior, which are formed by their different goals and strengths. Close strategies of cooperation require sharing common values and cultural identities [50]. The synergy of knowledge, resources, and strategies in the innovation system have a great effect on collaborative innovation behavior [48]. Only by finding a balance between "interests and risks" and by establishing strategic partnerships can the industrial innovation chain be complemented, expanded and extended [50]. Hence, the following propositions are advanced:

Hypothesis 4 (H4). *Strategic partnership has a significant positive effect on the degree of participation of the RI.*

Hypothesis 5 (H5). *Strategic partnership has a mediating effect on the degree of participation of the RI.*

2.2.5. Collaborative Mechanism and the Degree of Participation of the RI

The collaborative mechanism mainly includes incentive mechanisms, communication mechanisms, profit distribution mechanisms, output sharing mechanisms, risk-sharing mechanisms, and organizational cultural mechanisms. First, is the role of incentives and values in RIIC. Participants

need to affirm collaborative values that include a concern for the welfare of collaborating partners and the equitable distribution of rewards. Therefore, incentives need to be designed such that they reward people and organizations for collaborating [51,52]. The profit distribution mechanism is the main factor influencing the participation of scientists in collaborative innovation [53]. As far as the risk-sharing mechanism is concerned, innovation by its very nature is risky [39]. Collaborative innovation may be at risk when private industry exploits the process of innovation and its result to their own advantage [28]. In terms of the organizational cultural mechanism, the RI has an academic culture of exploring the truth, while private industry has commercial culture whereby profit maximization is pursued [54]. Members need to understand and respect their partner's culture and beliefs. In light of communication mechanisms, effective communication can integrate knowledge from different organizations to extract beneficial knowledge and wealth creation. Therefore, we advance the following propositions:

Hypothesis 6 (H6). *The collaborative mechanism has a significant positive effect on the degree of participation of the RI.*

Hypothesis 7 (H7). *The collaborative mechanism has a mediating effect on the degree of participation of the RI.*

3. Research Design

Following the theoretical model and research hypothesis, we design the research constructs, introduce the data sources, and give the descriptive statistics of the data in this part.

3.1. Measurements of Variables

According to the previous analysis, the latent variables contain innovation climate, strategic partnership, collaborative mechanism and the degree of participation. The following variables are measured by using a five-point Likert scale. The scale ranges from 1 (Strongly disagree) to 5 (Strongly agree). The scale data reflect the subjective judgment of the respondent. The design and measurement of the study variables are shown in Table 1.

Table 1. The setting and measurement of variables.

Latent Variables		Observed Variables (Explicit Variables)			
Code	**Variable Name**	**Code**	**Variable Name**	**Variable Definition**	**Supporting Literature**
$\xi 1$	Innovation climate	x1	Policy support	The relevant collaborative policies with support from the government	Martínez-Román, Gamero and Tamayo [46]; Thorgren, Wincent and Örtqvist [47]
		x2	Intermediary services	The function and development level of an intermediary service organization (i.e., SciTech Park, SciTech Incubator)	
		x3	Financial services	The beneficial measures from financial institutions for the collaborative innovation program	
		x4	Insurance services	The support from insurance institutions for the collaborative innovation program	
$\eta 1$	Strategic partnership	y1	Seed industry development strategy	The synergy-degree between the cooperation strategy and the development strategy of the national seed industry	He [42]; Chen and Yang [48]; Geisler [55]

Table 1. *Cont.*

Latent Variables		Observed Variables (Explicit Variables)			
Code	**Variable Name**	**Code**	**Variable Name**	**Variable Definition**	**Supporting Literature**
		y2	Knowledge innovation strategy	The synergy degree of cooperation strategy and knowledge innovation strategy	
		y3	Technology innovation strategy	The synergy degree of cooperation strategy and technology innovation strategy	
η2	Collaborative mechanism	y4	Incentive mechanism	Reasonableness of wage and welfare distribution of staff	Lee [13] López-Martínez et al. [56]
		y5	Communication mechanism	The RIC communication platform (i.e., Network Station, Germplasm Resource Base.)	
		y6	Output sharing mechanism	The sharing of the new variety of rights	
		y7	Profit distribution mechanism	Equity and rationality of the profit distribution	
		y8	Risk-sharing mechanism	Market risk-sharing in cooperation	
		y9	Resource sharing mechanism	The sharing degree of innovation climate	
		y10	Organizational cultural mechanism	Mutual understanding and mutual respect among team members	
η3	Degree of participation (behavior)	y11	Cooperation model	The cooperative model is conducive to RI to participate in the RIIC	DiMaggio and Powell [37] Hardy, Phillips and Lawrence [38] Zhao et al. [57]
		y12	Cooperation method	The suitable cooperative method can promote the RIIC	
		y13	Cooperation frequency	Times of cooperation can stabilize the collaborative relations in the RIIC and it is conducive to RI to achieve collaborative innovation	

Note: RIIC, means the collaboration between research institutions and industry. RI, means universities and research institutes.

3.2. Sampling and Data Collection

The data used in the empirical analysis was collected from 533 interviewees of 67 agricultural research institutes and agricultural universities of seven provinces (Sichuan, Yunnan, Guizhou, Shanxi, Gansu, Hunan, and Henan) and one municipality (Chongqing) in China (Figure 2, China has 34 provincial-level administrative regions, including 23 provinces, 5 autonomous regions, 4 municipalities and 2 special administrative regions.). We used a stratified random sampling method to choose research institutes, and interviewed around eight individuals in each research institution using a random sampling method. Respondents were limited to experienced staff, such as plant breeding experts, researchers, and managers in the RI, as they are more familiar with the collaborative innovation in the RIIC and can answer the questions effectively. Thus, the respondents selected in the questionnaire have a relatively high level of knowledge of collaborative innovation in the RIIC. A "face to face" interview took place, allowing the investigators to directly answer any doubts and questions raised by the respondents. The survey was conducted in 2014–2015. The descriptive statistics are shown in Table 2. Overall, we received valid responses from 533 individuals out of 561 interviewed individuals. These 533 observations are analyzed to derive the conclusion to this study.

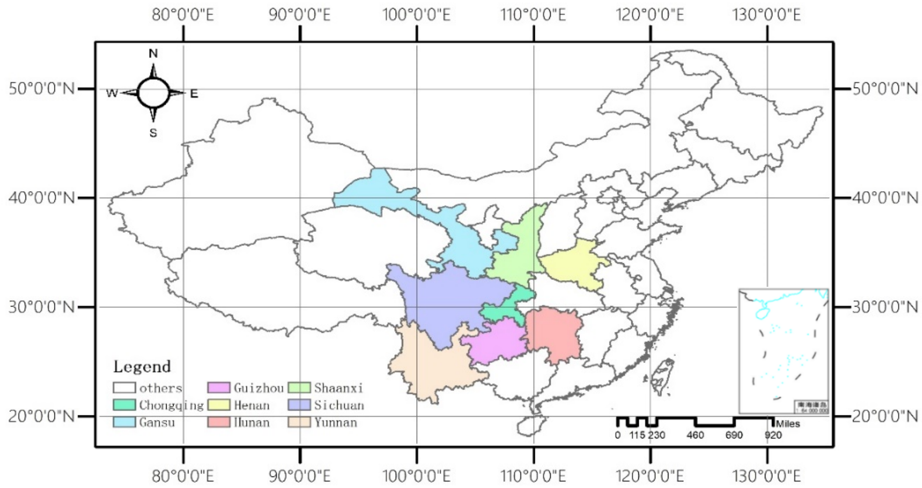

Figure 2. The study areas in China, which are denoted in different colors.

Table 2. Characteristics of respondents and geographic distribution.

Variable	Category	Number of Respondents (N = 533)
Regions	Sichuan	140 (26.27%)
	Yunnan	39 (7.32%)
	Guizhou	76 (14.26%)
	Chongqing	98 (18.39%)
	Gansu	42 (7.88%)
	Shanxi	37 (6.93%)
	Hunan	43 (8.07%)
	Henan	58 (10.88%)
Age	Under the age of 30	92 (17.26%)
	31–40	323 (60.61%)
	41–50	82 (15.38%)
	51–60	36 (6.75%)
Educational level	Undergraduate	85 (15.95%)
	Master	256 (48.03%)
	Doctor	192 (36.02%)
Working post	Scientific researchers	380 (71.29%)
	Teaching staff	153 (28.71%)
Working years	1 year or less	15 (2.81%)
	1–5	63 (11.82%)
	6–10	136 (25.52%)
	11–20	233 (43.71%)
	more than 21 years	86 (16.14%)
Professional title	Primary	30 (5.63%)
	Intermediate	81 (15.20%)
	Deputy high	326 (61.16%)
	Senior	96 (18.01%)

Source: Authors' calculations based on survey results.

4. Model Specification, Results, and Evaluation

We follow the research process of structural equation modeling (SEM) in this section. The SEM is a standard tool in management and psychological research. Details in conducting the SEM in management and psychological research can be found in several papers [58–60]. We specify the SEM

model, do a confirmatory factor analysis, estimate the parameters, modify the model, and conduct the model hypothesis test.

4.1. Model Specification

Structural equation modeling (SEM) is used to analyze multiple independent and dependent variables as well as hypothetical latent constructs that clusters of observed variables might represent. It also provides a way to test the specified set of relationships among observed and latent variables as a whole and allows theoretical testing even when experiments are not possible [34].

SEM generally contains a measurement model and a structural model. The measurement model reflects the relationship between the observed and the latent variables. While the latent variables cannot be directly measured, they can be defined by the observed variables. As such, conceptual variables need to be changed into operational variables. The structural model develops the advantage of path analysis. It can calculate the direct effect on latent variables and deduce the indirect effect and the total effect, which expresses the mediating effect and shows the causal relationship among latent variables. SEM generally consists of three matrix equations; the algebraic expression is as follows:

$$X = \wedge_x \xi + \delta \tag{1}$$

$$Y = \wedge_y \eta + \varepsilon \tag{2}$$

$$\eta = B\eta + \Gamma\xi + \zeta \tag{3}$$

Here, Equation (1) shows the measurement model of exogenous observed variables. Equation (2) shows the measurement model of endogenous observed variables. Equation (3) shows the structural model between the endogenous latent variables. X and Y denote the exogenous observed variables matrix ($q \times 1$) and the endogenous observed variable matrix ($p \times 1$), respectively. η and ξ denote the endogenous latent variable matrix ($m \times 1$) and the exogenous latent variable matrix ($n \times 1$), respectively. $\wedge_x$ denotes the factor load matrix ($q \times n$) of the exogenous observed variables on the exogenous latent variables, and $\wedge_y$ denotes the factor load matrix ($p \times m$) of the endogenous variables on the endogenous latent variables. δ denotes the measurement error matrix ($q \times 1$) of the exogenous observed variables. ε denotes the measurement error matrix of the endogenous observation variables ($p \times 1$). B denotes the matrix coefficient ($m \times m$) between the endogenous latent variables. Γ denotes the path coefficient matrix ($m \times n$) of the exogenous latent variable to the corresponding endogenous latent variable. ζ denotes the measurement error matrix ($p \times 1$) of the endogenous latent variable. P is the number of endogenous observed variables, and q is the number of exogenous observed variables. m is the number of endogenous latent variables, and n is the number of exogenous latent variables.

The empirical model of the structural equation of the innovation climate, the collaborative mechanism, and collaborative innovation behavior is established and represented by the path diagram, as shown in Figure 3.

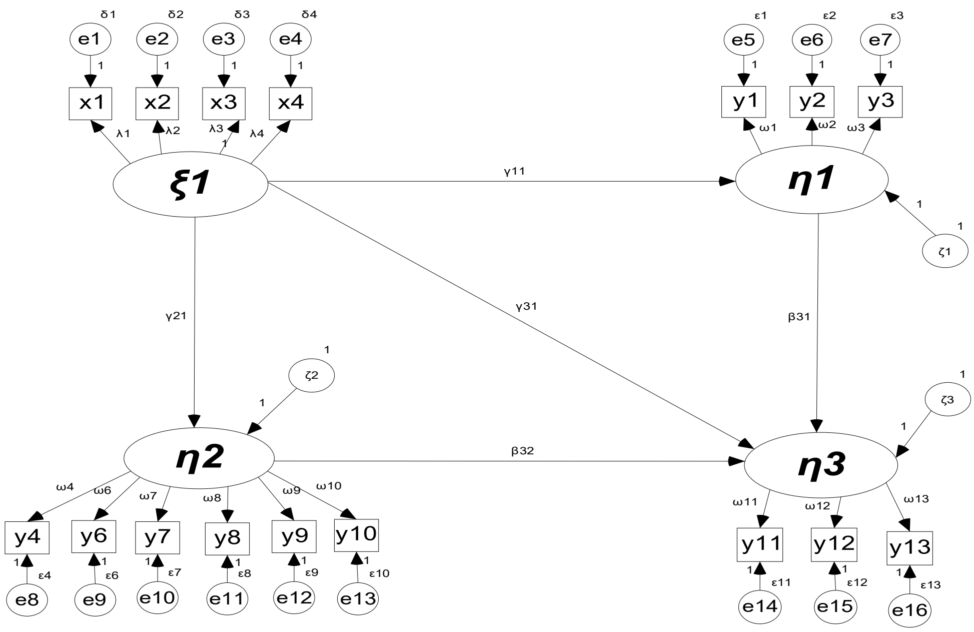

Figure 3. Structural equation empirical model path diagram of innovation climate, collaborative mechanism, and collaborative innovation behavior.

In Figure 3, the ellipses represent the latent variable, the box represents the observed variable, and the circle represents the residual variable, and arrows represent regression coefficients. ξ1 denotes the exogenous latent variable (innovation climate), η1 and η2 denote intermediary variable strategic partnership and collaborative mechanism, respectively. η3 denotes the endogenous latent variable (degree of participation). x1~x4 represent exogenous observed variables corresponding to ξ_1. y1~y3 are endogenous observed variables corresponding to η1, y4~y10 are endogenous observed variables corresponding to η2, and y11~y13 are endogenous observed variables corresponding to η3. λ1~λ4 denote the path coefficients of the exogenous latent variable ξ1, pointing to the corresponding exogenous observed variables x1~x4. ω1~ω13 are the path coefficients of the corresponding endogenous variables. γ11, γ21, γ31, β31, and β32 represent the path coefficients of the interaction among the latent variables. δ1~δ4 represent the measurement errors of the exogenous observed variables. ε1~ε13 represent the measurement errors of endogenous observed variables, ζ1~ζ3 represent the measurement error of the endogenous latent variables, and e1~e16 represent the residuals of the observed variables. The setting regression coefficient of each measurement error is 1 according to the software's setting.

4.2. A Confirmatory Factor Analysis (CFA)

4.2.1. Reliability Test

On the basis of the confirmatory factor analysis results of the measurement model obtained using SPSS22.0 and AMOS17.0, we deleted the observational variable y5, which failed the reliability test (y5: communication mechanism). Reliability test results are shown in Table 3: First, Cronbach's α is 0.832 and greater than 0.70, indicating that the whole reliability of the questionnaire is high. Second, Cronbach's α coefficient values of all latent variables are greater than or equal to 0.70 (rounded to one decimal number), indicating latent variables have higher reliability. Third, the composite reliability (C.R.) of each latent variable is greater than 0.80, which indicates there is a strong correlation between the observed variables and the consistency of the internal structure, and each measurement model has better stability and reliability. The test results show that the whole reliability of the measurement model set is strong.

Table 3. Reliability of test variables.

Latent Variable	Value of Cronbach's α	Composite Reliability (CR)
Innovation climate (ξ1)	0.734	0.837
Strategic partnership (η1)	0.743	0.878
Collaborative mechanism (η2)	0.776	0.877
Degree of participation (η3)	0.658	0.922
The whole questionnaire	0.832	——

Source: Authors' calculations based on survey results.

4.2.2. Validity Test

Confirmatory factor analysis (CFA) is used to test the convergent validity and discriminant validity of the four latent variables. The results of the CFA are shown in Tables 4 and 5, indicating that: (1) The standardized factor loading values of all observed variables in the four latent variables are in the range of 0.550–0.901 and greater than 0.50 (Table 4, last column). (2) The critical ratios of all path coefficients of the latent variables corresponding to the observed variables are in the range of 8.609–13.698 and greater than 3.28 (Table 4, fourth column). All are statistically significant at 0.1 percent level, which indicates the observed variables are aggregated in the corresponding latent variables and the latent variables have good explanatory power for the observed variables. Hence, the model has good convergent validity. (3) In Table 5, the square root of the average variance extracted (AVE) of each latent variable (the diagonal value in the table) is greater than the correlation coefficient between the latent variable and the other latent variables (the non-diagonal values), indicating that there is a clear distinction among the latent variables, and the difference validity of the measurement model is high.

Table 4. Results of the test for the polymerization validity of the measurement model.

Path Relationship	Non-Standard Factor Load Coefficient	Standard Error (S.E.)	Critical Ratio (C.R.)	Standard Factor Load Coefficient
x1←ξ1	1.286 ***	0.135	9.495	0.713
x2←ξ1	1.000	——	——	0.551
x3←ξ1	1.225 ***	0.127	9.675	0.675
x4←ξ1	1.313 ***	0.129	10.166	0.696
y1←η1	1.000	——	——	0.667
y2←η1	1.621 ***	0.142	11.446	0.798
y3←η1	1.651 ***	0.136	12.097	0.809
y4←η2	1.343 ***	0.147	9.146	0.606
y6←η2	1.044 ***	0.121	8.609	0.55
y7←η2	1.514 ***	0.154	9.842	0.695
y8←η2	1.422 ***	0.151	9.435	0.628
y9←η2	1.839 ***	0.165	11.123	0.838
y10←η2	1.000	——	——	0.555
y11←η3	0.537 ***	0.043	12.617	0.77
y12←η3	0.648 ***	0.047	13.698	0.811
y13←η3	1	——	——	0.901

Note: *** Indicates statistically significant at the 0.1 percent level.

Table 5. Test results for the difference validity of the measurement model.

Latent Variable	Innovation Climate	Strategic Partnership	Collaborative Mechanism	Degree of Participation
	(ξ1)	(η1)	(η2)	(η3)
Innovation climate (ξ1)	0.663	0.555	0.629	0.414
Strategic partnership (η1)	0.555	0.764	0.583	0.672
Collaborative mechanism (η2)	0.629	0.583	0.654	0.575
Degree of participation (η3)	0.414	0.672	0.575	0.828

Note: Covariance is below the diagonal, correlations are above the diagonal, and variances are on the diagonal.

4.3. Parameter Estimation

Based on the SEM, the basic parameters have been estimated by using the maximum likelihood estimation (MLE), resulting in our initial structural equation modeling (M1) (see Figure 4).

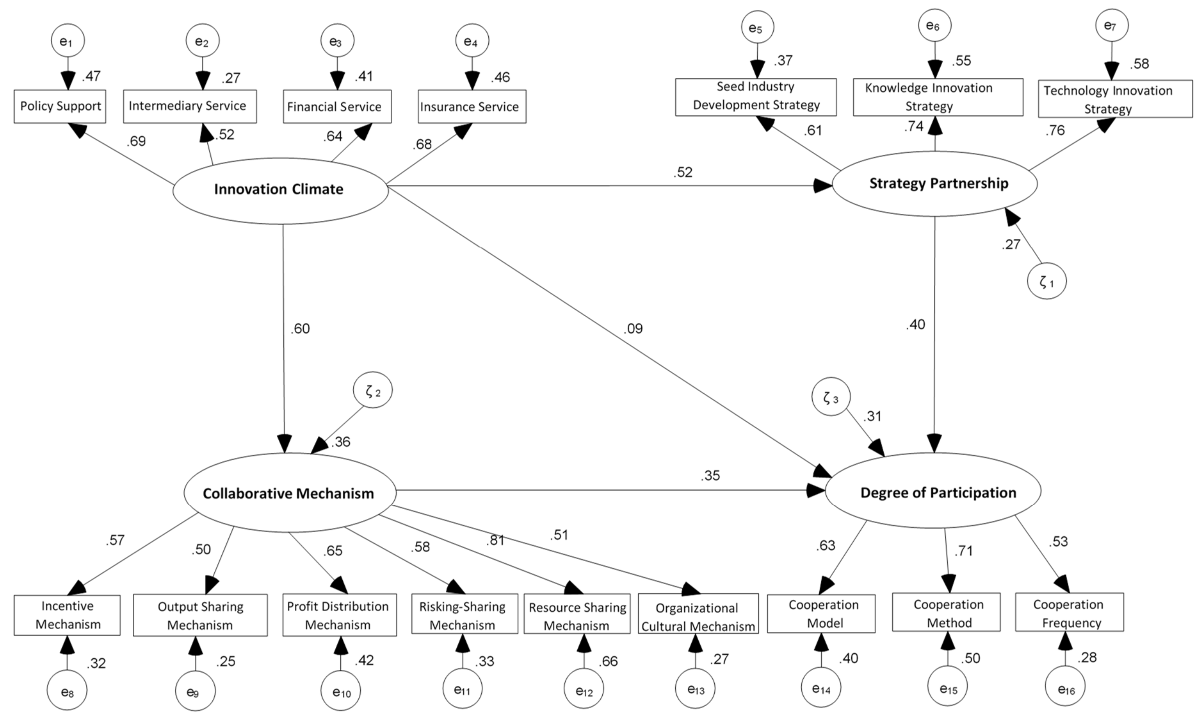

Figure 4. The initial model of the mechanism of innovation climate, collaborative mechanism, and collaborative innovation behavior.

4.4. Modified Model

Model revision and determination are done in two stages: First, according to the principle of model simplification, we revised the model based on a parametric rationality test and the fitness test. Second, based on the modification index (M.I.), we modified the expansion direction of M1, and the whole model fitting degree is improved by increasing the path relation of the model to reduce the chi-square value. The comparison of the fitting parameters before and after the modified model is shown in Table 6. From Table 6, most of the fit indices of the measurement and research models have reached the ideal level of the evaluation standard. This indicates that the modified model has passed the whole fitting of the model and is ideal for the whole fitting degree of the sample data. Therefore, the modified model can be used as the final model to be verified in this study (see Figure 5). The results of the significance test of the final model parameters are shown in Table 7.

Table 6. Results of the whole fitness test for the modified structural equation modeling.

Indices		Indices Meaning	Statistics		Recommendations
			Measurement Model	Final Model	
Absolute fitness index	χ^2	Chi-square value	298.606	267.75	The smaller the better
	χ^2/df	Chi-square degrees of freedom	3.016	2.789	<3.00
	RMR	root mean square residual	0.03	0.029	<0.05
	RMSEA	root mean square error of approximation	0.062	0.058	<0.08
	GFI	goodness-of-fit index	0.935	0.943	>0.90
	AGFI	adjusted goodness-of-fit	0.911	0.919	>0.90
	CN	number of critical samples	533	533	>200
Comparison of fitness index	NFI	normed fit index	0.872	0.886	>0.90
	IFI	incremental fit index	0.911	0.923	>0.90
	TLI	Non-canonical fitting index	0.891	0.903	>0.90
	CFI	compare fitting index	0.91	0.923	>0.90
Simple fit index	PGFI	parsimony goodness-of-fit index	0.681	0.666	>0.50
	PNFI	concise norm fitting index	0.72	0.708	>0.50
	PCFI	simple comparison of fitting index	0.751	0.738	>0.50

Note: Summary of the model fitting indices results.

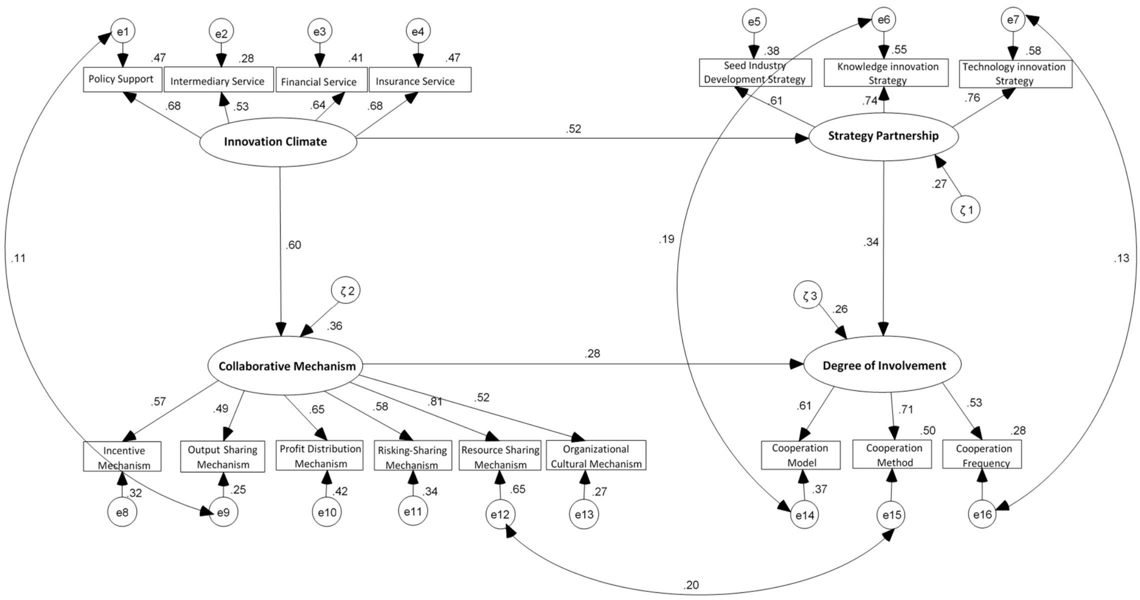

Figure 5. The mechanism final model of innovation environment, collaborative mechanism, and collaborative innovation behavior.

Table 7. The modified structural equation model parameter significance test results.

Parameter	Non-Standardized Parameter Estimate Value	S.E.	C.R.	Standardized Parameter Estimate Value
Structural model				
$\gamma 11$ ($\xi 1 \rightarrow \eta 1$)	0.607 ***	0.075	8.151	0.519
$\gamma 21$ ($\xi 1 \rightarrow \eta 2$)	0.743 ***	0.081	9.23	0.596
$\beta 31$ ($\eta 1 \rightarrow \eta 3$)	0.341 ***	0.069	4.962	0.344
$\beta 32$ ($\eta 2 \rightarrow \eta 3$)	0.263 ***	0.061	4.28	0.282
Measurement model				
$\lambda 1$ ($\xi 1 \rightarrow x1$)	0.536 ***	0.035	15.498	0.684
$\lambda 2$ ($\xi 1 \rightarrow x2$)	0.419 ***	0.037	11.44	0.527

Table 7. *Cont.*

Parameter	Non-Standardized Parameter Estimate Value	S.E.	C.R.	Standardized Parameter Estimate Value
λ3 (ξ1→x3)	0.504 ***	0.035	14.339	0.64
λ4 (ξ1→x4)	0.560 ***	0.036	15.435	0.684
ω1 (η1→y1)	0.317 ***	0.025	12.781	0.613
ω2 (η1→y2)	0.502 ***	0.032	15.701	0.74
ω3 (η1→y3)	0.517 ***	0.034	15.432	0.76
ω4 (η2→y4)	0.364 ***	0.03	12.325	0.567
ω6 (η2→y6)	0.273 ***	0.026	10.575	0.495
ω7 (η2→y7)	0.404 ***	0.029	13.897	0.649
ω8 (η2→y8)	0.382 ***	0.031	12.423	0.584
ω9 (η2→y9)	0.491 ***	0.03	16.581	0.805
ω10 (η2→y10)	0.271 ***	0.025	10.936	0.518
ω11 (η3→y11)	0.290 ***	0.025	11.726	0.609
ω12 (η3→y12)	0.373 ***	0.03	12.528	0.709
ω13 (η3→y13)	0.262 ***	0.025	10.309	0.532
Variance				
δ1 (e1→x1)	0.327 ***	0.028	11.809	
δ2 (e2→x2)	0.458 ***	0.032	14.4	
δ3 (e3→x3)	0.367 ***	0.029	12.825	
δ4 (e4→x4)	0.358 ***	0.03	11.785	
ε1 (e5→y1)	0.228 ***	0.017	13.34	
ε2 (e6→y2)	0.286 ***	0.029	9.919	
ε3 (e7→y3)	0.267 ***	0.029	9.204	
ε4 (e8→y4)	0.434 ***	0.03	14.417	
ε6 (e9→y6)	0.356 ***	0.024	15.094	
ε7 (e10→y7)	0.347 ***	0.025	13.667	
ε8 (e11→y8)	0.437 ***	0.031	14.037	
ε9 (e12→y9)	0.203 ***	0.022	9.24	
ε10 (e13→y10)	0.312 ***	0.021	14.979	
ε11 (e14→y11)	0.192 ***	0.017	11.254	
ε12 (e15→y12)	0.185 ***	0.023	8.118	
ε13 (e16→y13)	0.234 ***	0.018	13.147	
Covariance				
e6<–>e14	0.046 ***	0.014	3.31	
e1<–>e9	0.036 *	0.017	2.075	
e12<–>e15	0.038 **	0.013	2.907	
e7<–>e16	0.032 *	0.014	2.227	

Note: ***, **, * indicate statistically significant at the 0.1, 1, and 5 percent levels, respectively. If C.R. is greater than 3.28, then the test is significant at 0.1 percent.

Figure 5 and Table 7 show that the estimated values of all parameters are reasonable and the normalized factor loading values of all the path coefficients of the measurement model are greater than or near 0.50, and the C.R. values are greater than 1.96 (critical value). The parameters of the standard deviation are greater than zero, and the value of p is less than 0.05. All the parameters are tested by 5 percent significance levels, and the relationship between them is significant, indicating that the final model has passed the significance test.

4.5. Model Hypothesis Test

On the whole, the final model has passed the parameter rationality test, the overall fittest and the parameter significance test. It not only has good fitness degree or goodness-of-fit but also has the interpretative ability of the model, which means the model could describe how well it fits a set of observations and fully reflects most of the information contained in the survey data. The test results of the research hypothesis are shown in Table 8.

Table 8. Results for the hypothesis test.

Path	Corresponding Assumptions	Non-Standard Path Coefficient	Critical ratio (C.R.)	Test Result
ξ1→η1	H1	0.607 ***	8.151	True
ξ1→η2	H2	0.743 ***	9.23	True
ξ1→η3	H3	−0.107	−0.991	Not valid
η1→η3	H4	0.341 ***	4.962	True
η2→η3	H6	0.263 ***	4.28	True
ξ1→η1→η3	H5	0.607 ***→0.341 ***	8.151→4.962	True
ξ1→η2→η3	H7	0.743 ***→0.263 ***	9.230→4.280	True

Note: ***, **, * indicate statistically significant at the 0.1, 1, and 5 percent levels, respectively. If C.R. is greater than 3.28, then the test is significant at 0.1 percent.

5. Final Remarks

The results of the empirical analysis are shown in Figure 5 and Table 8. These results indicate:

- First, the path coefficient of ξ1 → η1 is 0.607 (C.R. = 8.151) and ξ1 → η2 is 0.743 (C.R. = 9.230). Both pathways are significant at a 0.1% level. The direction is positive, demonstrating that the innovation climate has a significant influence on strategic partnership and the collaborative mechanism. Therefore, we fail to reject H1 and H2.
- Second, the path coefficient of ξ1 → η3 is −0.107 (C.R. = 0.991). The value is not significant at a 5% level, indicating that there is no impact on the innovation climate on the degree of participation of the RI. Thus, we reject H3.
- Third, the path coefficient of η1 → η3 is 0.341 (C.R. = 4.962) and η2 → η3 is 0.263 (C.R. = 4.280). Both pathways are significant at a 0.1% level. The direction is positive, indicating the direct impact of strategic partnership and the collaborative mechanism on the degree of participation of the RI. Therefore, we fail to reject H4 and H6.
- Fourth, the intermediate effect of ξ1 → η1 → η3 is 0.607 × 0.341 = 0.207, and the CR values are 8.151 between ξ1 → η1 and 4.962 between η1 → η3, showing that ξ1 indirectly affects η3 via η1. These indicate that strategic partnership has an intermediary role in determining the degree of participation of the RI. Hence, we fail to reject H5.
- Fifth, the intermediate effect of ξ1 → η2 → η3 is 0.743 × 0.263 = 0.195 and the CR values are 9.230 between ξ1 → η2 and 4.280 between η2 → η3 indicating ξ1 indirectly affects η3 via η2. These indicate that the collaborative mechanism has an intermediary role in affecting the degree of participation. Consequently, we fail to reject H7.

6. Discussion and Policy Implications

This study used SEM to examine how the RIIC elements influence the sustainable collaborative innovation behavior between the RI and the seed industry. Based on analyses of data collected from experts located at the RI with direct involvement in RIIC, this study draws the following conclusions and policy implications.

6.1. Main Conclusions

First, the result of the structural model equation showed that the direct impact of the innovation climate on the RI's involved is not significant, but it can moderate the association in the RIIC [1]. Second, the innovation climate could indirectly influence the participation of the RI through two paths: the collaborative mechanism and strategic partnership. Third, the innovation climate had a direct effect on strategic partnership and the collaborative mechanism. Fourth, strategic partnership and the collaborative mechanism had direct as well as mediating effects on the degree of the RI's participation.

Based on the "factor-process-result" model proposed by Barnes, we developed an analytical framework of "factor-process-behavior." We found that strategic partnership and the collaborative

mechanism are two key factors in the process of the RIIC, because they have direct, as well as mediating effects on the participation of the RI. Additionally, there is the indirect effect of the innovation climate on the collaborative innovation behavior of the RI, which can affect through two paths: collaborative mechanism and strategic partnership. Innovation climate cannot directly affect the participation of the RI, but it can be a catalyst for the RI to take part in collaborative innovation.

There are other conclusions that can be drawn here that have not been addressed by prior research. We found policy support has a significant effect on the mechanism of achievement sharing in the RIIC, and the resource sharing mechanism has an important impact on the choice of collaborative mode. Moreover, the knowledge innovation strategy has a positive influence on the choice of collaborative mode. At the same time, the technological innovation strategy increased the collaborative frequency of the RI with industry.

6.2. Policy Implications

From the perspectives of the RI, given that we fully realize the impetus and indirect effect of the innovation climate, the RI would participate in the RIIC. It is necessary to formulate an intellectual property rights protection mechanism and an incentive mechanism for sustainable collaborative innovation. Policies should be formulated to guide the effective transfer of resources (knowledge, technology, human resources, and germplasm resources) from the RI to the seed industry to boost the innovation behavior of the RI. A harmonious innovation climate might facilitate more interaction between the RI and seed enterprises, thereby contributing to the improvement of the degree of the RI's participation in the RIIC.

From the perspectives of seed enterprises, the strategic partnership should help in effective interaction with the RI. To give full advantage to the initiative of research institutions in collaborative innovation, we need to attach importance to the seed industry development strategy, technology innovation strategy, and knowledge innovation strategy.

Considering the entire process of the RIIC, the output sharing mechanism and resource sharing mechanism have an obvious influence on the process of sustainable collaborative innovation. Researchers in the RI usually take their research output to get post promotion through publishing papers and patents, and ignore the practical application of the research results. Therefore, it would be better to give priority to formulate legible mechanisms to achieve long-term stable collaboration.

There are some limitations to the study. Since the data mainly came from provinces and municipalities located in the middle-west part of China and did not contain a sample from the eastern region, results may not be applicable to the entire country. We did not study the impact mechanism of advantageous resources on the sustainable collaborative innovation behavior of the RI in the seed industry. We also did not interview industry experts on their perspectives about RIIC. Future research should be conducted to address these remaining concerns.

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