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Extenics Analysis of Regional Innovation Coordination Ability

Yi Su [1,2*], Zhou-Zhou Lin [1]

[1] School of Economics and Management, Harbin Engineering University, P. R. CHINA
[2] School of Economics and Management, Tsinghua University, P. R. CHINA

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ABSTRACT

The study reviews Chinese and international regional innovation capacity and extenics theory, and applies extenics theory to construct a measurement model of regional innovation coordination. It empirically researches 31 Chinese provinces on the coordination of regional innovation in both 2007 and 2015. The research findings indicate that the Industry-University-Research status is not optimistic in China: on the one hand, the coordination abilities of most enterprises are relatively low; and on the other hand, compared with 2007, the proportion of areas with good coordination dropped 10% in 2015. It is thus clear that the effect of adjustments by relevant government departments relating to Industry-University-Research is poor and the coordination of innovation abilities in some provinces are falling rather than rising. Relevant decision-making authorities should take note of this and take more effective measures to promote the coordination of research cooperation and to enhance regional coordination.

Keywords: regional, innovation, coordination ability, extenics, correlation function

INTRODUCTION

The “Global Competitiveness Report 2016-2017” published by the World Economic Forum ranks China in 28th position, unchanged from the previous year. The Central Committee of the Communist Party of China, the State Council and entities at all government levels are focused on innovation in Chinese enterprises. The nonprofit social group, China Industry-University Research Institute Collaboration Association, was established in November 2007 to enhance independent innovation capabilities and to promote the commercialization, industrialization and internationalisation of innovative products. This Association built a national innovation base of 31 cooperating industrial parks, alliances and enterprises and initiated an Industry-University-Research collaborative innovation platform based on the Internet that strongly supports and facilitates local Industry-University-Research project activities. The China Industry-University Research Institute Collaboration Association plays an important role in promoting coordination across industry, third level and research. The year 2015 marked the 8-years anniversary of the “China Industry-University Research Institute Collaboration Association”, yet competitiveness is declining. Innovation is a key factor limiting the growth of overall competitiveness. The ancient Chinese philosopher Confucius emphasized “a good scholar can become an official” while a wealthy person cannot get a good position in society, moreover the ancient politician Buwei Lv abandoned business for politics.

This image has deeply influenced generations of Chinese people, with many people entering government positions and many research personnel joining research institutes and universities, impacting on the personnel structure of Chinese enterprises. This has resulted in an imbalance in regional innovative system that, coupled with poor regional coordination ability, has caused a decline of innovation capabilities in China. Regional coordination ability refers to industry, third level and research coordination within the region and the effective cooperation between regional innovation entities thereby enhancing overall competitiveness. Therefore, industry, third level and research coordination is crucial to resolving China’s low regional innovation coordination abilities.

✉ suyi@hrbeu.edu.cn **(*Correspondence)** ✉ 627609305@qq.com

Contribution of this paper to the literature

- This is the first time the extenics model has been applied to the study of regional innovation coordination capability and thus expands the area of extenics empirical research.
- Using the extenics theoretical analysis model, this paper set up a regional innovation coordination measurement model and researched regional innovation coordination ability levels. The results show that not enough provinces have good regional innovation coordination ability, and most enterprises have low abilities. Although relevant government departments have adjusted their policies on Industry-University-Research cooperation, they are not effective.
- This paper provided a theoretical basis for relevant government departments policy regulations as well as pointing the direction for further strengthening Industry-University-Research cooperation.

LITERATURE REVIEW

There are many studies on innovation capacity from both a macro (national innovation system) and micro (regional innovation systems) perspective. The era of the knowledge base fosters the national innovation system (Chung, 2002). Scholars have emphasized innovation entities, but have not sufficiently focused on building an effective national innovation system (Nelson, 1993; Patel and Pavitt, 1994; Samara, 2012). The national innovation system can be viewed from narrow and broad perspectives. The broad concept covers all direct or indirect subjects related to the innovation process and the narrow is those subjects that directly related to the creation of and the use of knowledge (Lundvall, 1988). In-depth studies of the national innovation system reveal that very considerable innovation benefits can be produced with good innovation investment conditions (Andersson and Mahroum, 2008), which attracted further attention (Archibugi and Coco, 2004; Archibugi, 2009; Mahroum, 2013). Furman (2007) carried out a detailed study on the national innovation system performance indicators and explored why different countries have different innovation capacities from an empirical analysis perspective. Some experts consider regionalization research to be most important and in the context of globalization, the country level is less important than the economy, research and development and innovation activities (Chung, 2002). There is an increasing emphasis on regional innovation research (Braczyk et al, 1996; Cooke, 1997, 2000, 2001; Doloreux, 2002; Hsueh & Su, 2016). From a regional economic development perspective, regional innovation is gradually highlighted (Gerstlberger, 2004). From a relatively macro perspective, the core regional innovation system consists of public, private, and public-private parts (Braczyk, 1998) and its main elements include innovative environment, third level institutes, public institutions and enterprises (Buesa, 2006). Theoretical and empirical research shows that the quality of third level academic research institutions, and the concentration, and the impact of foreign investment are the most important factors affecting regional innovation capability (Fritsch and Slavtchev, 2007; Haskel, 2007). Regional resources, behaviour subject ability, and the ability to interact between entities, and the research, education and technology transfer systems are the key factors causing differences in regional innovation (Todtling, 1998; Braczyk, 1998; Cook, 1998; Tsai, & Lei, 2016). The greater the differences among regions, the more attention should be paid to innovation system study (Buesa, 2006). Buesa (2010) used the knowledge production function for analysis, and pointed out that the national and regional environments, and the innovative companies, third level institutes, and research institutions have an important impact on regional innovation capacity.

The literature review revealed some studies on regional innovation capability, but none on regional innovation coordination capability. As outlined in the introduction, we identified regional innovation coordination capability as the key element in resolving China’s current low regional innovation capacity; hence, this paper uses extenics theories and methods, which will be introduced in the second part, to study the issues of regional innovation coordination. Current studies in extenics include: Wang (2009) combined extenics theory and genetic algorithm and proposed a so-called “extension genetic algorithm” clustering method; Ye (2009) applied extenics to gasoline engine misfire fault diagnosis; and Chao (2010) applied extenics theory to the maximum power tracking intelligent algorithm of solar radiation and ambient temperature. This paper uses extenics theory to measure the detailed situation of different regional innovation coordination capabilities in China from a quantitative analysis perspective.

BASIC KNOWLEDGE OF EXTENSION MODEL

Motifs are extension model logic cells that include matter, affair and relative elements (Chen, 2006). We can present a complex phenomenon by using its composite element or motif expression.

Matter-Element

The matter O_m is the object, c_m is the feature, O_m about c_m's value v_m forms an ordered triple element $M = (O_m, c_m, v_m)$ that is the basic element of description, and is called the one dimension element; $O_m, c_m, v_m$are three elements of matter-element M. Among them, c_m, v_m constitute two-tuples (c_m, v_m), called the feature element of matter O_m. Matter O_m have n features including $c_{m1}, c_{m2}, \cdots, c_{mn}$ and O_m about $c_{mi}(i = 1,2, \cdots, n)$'s value $v_{mi}(i = 1,2, \cdots, n)$ forming an array

$M = \begin{bmatrix} O_m & c_{m1} & v_{m1} \\ & c_{m2} & v_{m2} \\ & \vdots & \vdots \\ & c_{mn} & v_{mn} \end{bmatrix} = (O_m, C_m, V_m)$, is called the n-dimension matter-element, and, $C_m = \begin{bmatrix} c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn} \end{bmatrix}, V_m = \begin{bmatrix} v_{m1} \\ v_{m2} \\ \vdots \\ v_{mn} \end{bmatrix}$.

Affair-Element

The interaction between objects is called affair, described by the affair-element. The action O_a, action feature c_a and O_a about $c_{a1}, c_{a2}, \cdots c_{an}$'s value $v_{a1}, v_{a2}, \cdots v_{an}$ forming an array

$\begin{bmatrix} O_a & c_{a1} & v_{a1} \\ & c_{a2} & v_{a2} \\ & \vdots & \vdots \\ & c_{an} & v_{an} \end{bmatrix} = (O_a, C_a, V_a) \triangleq A$, is called the n-dimension affair-element.

Relative-Element

Any matter, affair, people, information, and knowledge are inextricably linked with other matter, affair, people, information, and knowledge. The relative element is the visualization tool to describe these relationship interactions. The relative 0_r, n feature value $c_{r1}, c_{r2}, \cdots c_{rn}$ and their value $v_{r1}, v_{r2}, \cdots v_{rn}$ constitute the dimension array

$$\begin{bmatrix} O_a & c_{r1} & v_{r1} \\ & c_{r2} & v_{r2} \\ & \vdots & \vdots \\ & c_{rn} & v_{rn} \end{bmatrix} = (O_r, C_r, V_r) \triangleq R.$$

Motifs and Class Motifs

For convenience, the matter-element, affair-element and relative-element are called motifs, denoted as

$$B = (O, C, V) = \begin{bmatrix} object & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix}.$$

Among them, $O(object)$ represents a certain object (matter, action, relative), $c_1, c_2, \cdots c_n$ indicate n features of object O, $v_1, v_2, \cdots v_n$ represent object O about the feature's relevant value.

REGIONAL INNOVATION COORDINATION CAPACITY MODEL CONSTRUCTION BASED ON EXTENICS

Extenics is the extraction of useful knowledge from large accumulations of data, and it is a knowledge discovery process known as a knowledge discovery database (KDD) (Yang, 2005; Yu, 2005; Chen, 2006; Cai, 2008).

Let $\underset{\cdot}{D}_+({}_{I_i}T_{D_i}) = \left\{D_i \middle| \mathrm{D}_i = (I_i, C_D, U_i), K(D_i) \le 0, K({}_{I_i}T_{D_i}D_i) > 0, i \in J_{\underset{\cdot}{D}_+}\right\}$, and D indicates the evaluation information element, $J_{\underset{\cdot}{D}_+}$ is in $\{D\}$ that satisfies $K(D_i) \le 0, K({}_{I_i}T_{D_i}D_i) > 0$, and it is an index set that indicates the evaluation information element D_i, take $\underset{\cdot}{E}_+(\varphi) = \left\{I_i \middle| I_i = (O_i, C, V_i), D_i \in \underset{\cdot}{D}_+({}_{I_i}T_{D_i}), i \in J_{\underset{\cdot}{D}_+}\right\}$,

$\underset{\cdot}{E}_+(\varphi)$'s index set, denoted as $J_{\underset{\cdot}{E}_+(\varphi)}$, then clearly, $J_{\underset{\cdot}{E}_+(\varphi)} = J_{\underset{\cdot}{D}_+}$. Let the initiative feature of $d_p(p = 1,2, \cdots, q)$'s all as $\{c_j'\}$ in $c_i(j = 1,2, \cdots, m)$, thus to $c_j \in \{c_j'\}$, denoted as $\underset{\cdot}{V}_{j+} = \left[\min_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}, \max_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}\right]$, $\underset{\cdot}{V}_{j+}' = \left[\min_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}', \max_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}'\right]$.

Let $\alpha_{\min} = \min_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} \{K({}_{I_i}T_{D_i}D_i) - K(D_i)\}$, $\alpha_{\max} = \max_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} \{K({}_{I_i}T_{D_i}D_i) - K(D_i)\}$

$\beta_{\min} = \min_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} \{K({}_{I_i}T_{D_i}D_i) \cdot K(D_i)\}$, $\beta_{\max} = \max_{i \in J_{\underset{\cdot}{E}_+(\varphi)}} \{K({}_{I_i}T_{D_i}D_i) \cdot K(D_i)\}$

Table 1. Original evaluation information

	$\boldsymbol{d_1}$	$\boldsymbol{d_2}$	$\cdots$	$\boldsymbol{d_q}$
$\boldsymbol{I_1}$	u_{11}	u_{12}	$\cdots$	u_{1q}
$\boldsymbol{I_2}$	u_{21}	u_{22}	$\cdots$	u_{2q}
$\vdots$	$\vdots$	$\vdots$		$\vdots$
$\boldsymbol{I_n}$	u_{n1}	u_{n2}	$\cdots$	u_{nq}
$\boldsymbol{I'_1}$	u'_{11}	u'_{12}	$\cdots$	u'_{1q}
$\boldsymbol{I'_2}$	u'_{21}	u'_{22}	$\cdots$	u'_{2q}
$\vdots$	$\vdots$	$\vdots$		$\vdots$
$\boldsymbol{I'_n}$	u'_{n1}	u'_{n2}	$\cdots$	u'_{nq}

Table 2. Regulate the number of associations

	$\boldsymbol{d_1}$	$\boldsymbol{d_2}$	$\cdots$	$\boldsymbol{d_q}$
$\boldsymbol{D_1}$	k_{11}	k_{12}	$\cdots$	k_{1q}
$\boldsymbol{D_2}$	k_{21}	k_{22}	$\cdots$	k_{2q}
$\vdots$	$\vdots$	$\vdots$		$\vdots$
$\boldsymbol{D_n}$	k_{n1}	k_{n2}	$\cdots$	k_{nq}
$\boldsymbol{D'_1}$	k'_{11}	k'_{12}	$\cdots$	k'_{1q}
$\boldsymbol{D'_2}$	k'_{21}	k'_{22}	$\cdots$	k'_{2q}
$\vdots$	$\vdots$	$\vdots$		$\vdots$
$\boldsymbol{D'_n}$	k'_{n1}	k'_{n2}	$\cdots$	k'_{nq}

if $I_i = \begin{bmatrix} O_i, & c_1, & v_{i1} \\ & c_2, & v_{i2} \\ & \vdots & \vdots \\ & c_n, & v_{in} \end{bmatrix}$, $I'_i = \begin{bmatrix} O'_i, & c_1, & v'_{i1} \\ & c_2, & v'_{i2} \\ & \vdots & \vdots \\ & c_n, & v'_{in} \end{bmatrix}$ satisfies $L\colon v_{ij} \in \underset{\cdot}{V}_{j+} \left(i \in J_{\underset{\cdot}{E}_+(\varphi)}, c_i \in \left\{ c'_j \right\} \right)$, the knowledge rules are

(1) $\{\varphi I_i = I'_i\} \wedge \{I_i \ni L\} \Rightarrow (\ell) \left(v'_{ij} \in \underset{\cdot}{V}'_{j+} \right)$;

(2) $\{\varphi I_i = I'_i\} \wedge \{I_i \ni L\} \Rightarrow (\ell) \left(I_i \in \underset{\cdot}{E}_+(\varphi) \right)$;

(3) $\{\varphi I_i = I'_i\} \wedge \{I_i \ni L\} \Rightarrow (\ell)\{(\alpha_i \in [\alpha_{\min}, \alpha_{\max}]) \wedge (\beta_i \in [\beta_{\min}, \beta_{\max}])\}$

Among them, ℓ = (support degree, credibility) = $\left(|E_-|/|\{I\}|, \left| \underset{\cdot}{E}_+(\varphi) \right| / E_- \right)$.

The detailed calculation steps of the extenics model are described here and in Section 4 are used to construct a measurement model of regional innovation coordination.

(1) List the original data before the change and after the change, and according to the relative requirement to prescribe eigenvalues $d_1, d_2, \cdots d_q$, give the original evaluation information element as shown in **Table 1**.

(2) Set the correlation function about the evaluation feature $k_p(x)(p = 1,2, \cdots q)$, and according to the original evaluation information element table calculate the correlation function of the evaluation information element $D_{ip} = (I_i, d_p, u_{ip})$ before φ changes and the correlation function of the evaluation information element $D'_{ip} = (I'_i, d_p, u'_{ip})$ after φ changes. Regularizing the number of associations, gives **Table 2**.

Among them, the calculation of the correlation function can be divided into two situations.

The first situation is the elementary correlation function whose optimal point is in the middle interval.

Set $X_0 = \langle a, b \rangle$, $X = \langle c, d \rangle$, and $X_0 \in X$, denote the common point of X_0 and X as x_z (x_z is empty if there is no common point), and for arbitrary $x \neq x_z$, let

$$k(x) = \begin{cases} \rho(x, X_0)/D(x, X_0, X) - 1, \rho(x, X_0) = \rho(x, X), & x \notin X_0 \\ \rho(x, X_0)/D(x, X_0, X), other \end{cases} \tag{1}$$

Here $k(x)$ is the maximum value elementary correlation function from the middle of X_0 and X on x, among them

$$\rho(x, X_0) = |x - (a + b)/2| - (b - a)/2 \tag{2}$$

The interval of location relation comprised by x, X_0 and X, is called the distance between x and interval X_0.

$$D(x, X_0, X) = \begin{cases} \rho(x, X) - \rho(x, X_0), \rho(x, X) \neq \rho(x, X_0), x \notin X_0 \\ \rho(x, X) - \rho(x, X_0) + a - b, \rho(x, X) \neq \rho(x, X_0), x \in X_0 \\ a - b, \rho(x, X) = \rho(x, X_0) \end{cases} \tag{3}$$

The location relation between x and nested interval comprised by X_0 and X, is called the location value of x and nested interval X_0, X.

Table 3. Qualitative change in the domain corresponding to the evaluation of information

	$\boldsymbol{K\left(D_i^{(2)}\right)}$	$\boldsymbol{K\left({}_{I_i}T_{D_i}D_i^{(2)}\right)}$	**Type**
$\boldsymbol{D_1^{(2)}}$	$\leq 0\ (\geq 0)$	$> 0\ (< 0)$	$\underset{\cdot}{D}_+\ (\underset{\cdot}{D}_-)$
$\boldsymbol{D_2^{(2)}}$	$\leq 0\ (\geq 0)$	$> 0\ (< 0)$	$\underset{\cdot}{D}_+\ (\underset{\cdot}{D}_-)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\boldsymbol{D_{n''}^{(2)}}$	$\leq 0\ (\geq 0)$	$> 0\ (< 0)$	$\underset{\cdot}{D}_+\ (\underset{\cdot}{D}_-)$

The second situation is the elementary correlation function whose optimal point is not in the middle interval.

(i) The left distance: the given interval $X_0 = \langle a, b\rangle$, $x_0 \in (a, (a+b)/2\rangle$, is called

$$\rho_l(x, x_0, X_0) = \begin{cases} a - x, x \leq a \\ (x-a)\,(b - x_0)/(a - x_0), x \in \langle a, x_0\rangle \\ x - b, x \geq x_0 \end{cases} \tag{4}$$

and is the left distance between x and x_0 on X_0.

(ii) The right distance: the given interval $X_0 = \langle a, b\rangle$, $x_0 \in ((a+b)/2, b\rangle$, is called

$$\rho_r(x, x_0, X_0) = \begin{cases} a - x, x \leq x_0 \\ (b-x)\,(a - x_0)/(b - x_0), x \in \langle x_0, b\rangle \\ x - b, x \geq b \end{cases} \tag{5}$$

and is the right distance between x and x_0 on X_0.

When applying elementary functions to solve practical problems, it should be noted that to determine if the optimal value is in the middle, left or right point of the interval must be based on the actual problem, and different types of elementary functions formula are used to calculate this.

The regular formula of the number of association

$$k_{ij} = k_j(u_{ij})/\max_{1\leq i\leq n}\left|k_j(u_{ij})\right|, i = 1,2,\cdots,n; j = 1,2,\cdots,q \tag{6}$$

(3) Calculate the Correlation Difference

Calculate

$$\alpha_{ip} = k'_{ip} - k_{ip}, \quad p = 1,2,\cdots q;\ i = 1,2,\cdots,n \tag{7}$$

List the table of correlation difference. Delete the raw 0 value and delete the 0 value column. Relist into a new standardized correlation table.

(4) Comprehensive Correlation Degree Calculation

The comprehensive correlation degree before φ changes:

$$K(D_i) = \sum_{j=1}^{q} \alpha_j k_{ij}. \tag{8}$$

The comprehensive correlation degree after φ changes:

$$K\left({}_{I_i}T_{D_i}D_i\right) = \sum_{j=1}^{q} \alpha_j k_{ij}. \tag{9}$$

Comprehensive correlation degree:

$$\alpha_i = K\left({}_{I_i}T_{D_i}D_i\right) - K(D_i).$$

(5) Compare the comprehensive correlation degree before and after the changes, and according to $K(D_i) \leq 0$ $(K(D_i) \geq 0)$ and $K\left({}_{I_i}T_{D_i}D_i\right) > 0$ $\left(K\left({}_{I_i}T_{D_i}D_i\right) < 0\right)$ determine $\underset{\cdot}{D}_+$ $(\underset{\cdot}{D}_-)$'s corresponding evaluation information element. List $\underset{\cdot}{D}_+$ $(\underset{\cdot}{D}_-)$'s corresponding original information table from the original data table and calculate the eigenvalues' corresponding value interval.

(6) Obtain Qualitative Change Knowledge

Let $\underset{\cdot}{E}_+(\varphi)$'s index set as $J_{\underset{\cdot}{E}_+(\varphi)}$. Obviously, $J_{\underset{\cdot}{E}_+(\varphi)} = J_{\underset{\cdot}{D}_+}$, if in $c_j (j = 1,2,\cdots,m)$ the $d_p (p = 1,2,\cdots q)$'s all original feature is $\{c'_j\}$, thus to $c_j \in \{c'_j\}$, denote $\underset{\cdot}{V}_{j+} = \left[\min_{i\in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}, \max_{i\in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}\right]$, $\underset{\cdot}{V}'_{j+} = \left[\min_{i\in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}^{(2)}, \max_{i\in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}^{(2)}\right]$.

Table 4. Qualitative change in the domain correspond to the information element

	$\boldsymbol{c'_1}$	$\boldsymbol{c'_2}$	$\cdots$	$\boldsymbol{c'_{m'}}$	**Type of evaluation information element**	**Type of original information element**
$\boldsymbol{O_1^{(2)}}$	$v_{11}^{(2)}$	$v_{12}^{(2)}$	$\cdots$	$v_{1m}^{(2)}$	$\underset{\cdot}{D}_+$ ($\underset{\cdot}{D}_-$)	$\underset{\cdot}{E}_+(\varphi)$ ($\underset{\cdot}{E}_-(\varphi)$)
$\boldsymbol{O_2^{(2)}}$	$v_{21}^{(2)}$	$v_{22}^{(2)}$	$\cdots$	$v_{2m}^{(2)}$	$\underset{\cdot}{D}_+$ ($\underset{\cdot}{D}_-$)	$\underset{\cdot}{E}_+(\varphi)$ ($\underset{\cdot}{E}_-(\varphi)$)
$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$
$\boldsymbol{O_{n''}^{(2)}}$	$v_{n''1}^{(2)}$	$v_{n''2}^{(2)}$	$\cdots$	$v_{n''m'}^{(2)}$	$\underset{\cdot}{D}_+$ ($\underset{\cdot}{D}_-$)	$\underset{\cdot}{E}_+(\varphi)$ ($\underset{\cdot}{E}_-(\varphi)$)
$\boldsymbol{\min_{i\in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}^{(2)}}$	a_1	a_2	$\cdots$	a'_m		
$\boldsymbol{\max_{i\in J_{\underset{\cdot}{E}_+(\varphi)}} v_{ij}^{(2)}}$	b_1	b_2	$\cdots$	b'_m		
$\boldsymbol{V_j}$	$[a_1, b_1]$	$[a_2, b_2]$	$\cdots$	$[a_m, b_m]$		

ANALYSIS OF REGIONAL INNOVATION COORDINATION CAPACITY BASED ON EXTENICS

We examined research from research and development institutions, enterprises, and third level institutions and calculated their respective external funding to measure their regional innovation capacity. We selected 31 Chinese provinces ($I_1, I_2, \cdots I_{31}$) as the research object. Among them, the corresponding research and development institution (d_1), industry enterprise (d_2) and third level institution (d_3) data respectively indicates the external fund sources. As mentioned earlier, the China Industry-University Research Institute Collaboration Association was established in November 2007. Therefore, we chose 2007 and 2015 data for research, to determine the role of the China Industry-University Research Institute Collaboration Association on the development of China's regional innovation. Relative data were obtained from the China Statistical Yearbook (2008–2016) and the China Statistical Yearbook on Science and Technology (2008–2016). According to the calculation procedure described in the previous section, we procedure performed it here as follows:

(1) Establish the correlation function, and calculate the number of associations before and after the change.

First, data before the change in 2007

For d_1, take $X_{01} = \langle 186815, 4065610\rangle$, $X_1 = \langle 12399, 4065610\rangle$;

For d_2, take $X_{01} = \langle 70393, 804706\rangle$, $X_1 = \langle 0, 804706\rangle$;

For d_3, take $X_{01} = \langle 119415, 1055869\rangle$, $X_1 = \langle 1974, 1055869\rangle$.

It should be noted, to select the satisfied value (X_{01}) we used our literature research to select the middle value sample from the 31 provinces. For example, in 2007 the provinces ranked in sixteenth position (mid-point) for each indicator d were Tian Jin (186,815), Tian Jin (70,393), and Chongqing (119,415); however, in 2015 they were Heilongjiang (229,667), Jiangxi (109,657), and Jilin (148,084). We selected the corresponding maximum value of each index in our 31 provinces as the satisfied value.

We analysed the elementary correlation function to calculate the number of associations and found they all had the characteristic of the larger the better. Therefore, we had to choose the right distance formula to calculate which could be referred to formulas (1), (3), and (5).

$$k_1(x) = \rho(x, 4056510, X_{01}) / D(x, X_{01}, X_1).$$

Among them, $\rho(x, 4056510, X_{01}) = 119415 - x, x \le 4056510$

$$D(x, X_{01}, X_1) = \begin{cases} -1053895, x \le 119415 \\ -117441, other \end{cases}$$

Using formula (6) to regularize and inserting the relative data into the calculation gives the detailed result shown in upper part of **Table 5**.

Second, data after the change in 2015.

The calculation steps are the same as for before the change (in 2007), and are not repeated here. Detailed data are shown in the lower part of **Table 5**.

Table 5. Regulate the number of associations

2007 (before change)	d_1	d_2	d_3	**2008 (after change)**	d_1	d_2	d_3
$\boldsymbol{D_1}$	0.956968	-0.32402	0.888565	D_1	0.949374	0.02371	0.885982
$\boldsymbol{D_2}$	0	0	0.072484	D_2	0.011987	-0.24628	0.072485
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
$\boldsymbol{D_{31}}$	-0.6335	-0.76184	-0.90407	D_{31}	-0.63368	-0.69835	-0.93704
$\boldsymbol{D'_1}$	1	-0.42532	0.982848	D'_1	1	0.033951	0.945514
$\boldsymbol{D'_2}$	0	0	0.080176	D'_2	0.012626	-0.35265	0.077355
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
$\boldsymbol{D'_{31}}$	-0.66199	-1	-1	D'_{31}	-0.66748	-1	-1

Table 6. Qualitative change in the domain corresponding to the evaluation of information

Province	**2007, Before Change**	**Type**	**2008, After Change**	**Type**	**Province**	**2007, Before Change**	**Type**	**2008 After Change**	**Type**
Beijing	0.311388	E_+	0.52213	E_+	Hubei	0.102764	E_+	-0.04911	
Tianjin	0.020846	E_+	-0.14588		Hunan	-0.16222		-0.04904	
Hebei	-0.41793		-0.38344		Guangdong	0.295922	E_+	0.356006	E_+
Shanxi	-0.33356		-0.42353		Guangxi	-0.59063		-0.66007	
Inner Mongolia	-0.69646		-0.58644		Hainan	-1.12689		-1.17312	
Liaoning	0.161787	E_+	0.201076	E_+	Chongqing	-0.17661		-0.15611	
Jilin	-0.49541		-0.55		Sichuan	0.157114	E_+	0.169582	E_+
Heilongjiang	0.081184	E_+	0.065455	E_+	Guizhou	-0.732		-0.8699	
Shanghai	0.243898	E_+	0.212416	E_+	Yunnan	-0.56652		-0.6352	
Jiangsu	0.742478	E_+	0.760385	E_+	Tibet	-1.18725		-1.20197	
Zhejiang	0.279196	E_+	0.233091	E_+	Shaanxi	0.200982	E_+	0.275441	D_+
Anhui	0.194731	E_+	0.084456	E_+	Gansu	-0.71134		-0.84588	
Fujian	-0.14966		-0.18804		Qinghai	-1.11483		-1.18286	
Jiangxi	-0.18346		-0.25966		Ningxia	-1.00219		-1.09629	
Shandong	0.295914	E_+	0.367986	E_+	Xinjiang	-0.91212		-0.91354	
Henan	0.018393	E_+	-0.0676						

(2) Calculation of Association Difference

To calculate the association difference according to formula (7), we found that the row or line of association difference 0 does not exist and the corresponding calculation steps do not change (the specific calculation process is omitted).

(3) Calculation of Comprehensive Correlative Degree

We used the coefficient of variance method to determine the comprehensive correlative degree according to (8), and (9), with α_j indicating weight. The benefit of this approach is that objective data determines the weight of indexes, thus avoiding errors caused by subjective reasons. Through the calculation and normalization of the calculation results, we determined the weights of the three indicators as: 0.26, 0.48, and 0.26. Of course, the calculation may be erroneous if only data and not their weights are considered. We must ascertain whether the weight established is reasonable. It is reasonable that the weight of research and development institutions and third level institutions are the same because they all act as enterprise innovation source providers. From international experiences, the former has technology innovation abilities while the latter focuses on basic research. However, in China, research and development institution functions are not perfect, and third level institutions have relatively strong scientific research abilities hence their functions are of equal importance in this context. Enterprise weight reached 0.48, higher than that of research and development institutions and third level institutions. Enterprises are the core of regional innovation and should occupy a relatively dominant position when measuring innovation coordination capacity; hence, their weighting is also reasonable. We thus find that the weight calculated by the coefficient of variation is basically consistent with the actual situation in China, and the specific data is shown in **Table 6**.

Table 6 shows that only 14 (45.16%) provinces and cities had relatively good regional innovation ability in 2007 (indicated by a positive value), meaning over half of the provinces and cities had poor coordination innovation ability. In 2015, the innovation coordination ability in three areas became negative, and the ratio of good innovation coordination ability decreased to 35.48%. The changed region is shown in **Table 7**. It is clear that the cooperation

Table 7. Qualitative change in the domain correspond to the information element

	$K\left(\boldsymbol{D}_i^{(2)}\right)$	$K\left({}_{I_i}\boldsymbol{T}_{D_i}\boldsymbol{D}_i^{(2)}\right)$	Type
$\boldsymbol{D}_2^{(2)}$	> 0	≤ 0	$\underset{\cdot}{D}_-$
$\boldsymbol{D}_{18}^{(2)}$	> 0	≤ 0	$\underset{\cdot}{D}_-$
$\boldsymbol{D}_{19}^{(2)}$	> 0	≤ 0	$\underset{\cdot}{D}_-$

Table 8. Qualitative change in the domain corresponding to the original data table and the corresponding interval

	c'_1		c'_2		c'_3		Type of Evaluation Information Element	Type of Original Information Element
	Before	**After**	**Before**	**After**	**Before**	**After**		
$O_2^{(2)}$	186815	281236	70393	82651.1	195806	237267.54	$\underset{\cdot}{D}_-$	$\underset{\cdot}{E}_-(\varphi)$
$O_{18}^{(2)}$	590631	585429	93000	88254.4	331945	424740.94	$\underset{\cdot}{D}_-$	$\underset{\cdot}{E}_-(\varphi)$
$O_{19}^{(2)}$	115064	165321	62103	115809	206460	264463.08	$\underset{\cdot}{D}_-$	$\underset{\cdot}{E}_-(\varphi)$
$\underset{\cdot}{\mathrm{V}}_{j+}$	[115064, 590631]		[62103, 93000]		[195806, 331945]			
$\underset{\cdot}{\mathrm{V}}'_{j+}$	[165321, 585429]		[82651.1, 115809]		[237267.54, 424740.94]			

among industry, third level and research is not enough and that the regulation of relevant departments did not resolve the issue resulting in the decrease of regional innovation coordination ability.

(4) Obtaining Qualitative Change Knowledge

According to the calculation presented in point (3), the corresponding original data and interval of qualitative change is listed before and after the change in **Table 8**.

Table 8 shows that after the implementation of policies to promote Industry-University-Research in China, the coordination ability of Tianjin (2), Henan (18), and Hebei (19) provinces all decreased. Although **Table 7** shows that the regional innovation coordination ability improved in parts of China, this did not result in qualitative change.

Our empirical study showed that although China attaches great importance on innovation and established a "China Industry-University Research Institute Collaboration Association", from a practical point of view, after one year of development the innovation coordination abilities of regions are non-decreasing rather than increasing. It is clear that the improvement of regional innovation coordination ability is a complex process and that the relevant departments need to strengthen Industry-University-Research cooperation reflecting the actual situation in China.

CONCLUSION

Using the extenics theoretical analysis model, this paper set up a regional innovation coordination measurement model and researched regional innovation coordination ability levels in 2007 and 2015. Our findings are not optimistic for the Industry-University-Research cooperation status quo. Not enough provinces have good regional innovation coordination ability, and most enterprises have low abilities. Although relevant government departments have adjusted their policies on Industry-University-Research cooperation, they are not effective. In 2015, the coordination ability of three provinces dropped from good to low in comparison to 2007. This is the first time the extenics model has been applied to the study of regional innovation coordination capability and thus expands the area of extenics empirical research. Moreover, this paper provided a theoretical basis for relevant government departments policy regulations as well as pointing the direction for further strengthening Industry-University-Research cooperation. This paper has some shortcomings. Because of time and space limitations, only the coordination of regional innovation is examined, and other regional innovation capacities are not included. The authors will further study regional innovation capacities and make efforts to form a comprehensive research system.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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