

# The Paths to Enhance the Collaborative Innovation Performance of Industry-University-Research Technological Chains: A Perspective from the Digital Economy

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## Abstract

The digital economy has fundamentally changed the traditional way of economic development and industrial patterns. It provides a powerful impetus for sustained and healthy economic and social development. As the digital economy turns to the stage of deepening application, standardized development, and universal sharing. It is necessary to accelerate the transformation and industrialization of scientific and technological achievements, promote the integration of industry-university-research (IUR) and application, and support leading enterprises to integrate the strengths of scientific research institutes colleges, and colleges and universities. At present, China has practiced a lot of collaborative innovation among industries, universities, and research institutes and has achieved certain successes. However, at the present stage, collaborative innovations have problems such as insufficient cooperation and short-term behaviors. Promoting deep integration of industry-university-research is the key to overcoming the difficulties and promoting the high-quality development of the economy. Therefore, this study first investigated the literature and theories in the fields of the digital economy and industry-university-research technological chains (IURC), then proposed a multi-dimensional indicator system to measure the current collaborative innovation situation in IURC under the perspective of the digital economy, and finally, studied the performance enhancement paths of the industry-university-research collaborative innovation (IURI) through the fuzzy set qualitative comparative analysis (fsQCA) method.

## Keywords

Digital Economy, Industry-University-Research Technology Chains,

## 1. Introduction

With the rapid development of information technology, the world is accelerating into the era of the digital economy. Bertani et al. (2021) argue that the digital economy, with the help of big data, cloud computing, block chain, and other technologies, breaks the original geographic limitations and fundamentally changes the traditional mode of economic development and industrial pattern. Nowadays, digital technologies are increasingly penetrating all aspects of economic and social life. New technologies, new business forms, and new models are emerging in the digital economy environment. In 2020, the added value of China's core industries in the digital economy reached 7.8% of GDP. The digital economy provides a powerful impetus for sustained and healthy economic and social development. Wu & Li (2022) point out that the digital economy has become an important force in accelerating the economic transformation and upgrading of national and regional economies to enhance future competitive advantages. In early 2005, China issued a document related to the development of the digital economy. Emphasizing the need to integrate the digital economy with enterprises. In the past 15 years, many documents have been issued to support the development of the digital economy. On December 12, 2021, the State Council issued a notice on the "14<sup>th</sup> Five-Year Plan" for the development of the digital economy. The document emphasized that the digital economy is turning to a new stage of deepening application, standardized development, and universal sharing. The new era plays the role of data elements to accelerate the digitization of industry, the need for the integration of the digital economy, and modern life development. Yuan (2022), Wang and Zhu (2019) proposed that relying on IURI is an important strategic way for the world's mainstream developed countries to optimize the allocation of scientific and technological resources and improve the competitiveness of innovation. It is also an important way and breakthrough for the reform and development of the country's education, science, and technology. At present, China has carried out a lot of practice in IURI and achieved certain success. However, at this stage, China's IURI highlights the problems of insufficient cooperation depth and short-term behavior. It is difficult to solve the "neck" technical problems, and most of the collaboration between industry, university, and research stays on solving short-term, specific technical problems (Guo, 2014). The 20<sup>th</sup> report pointed out that it is necessary to strengthen the deep integration of enterprise-led IUR. Strengthen the status of enterprises as the main body of scientific and technological innovation, creating a favorable environment conducive to the growth of science and technology-based small and medium-sized micro-enterprises. To promote the deep integration of the innovation chain the capital chain and the talent chain.

This paper mainly studies the current situation of the collaborative innovation system of IURC under the perspective of the digital economy and the path to improving the collaborative innovation performance of IURC. The current situation and realistic dilemma of collaborative innovation of the digital economy and IURC in China are sorted out. The index system of collaborative innovation of the IURC under the perspective of the digital economy is constructed. The empirical analysis method is used to validate it and to explore the paths and countermeasure suggestions to improve the performance of IURI in the digital economy.

## 2. Literature Review

### 2.1. Digital Economy

Ge et al. (2022) believed that with the rapid development of digital technology, the digital economy has become more diverse in form and rich in connotation. It is a very difficult thing to define the digital economy only from one or several aspects. Nowadays, most scholars agree on the concept that the digital economy is an economic activity formed based on the Internet and related information and communication technology (ICT), focusing on the use of the Internet (Li, 2017). Shi (2022) summarizes the digital economy as an emerging economic form based on the three elements of big data, intelligent algorithms, and computing power platforms. It is based on the computing power platform and uses intelligent algorithms to store, process, analyze, and discover knowledge about big data. It ultimately serves the optimal allocation of resources and transformation and upgrading of various industries and promotes the high-quality development of the economy. Without big data, the digital economy is “cooking without rice”. Ge et al. (2022) suggest that data is a key element in the development of the digital economy. Big data has formally changed from an asset to a means of production, reshaping the organizational and operational modes of production, exchange, and consumption, as well as the entire economic and social order and governance system. He and Cheng (2021) concluded that there is a high degree of fit between the digital economy and the high-quality development of the economy and that the digital economy can promote the high-quality development of the economy. Guo et al. (2022) also argued that digital technology applications could promote the development of the digital economy and, thus, regional high-quality development. Jiang and Sun (2020) also believed that the digital economy has a significant role in realizing the real economy’s power to turn, which can bring new kinetic energy for the high-quality development of a solid economy. And the digital economy can reduce the urban-rural income gap through technological development (Wang, 2024). Cai and Ma (2021) argued that the digital economy can create multiplied value, but it may bring negative impacts on economic development due to issues such as privacy leakage.

## 2.2. Collaborative Innovation between Industry, Academia and Research

As early as 1985, China initiated research work on the organizational forms, development paths, strategic directions, and other relevant aspects of IUR. [Veronica & Fischer \(2007\)](#) believed that IURI is the process of systematic optimization and cooperative innovation of the elements of each innovation subject. [Chen and Yang \(2012\)](#) proposed that collaborative innovation is based on co-creation, a complex way of organizing innovation. Its essence is the innovation organization mode of large-span integration carried out by multiple subjects in order to achieve major scientific and technological innovation, with dynamic and holistic characteristics. The key to the effective execution of IURC lies in the construction of the collaborative innovation platform, which can be macroscopically laid out in the context of the digital economy through the establishment of the digital platform. [Zhou et al. \(2013\)](#) believed that the power formation process of IURI is the process of continuous cultivation and enhancement of the core competence of each subject of IUR and ultimately complementary integration to improve the overall collaborative innovation capability and establish the competitive advantage of the alliance. [Li \(2023\)](#) proposed that the deep integration of IUR is conducive to the accumulation of enterprise intellectual capital. The core competence of enterprises is embodied in the insight and demand of the market. However, the core competitiveness of universities and research institutions is strong technical support. [Li et al. \(2022\)](#) pointed out that enterprises are both the landing point of the development of the digital economy and the main body of China's innovation-driven development strategy. Under the influence of the digital economy and the epidemic, the establishment of a good digital environment and platform can allow industry, academia, and research to break the geographical limitations to create a good atmosphere. It can not only help enterprises overcome the difficulties in core technology but also make the scientific research results come out smoothly. [Chen et al. \(2020\)](#) proved through research that both formal and informal systems have a positive impact on IURI. [Yuan \(2022\)](#) empirical study proved that digitalization can promote the improvement of regional IURI, and is affected by regional intellectual property rights protection and the absorptive capacity of enterprises.

## 2.3. The Summary

Through the combing of the above literature, it can be found that the digital economy can not simply be defined from a connotation, but contains many angles and levels, focusing on information technology, information platforms, and the use of knowledge. In general, the digital economy is the sharing of knowledge and technology using the construction of digital platforms. Various social subjects can acquire knowledge through the platform, and then utilize and innovate the knowledge to create new value. The digital economy has long penetrated all industries, but enterprises, universities, and research institutions have

encountered more or less obstacles. If the three main bodies combine, complement each other's strengths, and build a good digital ecosystem, it is worth pondering whether the three synergistic innovations can achieve better results. With the development of the digital economy and the impact of the epidemic, traditional IUR cooperation is no longer suitable for the current environment. Simple collaborative innovation lacks internal logic and chain cooperation, while the establishment of an IURC will make IURI more logical. Nowadays, it is worth studying whether the collaborative innovation of the IURC can burst into greater vitality if it is combined with the digital economy.

### **3. Evaluation Research on Collaborative Innovation System of IURC under the Perspective of the Digital Economy**

It can be seen from the combing of basic theories that collaborative innovation is a complex dynamic process involving the enthusiasm and creativity of the participating subjects. It also involves cross-organizational, cross-disciplinary, cross-industry, cross-sectoral collaboration, knowledge fusion and diffusion, etc. In the cooperation, we should not only consider the profitability of the subject "enterprise", but also consider how to establish the competitive advantage of the cooperation of the three subjects in the digital economy.

#### **3.1. Design of Evaluation Indexes for Collaborative Innovation of IURC under the Perspective of the Digital Economy**

##### **3.1.1. Indicator Design Ideas**

The IURC is mainly composed of three main bodies, namely, universities, scientific research institutions, enterprises, and the government also influences the construction of the IURC. Colleges and universities are the main knowledge supporters and vital forces of the cooperation of the IURC, and various types of enterprises are related to whether the results of innovation can take root. IURI is inevitably affected by the development of the digital economy.

From the existing literature, [Xue et al. \(2022\)](#) combed the research hotspots and development vein of IURI research. It is believed that the guiding role of government agencies will be strengthened, the support capacity of knowledge innovation will be improved, and the ecological environment of collaborative innovation will be more optimized. [Yuan \(2022\)](#) empirically found that the current deepening digitalization process has deepened the integration between industry, academia, and research and enhanced the value-added knowledge in the innovation system. [Zhang et al. \(2022\)](#) argued that IURI is a process that involves the interaction of three core innovation subsystems, namely, enterprises, universities, and research institutions.

The ultimate goal of this study is to improve the collaborative innovation system of IUR. To promote high-quality development and improve the matching of technology demand. According to the current situation, literature combing and the research objectives of this paper, the first-level indicators are determined as

four dimensions: the degree of digitization, the degree of participation of the main body of collaborative innovation, the operation mechanism of the digital ecosystem, and the degree of collaborative innovation between industry, university, and research (Fan & Wu, 2020).

### 3.1.2. Evaluation Index System Construction

Determining the number of levels of evaluation indicators is the first task in designing the indicator system of IURC from the perspective of the digital economy. By the general method of indicator system design, and based on the theory of systematic evaluation. The overall goal of collaborative innovation is hierarchically decomposed, and a three-tier “pyramid” structure of the indicator system is constructed. The first-level indicators are the four dimensions of the degree of digitization, the degree of participation of the main body of collaborative innovation, the operation mechanism of the digital ecosystem, and the degree of collaborative innovation between industry, university, and research, while the second-level indicators (guideline level) and the third-level indicators (implementation level) are formulated according to the existing literature and the actual situation, as shown in **Table 1**.

**Table 1.** Evaluation indexes of collaborative innovation of industry-university-research technology chain under the perspective of digital economy.

Degree of digitization (Xue et al., 2022)	Digitization of government	Construction of a basic digital platform for the Government Data sharing on digital platforms Digital Intelligent Service Platform Construction
	Digitization of enterprise production	Enterprise ERP Enterprise MES/DSC Enterprise SCM Enterprise equipment numerical control Enterprise Informatization Service Platform
	Smart Campus Construction in Higher Education (Li & Wang, 2020)	Smart Learning Environment Smart Learning Resources Digital Talent Development in Higher Education Higher Education Informatization Guarantee Mechanism
	Digitization of scientific institutions	Infrastructure development Relevant Talent Introduction Willingness to develop digitally
Degree of participation of subjects involved in collaborative innovation (Zhang, Fan, & Li, 2022)	Business inputs and outputs	Enterprise R&D full-time equivalent Internal expenditures on corporate R&D expenditures Status of corporate R&D programs Corporate operating profit
	Higher education inputs and outputs	Full-time equivalent of R&D personnel in higher education Internal Expenditures on R&D Funding for Higher Education Institutions Publishing scientific and technical papers in higher education Number of patent applications in higher education

## Continued

	Inputs and outputs of scientific research institutions	<p>Full-time equivalent of R&amp;D personnel in research and development organizations</p> <p>Internal expenditures on R&amp;D funding for research and development organizations</p> <p>Publication of scientific and technical papers by research and development organizations</p> <p>Patents for inventions by research and development organizations</p>
Mechanisms for the functioning of digital ecosystems	Internal operating mechanisms (Chu & Li, 2022)	<p>Symmetrical and reciprocal symbiosis between enterprises as well as universities and research institutes</p> <p>Asymmetric reciprocal symbiosis between enterprises as well as university research institutes</p> <p>Parasitic model of enterprises as well as universities and research institutes</p> <p>The enterprises as well as the universities and research institutes are biased in favor of symbiosis</p> <p>Competitive models for companies as well as universities and research institutes</p>
	External operating mechanisms (Liu & Zou, 2020)	<p>web-based trust mechanism</p> <p>Network sharing mechanisms</p> <p>Multi-party synergistic mechanisms</p>
Industry-university-research collaborative innovation performance (Yuan, 2022)	Knowledge transfer and sharing	<p>Internal expenditure on R&amp;D in higher education from enterprises</p> <p>Internal expenditures on R&amp;D funding for research institutions from enterprises</p> <p>Total amount of technology transfer contracts signed between universities and enterprises</p>
	Scientific and technical outputs	<p>Number of scientific and technical papers by authors from different units in the same province</p> <p>Full-time equivalents of R&amp;D personnel in universities and research institutes</p> <p>Internal Expenditures on R&amp;D Funds for Universities and Research Institutions</p> <p>Number of patent applications for inventions in universities and research institutions</p> <p>Number of scientific and technical papers published by universities and research institutions</p>
	Transformation of scientific and technological achievements	<p>Number of enterprise invention patents</p> <p>Number of enterprise new product development projects</p> <p>Revenue from sales of enterprise-based products</p> <p>Number of contracts closed in the technology market</p>

### 3.2. IURC Collaborative Innovation Evaluation Index System Empirical Analysis

#### 3.2.1. Descriptive Statistical Analysis

A total of 218 questionnaires were collected through Wenjuanxing (WJX) formal research. Eliminating the questionnaires with short answer time and answers showing obvious regularity, a total of 199 valid questionnaires were obtained,

with an effective rate of 91%. According to the analysis results, it can be seen that the numerical characteristics of the statistical variables reflect the distribution of the respondents in this survey. According to **Table 2**, the percentage of respondents by occupation, type of business and type of institution can be found. The study mean and standard deviation can also be seen.

**Table 2.** Variable frequency analysis.

Frequency analysis of variables					
variant	options (as in computer software settings)	Frequency (persons)	percentage	average value	(statistics) standard deviation
careers	worker in the business community	57	26.15%	3.12	1.448
	Higher Education Teachers	5	2.29%		
	Currently enrolled in a specialist program	36	16.51%		
	Undergraduate and above	88	40.37%		
Type of business	scientific researcher	31	14.22%	3.56	1.445
	Wholly state-owned enterprises	2	3.51%		
	limited liability company	16	28.07%		
	corporation	18	31.58%		
	Sino-foreign joint venture	9	15.79%		
	Wholly Owned Enterprise (WOE)	3	5.26%		
Type of institution	Locally Affiliated Colleges and Universities	71	58.91%	1.52	0.661
	Colleges and universities directly under the Ministry of Education	43	33.33%		
	Colleges and universities under the central ministries and commissions	10	7.75%		

### 3.2.2. Reliability Test

Cronbach's alpha coefficient is an important reference index to determine the reliability of the scale, when the coefficient is greater than 0.7. It indicates that the reliability of the scale is credible and further data analysis can be conducted. As shown in **Table 3**, each value of Cronbach's for the efficient system of collaborative innovation of IURC (X1 X2 X3 X4 X5 X7 X8 X9), and the performance of collaborative innovation of IURC (Y1 Y2) in the digital economy is higher than 0.7. It shows that the scale used in this study has a high degree of reliability and the data quality is reliable.

### 3.2.3. Validity Analysis

When the validity of the data is tested using factor analysis, the KMO value and Bartlett's Spherical Test value are first tested. In this case, when the KMO value is greater than 0.6 and at the same time the Bartlett's Spherical Test value is less

than 0.05 the conditions for doing factor analysis are met. After testing, it is known that the KMO value of this study is 0.938 and the Bartlett value is less than 0.01. **Table 4** shows that the questionnaire satisfies the prerequisites for factor analysis.

**Table 3.** Scale reliability analysis.

variant	variant	subject	Cronbach's	reference point	in the end
	Efficient System of Collaborative Innovation of IURC in Digital Economy	36	0.738	0.7	credible
X1	Digitization of government	3	0.788	0.7	credible
X2	Enterprise Digitization	6	0.932	0.7	talented
X3	Digitization of higher education	4	0.882	0.7	favorable
X4	Digitization of scientific institutions	3	0.743	0.7	credible
X5	Business inputs and outputs	4	0.860	0.7	favorable
X6	Higher education inputs and outputs	4	0.731	0.7	credible
X7	Inputs and outputs of scientific research institutions	4	0.868	0.7	favorable
X8	Internal operating mechanisms	5	0.870	0.7	favorable
X9	External operating mechanisms	3	0.834	0.7	favorable
	Collaborative Innovation Performance of IURC	9	0.768	0.7	credible
Y1	Scientific and technical outputs	5	0.998	0.7	talented
Y2	Transformation of scientific and technological achievements	4	0.873	0.7	favorable

**Table 4.** Scale KMO analysis.

KMO and Bartlett's test		
	KMO Sample Suitability Quantity	0.938
	approximate chi-square (math.)	26,172.183
Bartlett's test of sphericity	(number of) degrees of freedom (physics)	1081
	significance	0.000

### 3.2.4. Correlation Analysis

**Table 5** shows the correlation between the variables. It can be seen that the positive correlation between the degree of digitization and the collaborative innovation performance of IURC ( $\beta = 0.288$ ,  $p < 0.01$ ). Positive correlation between the operation mechanism of the digital ecosystem and the performance of IURI ( $\beta = 0.173$ ,  $p < 0.05$ ). Positive correlation between the participation degree of the main body of the collaborative innovation and the collaborative innovation performance of IURC ( $\beta = 0.474$ ,  $p < 0.01$ )

**Table 5.** Scale correlation analysis.

	Q1	Q2	Q3	Q4	Q5	Degree of digitization	Degree of participation of the main body of collaborative innovation	Mechanisms for the functioning of digital ecosystems	Collaborative Innovation Performance of IURC
Q1									
Q2	-0.807**								
Q3	-0.821**	0.982**							
Q4	0.432**	-0.727**	-0.740**						
Q5	0.455**	-0.755**	-0.769**	0.932**					
Degree of digitization	-0.577**	0.587**	0.608**	-0.321**	-0.368**				
Degree of participation of the main body of collaborative innovation	-0.025	-0.260**	-0.254**	0.552**	0.539**	0.403**			
Mechanisms for the functioning of digital ecosystems	-0.103	0.061	0.067	-0.055	-0.100	0.695**	0.568**		
Collaborative Innovation Performance of IURC	-0.407**	0.611**	0.625**	-0.859**	-0.901**	0.288**	0.474**	0.173*	

\*\*The correlation is significant at the 0.01 level (two-tailed). \*At the 0.05 level (two-tailed), the correlation is significant.

### 3.2.5. Status Analysis

The questionnaire was measured using a five-point Likert scale with 1 - 5 indicating very dissatisfied, dissatisfied, neutral, satisfied, and very satisfied, respectively.

**Table 6** shows the degree of digitization of each subject. The mean value of the degree of digitization of colleges and universities is lower than the mean value of digitization of all subjects, which indicates that the degree of digitization development of colleges and universities is relatively slow. At the same time, the mean value of the degree of digitization of government digitization, enterprise digitization, and research institutions digitization are all around 3.5. Among them, the questionnaire shows that enterprises have the best degree of digitization. But overall, the subjects are not satisfied with the degree of digitalization and the current situation, none of the dimensions has a mean value of more than 4 (satisfied). The development of digitalization needs to be further improved.

**Table 6.** Descriptive Statistical Analysis

	N	minimum value	maximum values	average value
Status of digitization in government	199	1	5	3.53
The current state of digitization in the enterprise	50	1	5	3.59
The state of digitization in higher education	109	1	5	3.21
The current state of digitization in research institutions	31	1	5	3.52

In summary, the analysis of the questionnaire reveals that the digitization level of each participating subject needs to be further improved. The cooperation between each subject needs to be deeper and more effective. The integration and development of the IURC is still in the primary stage. The next research on how to promote the collaborative development of the IURC under digitization and improve the performance of collaborative innovation is particularly important. It lays the foundation for further research below.

#### **4. fsQCA High IURC Collaborative Innovation Performance Path Combination Analysis**

##### **4.1. Path Combination Analysis of Collaborative Innovation Performance of High IURC**

Qualitative Comparative Analysis (QCA) is a method that began to emerge in the 1980s. It focuses on the complex causal relationship between conditions and outcomes. Since the causes of social phenomena are often interdependent rather than independent. Explaining the causes of social phenomena cannot be limited to focusing on the effects of individual conditions on the outcomes. The QCA approach to analyzing outcomes using histograms combines the strengths of both qualitative and quantitative analyses.

According to the empirical research, it is known that the evaluation index of collaborative innovation of IURC is feasible. But what kind of situation will promote the performance of collaborative innovation of IURC needs to be further explored, and whether its performance is affected by multiple paths? On the basis of the previous study, this chapter adopts the fsQCA method to further explore the formation path of collaborative innovation performance of the IURC. Not only can we find the cause paths that trigger the same outcome variables, but also explore the complementarity and substitutability between different paths. It is conducive to further deepening the understanding of collaborative innovation in the IURC. This paper uses fsQCA3.0 software to analyze this.

## 4.2. IURC Collaborative Innovation Performance fsQCA Research Steps

Step 1: Data calibration. fsQCA needs to determine the full affiliation point, crossover point and full unaffiliated point, and calibrate each antecedent condition, and result into a fuzzy set of 0 - 1. According to Pappas and Woodside's study, this paper sets the criteria of fully unaffiliated point, intersection point, and fully unaffiliated point to 0.05, 0.5, and 0.95, respectively. The calibration was performed using the direct calibration method and the calibration results are shown in **Table 7**.

**Table 7.** Data calibration.

variant	variant	Full affiliation	average value	Totally unaffiliated
X1	Digitization of government	4.67	3.67	1.67
X2	Enterprise Digitization	3.83	0	0
X3	Digitization of higher education	4.50	3.50	0
X4	Digitization of scientific institutions	2.58	0	0
X5	Business inputs and outputs	3.50	0	0
X6	Higher education inputs and outputs	4.00	3	0
X7	Inputs and outputs of scientific research institutions	1.80	0.75	0
X8	Internal operating mechanisms	4.40	3.40	1.60
X9	External operating mechanisms	4.66	3.66	1.66
Y1	Scientific and technical outputs	3.40	0	0
Y2	Transformation of scientific and technological achievements	3.89	0	0

Step 2: Necessity Condition Analysis (**Table 8**). The necessity condition is to determine whether the existence or non-existence of a single condition is necessary for the outcome variable. The results show that there are X2 X4 X5 higher than 0.9. Indicating that these three conditions are necessary to achieve high collaborative innovation performance in the IURC.

Step 3: Sufficiency analysis of conditional path. The measure of the adequacy of the path is also analyzed according to the consistency of the different conditions, with the consistency threshold set at 0.75 and the case threshold set at 1. First, the high IURC co-innovation performance (scientific and technological transformation and scientific and technological output) is analyzed as an outcome variable for adequacy analysis, which can derive the path of the managerial practices constituting the high IURC co-innovation performance. Then also analyzed as an outcome variable for path, to further explore which IURC collaborative practice deficiencies negatively affect organizational resilience, and to make this study more comprehensive. Conditional variable occurrences are de-

noted by  $\bullet$  and  $\bullet$ , where  $\bullet$  denotes the core condition,  $\bullet$  denotes the edge condition,  $\otimes$  denotes the absence of the core causal variable, and  $\otimes$  denotes the absence of the edge causal variable. A blank indicates that the conditioning variable had a negligible effect on the outcome.

**Table 8.** Analysis of necessary conditions.

conditional variable	outcome variable	
	Collaborative Innovation Performance of IURC	
	consistency	site coverage
NX1	0.777825	0.807738
~NX1	0.742447	0.825325
NX2	0.933135	0.913211
~NX2	0.840729	1.000000
NX3	0.706299	0.749092
~NX3	0.739766	0.804378
NX4	0.981710	0.996998
~NX4	0.877881	1.000000
NX5	0.933135	0.910926
~NX5	0.838167	1.000000
NX6	0.720490	0.779309
~NX6	0.772228	0.866429
NX7	0.792223	0.843862
~NX7	0.798304	0.808913
NX8	0.795869	0.742354
~NX8	0.632231	0.799827
NX9	0.777761	0.793983
~NX9	0.703100	0.796282

### 4.3. Analysis of the Output Paths of Scientific and Technological Achievements in the Collaborative Innovation Performance of High IURC

After the counterfactual analysis to obtain the intermediate solution, it is concluded that eight groupings produce the output of scientific and technological achievements of high IURC collaborative innovation performance. As can be seen in **Table 9**, the coverage of high IURC collaborative innovation performance scientific and technological achievements output is 0.967430, respectively, which is more than half of the overall sample. The consistency index of the solution presented in the table is 0.854817, which means that the different combinations of IURI in the 8 groupings can be used as sufficient conditions to

**Table 9.** Conditional configuration analysis Y1.

	Collaborative innovation performance of IURC (scientific and technological output Y1)							
	H1a	H1b	H1c	H1d	H2	H3	H4a	H4b
X1	●	●	●	●		⊗	⊗	●
X2	●	●	●	●	●	●	●	●
X3	⊗	⊗			●	⊗	●	●
X4	●	●	●	●	●	●	●	●
X5	●	●	●	●	●	●	●	●
X6	⊗	●	⊗	⊗		⊗	●	●
X7			●		●	●		⊗
X8		⊗	●	⊗		⊗	⊗	⊗
X9	⊗			●	⊗		●	⊗
original coverage	0.436493	0.363551	0.460630	0.351656	0.437134	0.368656	0.376688	0.477551
Unique coverage	0.021955	0.001587	0.005994	0.004267	0.001823	0.017660	0.003558	0.032542
Overall consistency		0.854817						
Overall coverage		0.967430						

explain the output of the scientific and technological achievements of the IURC. The comprehensive analysis of the eight paths shows the output of scientific and technological achievements of IURC collaborative innovation performance under the complex effect of nine conditions. It can be summarized into four realization configurations, namely, configuration 1 (H1a, H1b, H1c, H1d), configuration 2 (H2), configuration 3 (H3), and configuration 4 (H4a, H4b). The mechanisms of the four different groupings leading to the output of scientific and technological achievements of high IURC collaborative innovation performance are detailed below.

- Configuration 1 (H1a, H1b, H1c, H1d). The unique coverage of H1a is 0.021955, the unique coverage of H1b is 0.001587, and the unique coverage of H1d is 0.004267. Only government digitization plays a central role in these three paths. Government digitization and the internal operation mechanism play a central role in the path of H1c. Not only do these four paths have simultaneous core conditions, but also enterprise digitization, digitization of research institutions, and enterprise inputs and outputs. Although they are non-core conditions, are also present in H1a, H1b, H1c, and H1d at the same time. This means that regardless of the existence of other factors. The existence of government digitization as a core condition. The simultaneous existence of the three non-core conditions of enterprise digitization, research institution digitization, and enterprise input and output can effectively enhance

the output of scientific and technological achievements.

- Configuration 2 (H2). The unique coverage of H2 is 0.001823. In this configuration, digitization of universities as a core condition. And the existence of digitization of enterprises, digitization of research institutes, inputs and outputs of enterprises, and inputs and outputs of research institutes as a non-core condition can also be effective in enhancing the outputs of scientific and technological achievements.
- Configuration 3 (H3). The unique coverage of H3 is 0.017660. In this configuration, research institution inputs and outputs are the core conditions present. The enterprise digitization, research institution digitization, and enterprise inputs and outputs are present as non-core conditions, which also enhance the output of scientific and technological achievements.
- Configuration 4 (H4a, H4b). The unique coverage of H4a is 0.003558, and the unique coverage of H4b is 0.032542. In H4a and H4b university inputs and outputs are present at the same time as the core conditions. There is also an external operation mechanism as the core condition in H4a. In addition to this. There are enterprise digitization, university digitization, research institution digitization, and enterprise input and output as non-core conditions exist at the same time, configuration 4 can also improve the efficiency of scientific and technological output, but it is more demanding for multi-party cooperation.

As a result, four effective paths of collaborative innovation performance of the IURC to improve the output of scientific and technological achievements can be summarized:

- Path 1: Regardless of the existence of other factors, government digitization exists as a core condition. The simultaneous existence of three non-core conditions, namely enterprise digitization, research institution digitization, and enterprise input and output. These can effectively enhance the output of scientific and technological achievements of industry-university-research collaborative innovation. (H1a, H1b, H1c, H1d of configuration 1).
- Path 2: Missing the premise that the external operation mechanism is carried out effectively. The digitization of universities as a core condition can also effectively enhance the output of scientific and technological achievements. (H2 of Configuration 2).
- Path 3: Inputs and outputs of research institutions as a core condition, digitization of enterprises, digitization of research institutions, and inputs and outputs of enterprises exist as non-core conditions. Digitization of universities, a condition that does not exist, can also enhance the outputs of scientific and technological achievements. (H3 of configuration 3).
- Path 4: In order to improve the efficiency of scientific and technological output. University input and output as a core condition. There are enterprise digitization, university digitization, research institution digitization and enterprise input and output as a non-core condition. (H4a, H4b of configuration 4).

#### 4.4. Analysis of the Paths of Scientific and Technological Achievements Transformation of High IURC Collaborative Innovation Performance

The analysis is done in the same way as coming up to obtain the intermediate solution. It can be concluded that there are eight paths that generate high IURC innovation performance of scientific and technological achievements transformation. As can be seen in **Table 10**, the coverage of the high IURC collaborative innovation performance of scientific and technological achievements transformation is 0.985381, which is more than half of the overall sample. And the consistency index of the solution presented in the table is 0.773702. Which means that the different combinations of IURI in the 8 paths can be used as sufficient conditions to explain the transformation of scientific and technological achievements of the IURC. Comprehensive analysis of the eight groupings to see, the complex role of the nine conditions. The IURC collaborative innovation performance of scientific and technological achievements of the transformation the more complex. It is more difficult to unify the generalization, which can be summarized as seven kinds of realization of the path. The mechanisms of the seven different paths leading to the transformation of scientific and technological achievements of high IURC collaborative innovation performance are detailed below.

**Table 10.** Conditional configuration analysis Y2.

Collaborative Innovation Performance of High IURC (Transformation of Scientific and Technological Achievements Y2)								
	L1a	L1b	L2	L3	L4	L5	L6	L7
X1	●	●		⊗	⊗	●		⊗
X2	●	●	●	●	●	●	●	●
X3	⊗	⊗	●	⊗	●	●	⊗	●
X4	●	●	●	●	●	●	●	●
X5	●	●	●	●	●	●	●	●
X6	⊗	●	●	⊗	●	⊗	●	⊗
X7		●	●	●		●	●	⊗
X8			⊗		⊗		●	⊗
X9	⊗			●	●	●	●	⊗
original coverage	0.430446	0.387328	0.430719	0.344332	0.367812	0.382439	0.352143	0.340479
Unique coverage	0.011704	0.000627	0.005101	0.007155	0.005901	0.012103	0.001225	0.002710
Overall consistency		0.773702						
Overall coverage		0.985381						

- Path 1 (L1a, L1b). The unique coverage of L1a is 0.011704, and the unique coverage of L1b is 0.000627. Only government digitization plays a central role in these two paths. And the non-core conditions of enterprise digitization, research institution digitization and enterprise input and output also exist in both L1a and L1b. But L1a can improve the transformation of scientific and technological achievements in the absence of university input and output and external operation mechanism. This means that government digitization as a core condition exists, and the simultaneous existence of enterprise digitization, research institution digitization, and enterprise input and output three non-core conditions. It can effectively improve the transformation of scientific and technological achievements. Combined with the above analysis, it can be seen that under the leadership of the government as the core condition, the efficiency of scientific and technological achievements output and transformation can be improved.
- Path 2 (L2). The unique coverage of L2 is 0.005101. In this path, the digitization of universities is the core condition. And the digitization of enterprises, the digitization of research institutes, the inputs and outputs of enterprises, the inputs and outputs of universities. And the inputs and outputs of research institutes exist as a non-core condition, which can also effectively enhance the transformation of scientific and technological achievements.
- Path 3 (L3). The unique coverage of L3 is 0.007155. In this path, digitization of research institutions exists as a core condition. And digitization of firms, firms' inputs and outputs, research institutions' inputs and outputs, and external operational mechanisms exist as non-core conditions, which also enhance the transformation of scientific and technological achievements.
- Path 4 (L4). The unique coverage of L4 is 0.005901. In this path, university inputs and outputs as the core conditions. Enterprise digitization, university digitization, research institution digitization, enterprise inputs and outputs, and external operation mechanisms as the non-core conditions appear. Which can improve the efficiency of scientific and technological achievements transformation.
- Path 5 (L5). The unique coverage of L5 is 0.012103. The input and output of scientific research institutions as the core conditions. The internal operation mechanism is ignored, the input and output of universities do not appear. And all other conditions appear as non-core conditions that can enhance the transformation of scientific and technological achievements of the IURC collaborative innovation technology chain.
- Path 6 (L6). The input and output of scientific research institutions and internal operation mechanism as the core conditions. In the absence of this condition of digitization in universities, the other conditions appear as non-core conditions. The role of government digitization is negligible is also a way to improve the transformation of scientific and technological achievements.
- Path 7 (L7). The digitalization of colleges and universities is the core condi-

tion of smooth cooperation with enterprise digitalization. The digitalization of research institutions and enterprise input and output, to a certain extent. It can also improve the transformation of scientific and technological achievements in the collaborative innovation of the IURC. As a result, we can summarize the seven effective paths to improve the transformation of scientific and technological achievements in the collaborative innovation performance of the IURC. Compared with the path of scientific and technological achievements output, the path of scientific and technological achievements transformation is relatively more complicated and more demanding for each subject.

## 5. Conclusion

There are various operation modes and realization paths of IURI, and promoting the deep integration of IUR is the key to overcoming the difficulties and promoting the high-quality development of the economy. This paper studies the design of evaluation indexes of IURC collaborative innovation system under the perspective of the digital economy according to the strategic planning of digital economy development. The article completes the indicator system setting and scale reliability and validity measurement, which provides a foundation for the analysis of the performance path of collaborative innovation of the IURI. On this basis, it completes the exploration of the path to improve the performance of collaborative innovation of the IURI.

Secondly, the conceptual dimensions of the digital economy, IURC, and IURI are also sorted out. The digital economy from the connotation and extension of the perspective to develop, providing a new dimension of interpretation. The digital economy can not be defined simply from a connotation, including the digital economy itself and the three elements of the digital economy, including its extension. Analyzing the IURC, it is an upward process of input-use-renewal-development-reinvestment. The process of upgrading. The synergistic nature of IURC refers to the technological links that support the operation and development of the core industry chain. The core industry chain and the core technology chain develop synergistically to realize the upgrading and development of industry and technology.

In addition, the questionnaire survey shows that the degree of digitization and cooperation of the collaborative innovation subjects in the IURC under the perspective of the digital economy is still insufficient. There is also the problem that the technical investment cannot reach the expected effect, the digitalization transformation is slow, and the a lack of talent. Then, for the government, it is necessary to continuously optimize the function of the government service platform to establish a digital platform for information sharing. The government should comprehensively improve the level of public service digitization and intelligence, and provide a basic platform for the collaborative innovation of the IURC. From the perspective of the three main bodies of industry, academia and

research. An information-sharing platform among the three needs to be established to reduce communication costs. The knowledge resources of universities and research organizations should flow into enterprises and provide support for them. The transformed results of the enterprise should feed back to the universities and scientific research institutions to achieve a win-win situation.

## 6. Recommendation

1) Playing the role of enterprise as the main body of the IURC collaborative innovation.

As a result of the above path analysis, the digitalization of the firm and the inputs and outputs of the firm do not appear as core conditions. However, in each path “enterprise appears as a non-core condition. This indicates that the improvement of collaborative innovation performance of IURC cannot be separated from enterprises. The construction of an innovation system is the key to improving the innovation ability and innovation performance of enterprises, and it is also an important factor in promoting the high quality of the economy. First of all, enterprises should be prompted to become the main body of IURI, and they should play a main role in innovation decision-making, R&D investment, and scientific research organization. Efforts should be made to apply the results of technological innovation to enterprises in order to improve their innovation capacity and innovation performance, and they should not excessively pursue theoretical innovation and technological breakthroughs. Secondly, the government can guide enterprises to increase R&D investment, support enterprises to jointly build R&D institutions with universities and research institutes. And explore the way of multi-principal input, diversified formation, and entrepreneurial operation. Finally, an efficient and reasonable benefit distribution mechanism should be developed and improved. It can mobilize the cooperation enthusiasm of all parties in the institute and improve the degree of synergy among all parties in the Institute.

2) Playing a leading role in governmental collaborative innovation.

In the analysis of collaborative innovation performance paths in the IURC, government digitization appears as a core condition many times. Government digitization can promote the output and transformation efficiency of scientific and technological achievements to increase at the same time when it appears as the core condition. This shows that although the main body of the collaborative innovation of the technology chain under the digital economy is the three parties of the IUR institute, the behavior of the government plays the role of “wind vane”. Therefore, the government should give full play to its guiding role. It is necessary for the government to take the lead in establishing a more authoritative and comprehensive information service platform on the basis of the original platform by utilizing its own advantages. Give full play to the role of the government in the IURI, and improve the digital economy industry innovation incentive policies. Construct a cooperation and sharing mechanism for the digital

economy industry, and promote the integrated development of the digital economy industry and its related industries. By building a digital government, enterprises, universities, and research institutes can display their advantageous resources, latest achievements, and technical needs through the platform. This will reduce the cost of collaborative innovation in the IURC and improve the IURI.

3) Utilizing the advantages of the digital economy to create a collaborative innovation system for the digital economy.

Digitalization is indispensable for the realization of the collaborative innovation performance path of the industry-university-research technology chain. The digital economy plays an increasingly important role in social development and promotes profound change in industrial structure and enterprise organization. A good digital economy innovation ecosystem is an important support for the smooth operation of enterprise-oriented IURI. With the support of the digital economy, the efficient allocation of resources and the rapid flow of elements should be realized through the mutual exchange of innovative material flow, information flow, and energy flow by the main body. In turn, a mutually coupled dynamic equilibrium system of sharing innovation resources, complementing each other's advantages and sharing risks will be formed. The government can strengthen the construction of a digital economy industrial innovation ecosystem infrastructure. It can facilitate the construction of network infrastructure. It can also provide basic guarantee for the development of IURI system. It will form an environment that is favorable to the development of each innovative subject in the system.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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