A Research on Comprehensive Evaluation Model of Regional Autonomous Technological Innovation Ability

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Abstract In this paper, we present a comprehensive evaluation model of regional autonomous technological innovation ability based on system theory, including two parts of transversal and longwise evaluation. Besides, two index systems are built for horizontal and vertical assessment and applying algorithms on evaluation model is used to evaluate the indices including transversal method (information entropy methods and osculating value methods) and longwise evaluation (DEA methods).
Key words Region; Independent innovation; Comprehensive evaluation; Model

1 Introduction

The fundamental objective of operation of regional independent technology innovation system is to enhance the capability of regional independent innovation. In order to realize the objective, control functions need to measure, feedback the objective completed bad or well and verify their deviation, where the primary part of regional independent technology innovation is measurement[1]. Only comprehensive evaluation of independent innovation is analyzed accurately and inspected dynamically at any time, the evaluation results can help to promote the capability of regional independent innovation effectively and continuously. As far as we know, there are many people study on model of regional independent technology innovation and its comprehensive evaluation[2], however a few study based on system theory. In this paper, we present a comprehensive evaluation model of regional technology independent technological innovation based on system theory, including transversal index and longitudinal index and evaluate the indices using transversal method (information entropy methods and osculating value methods) and longitudinal evaluation (DEA methods).

2 Designing of Evaluation Index for Regional Technology Independent Innovation Ability

Selection of index: the comprehensive index of the regional independent technology innovation is different from the comprehensive evaluation index of innovative cities. Combining with the feature of independent technology innovation, we specially focus on the collocation of innovation’s input and output indices. In order to ensure the validity of the assessment algorithm and the complete collection of data indices as well as conduct an effective transversal and longitudinal evaluation, based on the index system and the everywhere Statistical Yearbook in China Urban Competitiveness Report (NO 3)--Cluster: the root of Chinese economy, we scientifically revise the original three-level indices which are mainly longitudinal evaluation indices, combining with the specific issues of the regional independent technology innovation ability’s assessment. Based on the pragmatic needs and the convenience rationality requirements of DEA evaluation methodology, two index systems, which are used for the comprehensive evaluation of the regional independent technology innovation, are reconstructed. They are listed in table 1 and table 2. This study constructs a comprehensive evaluation matrix (abbreviated) from table 1 and table 2 on the choice of 17 cities, and carries out comprehensive evaluations for regional independent technology innovation ability.

3 Designing of Comprehensive Evaluation Method for Regional Independent Technology Innovation Ability

3.1 Information entropy and close value method (transversal evaluation of index system)

Information entropy is an objective way of empowerment, which is different from subjective ways of empowerment such as factor analysis, principal component analysis etc. Since the objective constraints, a wide range of expert advice can not be collected, so we adopt objective ways of empowerment. In this kind of method, entropy method is the most suitable way for the assignment of this index system. Finally, close value method is used to complete evaluation and obtain rankings.

Table 1 Transversal Evaluation Index System: The Comprehensive Evaluation Index System 1 of Regional Independent Technology Innovation Ability

Target level	Criterion level	Index level	Variable symbol	Unit
Regional independent technology innovation ability (transversal)	Technology and information (A)	Scientific and technological strength index	A1	Dimensionless
		Science and technology transfer ability index	A2	Dimensionless
		Technological innovation ability index	A3	Dimensionless
		Property rights protection index	A4	Dimensionless
		Information technology infrastructure Index	A5	Dimensionless
		Innovation environment index	A6	Dimensionless
	Human and government (X)	Quality of human resources index	X1	Dimensionless
		Education of human resources index	X2	Dimensionless
		Government innovation capability index	X3	Dimensionless
	Industry (Y)	Comprehensive productivity	Y1	Dimensionless
		Market development level index	Y2	Dimensionless
		Economic internationalization level	Y3	Dimensionless
		Upgrading level index of industrial structure	Y4	Dimensionless
		Speed index of economic structure conversion	Y5	Dimensionless

Table 2 Longitudinal Evaluation Index System: The Comprehensive Evaluation Index System 2 of Regional Independent Technology Innovation Ability

Target level	Criterion level	Index level	Variable symbol	Unit
Regional independent technology innovation ability (longitudinal)	Activity base(A)	Gross domestic product(GDP)	A1	T RMB
		Patent ownership	A2	Piece
		The number of technological activity staffs	A3	Person
		The total number of science and technology projects	A4	Item
		Government funds in the total provision of scientific and technological activities	A5	T RMB
	Input(X)	Research and experimental development staff(R&D)	X1	Person
		R&D appropriation expenditure	X2	T RMB
		The total collected funds for scientific and technological activities	X3	T RMB
		The number of R&D projects	X4	Item
		Appropriation expenditure which is used for infrastructure development of scientific research	X5	T RMB
		Appropriation expenditure for new product development	X6	T RMB
	Output(Y)	Sale revenue of new product	Y1	T RMB
		Export sale revenue of new products	Y2	T RMB
		The number of invention patent applications	Y3	Piece
		The number of new product development projects	Y4	Item

Entropy method determines the objective weight based on the size of indices' variability[3]. Close value, as the multi-objective decision-making evaluation method, is widely used. This study use indices' data of the same year to carry out transversal evaluations. Since this study considers both the positive and negative indices and refers internal indices, combining with redundancy indices, the accuracy of the evaluation is effectively improved, which makes the results of comprehensive evaluations more accurate. And since the entropy method is used to empower, the results of evaluation become more accurate and more reasonable.

3.2 Data envelopment analysis (DEA) (longitudinal evaluation of index system)

For multiple input and output multi-objective decision-making problems, DEA method is very suitable. The efficiency of DEA is equivalent to the corresponding multi-objective Pareto efficient solution. Data envelopment analysis (DEA) is a new method of statistical analysis, which derives from programming theory of operations research. It estimates the efficient production frontier based on a set of input-output observations. On the effectiveness of evaluation, many methods of evaluation are limited to a single output situation. But the DEA has an absolute advantage on handling multi-input, especially multi-output problems. In addition, a lot of additional useful information can be gotten while we judge whether the corresponding point of the decision-making unit is on the efficient production frontier surface by planning methods. Therefore, it is broader than statistical regression and other statistical and non-statistical methods. The evaluation results are more accurate and more useful information can be obtained. As the DEA method is only a technology method and it is independent of geographical and ideological characteristics etc, it is very suitable for the evaluation of the regional independent technology innovation ability in this study.

4 The Comprehensive Evaluation Model and Algorithm of Regional Independent Technology Innovation Ability

4.1 The transversal comprehensive evaluation of regional independent technology innovation ability

Firstly, given complete data can be collected and their suitability for the transversal evaluation of independent technology innovation ability, index system used for transversal evaluation is designed based on China's Urban Competitiveness Report. It is shown in Table 1.

Secondly, concerning the transversal comprehensive evaluation algorithm, given the complexity of algorithm analysis and a large amount of sample data that has a matrix form, MATLAB 5.2 software program is used to calculate. Part of the calculation matrix data can be seen in attached list. MATLAB software is commercial mathematical software, which was produced by Math Works Inc. in the United States. It is mainly used for algorithm development, data analysis, high-level technology computing language of numerical calculation and interactive environment. Transversal evaluation is carried out according to the evaluation process of information entropy and close value method.

4.1.1 Establish standardization matrix of evaluation index

The types of evaluation index are generally divided into efficiency-based, cost-based and fixed-based index. The closer to a fixed value, the more excellent the fixed-based index will be. Evaluation data of the relevant indices need to be converted at first and then a further standardization is conducted on processed evaluation index[4].

We now suppose that there are m cities and n indices. Then we have a $m \times n$ matrix of standardization index

$$\boldsymbol{X} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \cdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} = (x_{ij})_{m \times n} \tag{1}$$

Where the element X_{ij} called standardized value of evaluation index.

If the dimensions of evaluation index are different and there are great differences among the measured data under different indices, a standardized conversion on dimensionless will be carried out and then the X_{ij} that is the j-th evaluation index standardization value of i-th city in the formula (1) will be gotten.

As the evaluation data that referred in this study are the data in China Urban Competitiveness Report[5], they are all fixed-based index and dimensions of indices are the same, the differences of data size are small, all data of indices in table 1 are conducted standardized processes (abbreviated). An evaluation matrix X of standardized index is established as follow.

$$
X = \begin{bmatrix}
1.000 & 1.000 & 1.000 & 0.423 & 0.837 & 1.000 & 0.843 & 0.701 & 0.282 & 1.000 & 0.845 & 0.832 & 0.701 & 0.571 \\
0.540 & 0.656 & 0.560 & 1.000 & 0.903 & 0.725 & 0.888 & 1.000 & 0.418 & 0.729 & 0.855 & 0.935 & 0.861 & 0.715 \\
0.168 & 0.447 & 0.277 & 0.317 & 0.626 & 0.563 & 0.817 & 0.634 & 0.300 & 0.724 & 0.859 & 0.324 & 0.776 & 0.658 \\
0.199 & 0.460 & 0.320 & 0.529 & 0.600 & 0.539 & 0.790 & 0.538 & 0.209 & 0.743 & 0.725 & 0.263 & 0.714 & 0.530 \\
0.112 & 0.405 & 0.127 & 0.533 & 0.659 & 0.666 & 0.873 & 0.824 & 0.199 & 0.740 & 0.851 & 0.312 & 0.790 & 0.665 \\
0.073 & 0.288 & 0.069 & 0.262 & 0.558 & 0.597 & 0.793 & 0.466 & 0.192 & 0.823 & 0.742 & 0..533 & 0.642 & 0.533 \\
0.089 & 0.225 & 0.109 & 0.255 & 0.555 & 0.654 & 0.852 & 0.590 & 0.077 & 0.837 & 0.827 & 0.267 & 0.705 & 0.562 \\
0.083 & 0.343 & 0.097 & 0.470 & 0.506 & 0.523 & 0.837 & 0.679 & 0.208 & 0.761 & 0.846 & 0.350 & 0.674 & 0.632 \\
0.059 & 0.188 & 0.049 & 0.374 & 0.414 & 0.630 & 0.916 & 0.728 & 0.205 & 0.741 & 0.799 & 0.430 & 0.790 & 0.708 \\
0.101 & 0.415 & 0.115 & 0.370 & 0.548 & 0.537 & 0.898 & 0.634 & 0.102 & 0.878 & 0.826 & 0.418 & 0.736 & 0.594 \\
0.168 & 0.421 & 0.217 & 0.298 & 0.550 & 0.587 & 0.830 & 0.583 & 0.105 & 0.908 & 0.783 & 0.003 & 0.716 & 0.567 \\
0.011 & 0.231 & 0.013 & 0.216 & 0.490 & 0.207 & 0.827 & 0.531 & 0.283 & 0.728 & 0.653 & 0.285 & 0.705 & 0.563 \\
0.081 & 0.213 & 0.085 & 0.352 & 0.491 & 0.639 & 0.842 & 0.466 & 0.094 & 0.857 & 0.845 & 0.220 & 0.717 & 0.608 \\
0.132 & 0.283 & 0.265 & 0.478 & 0.709 & 0.590 & 0.817 & 0.633 & 0.369 & 0.747 & 0.806 & 0.422 & 0.651 & 0.516 \\
0.014 & 0.157 & 0.008 & 0.249 & 0.384 & 0.476 & 0.679 & 0.627 & 0.175 & 0.569 & 0.867 & 0.262 & 0.509 & 0.684 \\
0.027 & 0.145 & 0.011 & 0.259 & 0.459 & 0.438 & 0.857 & 0.634 & 0.106 & 0.854 & 0.812 & 0.200 & 0.705 & 0.618 \\
0.064 & 0.255 & 0.055 & 0.431 & 0.592 & 0.462 & 0.856 & 0.603 & 0.383 & 0.740 & 0.855 & 0.355 & 0.705 & 0.579
\end{bmatrix}
$$

Now we evaluate the comprehensive indices not using Assignment method but information entropy method to avoid the subjective error and denote by e_j the index decision-making entropy. Then

$$
e_j = -k \sum_{i=1}^{m} x_{ij} \ln x_{ij} \qquad (j=1,2,\ldots,n), \tag{2}
$$

$$
k = 1/\ln m
$$

Where m=17, the number of the cities, and so k=0.35296,

$$
d_j = 1 - e_j \qquad (j = 1, 2, \cdots, n)
$$

The vale can be used to measure the dispersion degree of index date. When the value tents to increase, the corresponding index x_i tents to large dispersion degree, and consequently the weight of the index tents to increase. Conversely, the weight of the index tents to decrease. If all the values of the index is the same each other, then this means the values contribute nothing to the evaluation and they must be deleted. Then we obtain the following weight formula

$$
w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{3}
$$

By information entropy method and MATLAB Soft, So

W =(0.176, 0.168, 0.181, 0.011, 0.035, 0.031, 0.024, 0.006, 0.009, 0.074, 0.037, 0.052, 0.099, 0.098).

Let be $w_j x_{ij}$ the weight value of the of element of the normoralizing matrix, then we get the weight normoralizing matrix

$$
X' = \begin{bmatrix}
w_1 x_{11} & \cdots & w_n x_{1n} \\
w_1 x_{21} & \cdots & w_n x_{2n} \\
w_1 x_{m1} & \cdots & w_n x_{mn}
\end{bmatrix} \tag{4}
$$

$$
X' = \begin{bmatrix}
0.176 & 0.168 & 0.181 & 0.005 & 0.029 & 0.031 & 0.020 & 0.004 & 0.003 & 0.074 & 0.031 & 0.043 & 0.069 & 0.056 \\
0.095 & 0.110 & 0.101 & 0.011 & 0.032 & 0.022 & 0.021 & 0.006 & 0.004 & 0.054 & 0.031 & 0.049 & 0.085 & 0.070 \\
0.029 & 0.075 & 0.050 & 0.003 & 0.022 & 0.020 & 0.020 & 0.004 & 0.002 & 0.054 & 0.032 & 0.017 & 0.077 & 0.064 \\
0.035 & 0.077 & 0.058 & 0.006 & 0.021 & 0.017 & 0.019 & 0.003 & 0.001 & 0.055 & 0.027 & 0.014 & 0.071 & 0.052 \\
0.019 & 0.068 & 0.023 & 0.006 & 0.023 & 0.021 & 0.021 & 0.005 & 0.002 & 0.055 & 0.031 & 0.016 & 0.078 & 0.065 \\
0.012 & 0.048 & 0.012 & 0.003 & 0.020 & 0.019 & 0.019 & 0.003 & 0.002 & 0.061 & 0.027 & 0.028 & 0.064 & 0.052 \\
0.015 & 0.004 & 0.020 & 0.003 & 0.022 & 0.020 & 0.020 & 0.004 & 0.001 & 0.062 & 0.031 & 0.014 & 0.070 & 0.055 \\
0.015 & 0.058 & 0.018 & 0.005 & 0.018 & 0.016 & 0.020 & 0.004 & 0.002 & 0.056 & 0.031 & 0.018 & 0.067 & 0.062 \\
0.010 & 0.032 & 0.009 & 0.004 & 0.014 & 0.020 & 0.022 & 0.004 & 0.002 & 0.055 & 0.030 & 0.022 & 0.078 & 0.069 \\
0.018 & 0.070 & 0.021 & 0.004 & 0.019 & 0.017 & 0.022 & 0.004 & 0.001 & 0.065 & 0.031 & 0.022 & 0.073 & 0.058 \\
0.030 & 0.071 & 0.039 & 0.003 & 0.019 & 0.018 & 0.020 & 0.003 & 0.001 & 0.067 & 0.029 & 0.000 & 0.071 & 0.056 \\
0.002 & 0.039 & 0.002 & 0.002 & 0.017 & 0.006 & 0.020 & 0.003 & 0.003 & 0.054 & 0.024 & 0.015 & 0.070 & 0.055 \\
0.014 & 0.036 & 0.015 & 0.004 & 0.017 & 0.020 & 0.020 & 0.003 & 0.001 & 0.063 & 0.031 & 0.011 & 0.071 & 0.060 \\
0.023 & 0.048 & 0.048 & 0.005 & 0.025 & 0.018 & 0.019 & 0.004 & 0.003 & 0.055 & 0.030 & 0.022 & 0.064 & 0.051 \\
0.002 & 0.026 & 0.001 & 0.003 & 0.013 & 0.015 & 0.016 & 0.004 & 0.002 & 0.042 & 0.032 & 0.014 & 0.050 & 0.067 \\
0.005 & 0.024 & 0.002 & 0.003 & 0.016 & 0.014 & 0.021 & 0.004 & 0.001 & 0.063 & 0.030 & 0.010 & 0.070 & 0.061 \\
0.011 & 0.043 & 0.010 & 0.005 & 0.020 & 0.014 & 0.021 & 0.004 & 0.003 & 0.055 & 0.032 & 0.018 & 0.070 & 0.057
\end{bmatrix}
$$

4.1.2 Comprehensive evaluation based on osculating value methods

Consider the optimal city and negative optimal city:

$$x^{+}=\left\{\max(x_{ij}^{'})(1\le i\le m)\right\}=\left\{x_1^{+},x_2^{+},\cdots,x_n^{+}\right\}\qquad \left(j=1,2,\cdots m\right)$$

(5)

$$x^{-}=\left\{\min(x_{ij}^{'})(1\le i\le m)\right\}=\left\{x_1^{-},x_2^{-},\cdots,x_n^{-}\right\}\qquad \left(j=1,2,\cdots m\right)$$

x^{+}=(0.176, 0.168, 0.181, 0.011, 0.032, 0.031, 0.022, 0.006, 0.004, 0.074, 0.032, 0.049, 0.085, 0.070)

x^{-}=(0.002, 0.004, 0.001, 0.002, 0.013, 0.006, 0.016, 0.003, 0.001, 0.042, 0.024, 0.000(0.010), 0.050, 0.051)

Let m_{ii}^{+} and m_{ii}^{-} be the distance between each city and the optimal city and the negative optimal city, respectively. Then we get the following formulas:

$$m_{i\ i}^{+}=\sqrt{\sum_{j=1}^{14}(x_{ij}^{'}-x_j^{+})^2}\qquad (i=1,2\cdots17)$$

(6)

$$m_{i\ i}^{-}=\sqrt{\sum_{j=1}^{14}(x_{ij}^{'}-x_j^{-})^2}\qquad (i=1,2\cdots17)$$

Let

$$m^{+}=\min\{m_i^{+}\}$$

$$m^{-}=\max\{m_i^{-}\}$$

Then we may get formula of the osculating value of the i-th city as following

$$h_i=\frac{m_i^{+}}{m^{+}}-\frac{m_i^{-}}{m^{-}}\quad (i=1,2\cdots17),\qquad (7)$$

The smaller the value of h_i, is the more it closes to optimal city and the more it avoids negative optimal city. By MTLAB Soft and the verified value of the osculating value of every city, we may order each h_i.

4.2 The longitudinal comprehensive evaluation of regional independent technology innovation ability

According to date complicity, we evaluate the indices using longitudinal comprehensive evaluation based Table 2 and DEA method.

4.2.1 The model of evaluation of DEA method

The key to the DEA methods is the decision-making unit (DMU). Decision Making Unit is a society system through a series of decisions making and the investment of certain amount production element. We use C^2R model to judge the validity of each unit for n-th DMU[6]. So for a contain DMU, we get dual program of its C^2R model

$$(\boldsymbol{D})\begin{cases}\min\theta\\ s.t: \sum_{j=1}^{n}\boldsymbol{x}_i\lambda_i+s^- =\theta\boldsymbol{x}_0\\ \sum_{j=1}^{n}\boldsymbol{y}_i\lambda_i-s^+=\boldsymbol{y}_0\\ \lambda_j\ge 0,\quad j=1,2,\cdots,n\\ s^-\ge 0,\quad s^+\ge 0\end{cases} \tag{8}$$

We need to consider its optimal solution $\lambda^0,s^{0-},s^{0+},\theta^0$ whether meets such conditions: $s^{0-}=0,s^{0+}=0$ and $V_p=\theta^0=1$. Since it is difficult to solve the linear programming (D), we choice C^2R model ($\overline{P}\varepsilon$) with Archimedean infinitesimal ε(ε>0)[7-10].

$$(\overline{P}\varepsilon)\begin{cases}\max\dfrac{\boldsymbol{u}^{\mathrm{T}}\boldsymbol{y}_0}{\boldsymbol{v}^{\mathrm{T}}\boldsymbol{x}_0}=V_{\overline{P}}\\ s.t: \dfrac{\boldsymbol{u}^{\mathrm{T}}y_j}{\boldsymbol{v}^{\mathrm{T}}x_j}\le 1\quad (j=1,2,\cdots,n)\\ \dfrac{\boldsymbol{v}^{\mathrm{T}}}{\boldsymbol{v}^{\mathrm{T}}x_0}\ge\varepsilon\cdot\hat{\boldsymbol{e}}^T\\ \dfrac{\boldsymbol{u}^{\mathrm{T}}}{\boldsymbol{v}^{\mathrm{T}}x_0}\ge\varepsilon\cdot\boldsymbol{e}^T\end{cases} \tag{9}$$

where

$$\hat{\boldsymbol{e}}=(1,1,\cdots,1)^{\mathrm{T}}\in E_m$$

$$\boldsymbol{e}=(1,1,\cdots,1)^{\mathrm{T}}\in E_s\ .$$

By Charnes-Cooper transform

$$t=\frac{1}{\boldsymbol{v}^{\mathrm{T}}\boldsymbol{x}_0},\quad \boldsymbol{\omega}=t\boldsymbol{v},\quad \boldsymbol{\mu}=t\boldsymbol{u}, \tag{10}$$

Fractional programming $(\overline{P}\varepsilon)$ is equivalent to the following:

$$(P\varepsilon)\begin{cases}\max\boldsymbol{\mu}^{\mathrm{T}}\boldsymbol{y}_0=V\,P(\varepsilon)\\ s.t: \omega^{\mathrm{T}}\boldsymbol{x}\boldsymbol{i}-\boldsymbol{\mu}^{\mathrm{T}}\boldsymbol{y}_j\ge 0\quad (j=1,2,\cdots,n)\\ \boldsymbol{\omega}^{\mathrm{T}}\boldsymbol{x}_0=1\\ \boldsymbol{\omega}^{\mathrm{T}}\ge\varepsilon\cdot\hat{\boldsymbol{e}}^T\\ \boldsymbol{u}^{\mathrm{T}}\ge\varepsilon\cdot\boldsymbol{e}^T\end{cases} \tag{11}$$

Write linear programming (11) dual question:

$$(D_\varepsilon)\begin{cases}\min\left[\theta-\varepsilon(\hat{e}^{T}s^{-}+e^{T}s^{+})\right]=V_D(\varepsilon)\\ s.t.: \sum_{j=1}^{n}x_j\lambda_j+s^{-}=\theta x_0\\ \sum_{j=1}^{n}y_j\lambda_j-s^{+}=y_0\\ \lambda_j\geq 0,\quad j=1,2,\cdots,n\\ s^{-}\geq 0,\ s^{+}\geq 0\end{cases}$$

$$\hat{e}^{T}=(1,1,\cdots,1)\in E_m \tag{12}$$

$$e^{T}=(1,1,\cdots,1)\in E_s$$

Let $\lambda^0, s^{0-}, s^{0+}, \theta^0$ be optimal solution of (D_ε). Then the optimal value $V_D(\varepsilon)$ of (D_ε) has the complex number type a-εb :

$$a=\theta^0, b=e^{\wedge T}s^{0-}+e^{T}s^{0+} \tag{13}$$

Where denote a by the efficiency evaluation index of weak DEA of decision making unit j_0,b the sum of the optimum slack of input surplus and output deficit. We now may estimate the efficiency of decision making unit j_0 of DEA and weak DEA according to the optimal solution of (Dε).

4.2.2 Computation of comprehensive evaluation

We calculate the comprehensive evaluation using Lingo 9.0 and DEAP 2.1 respectively to ensure the accuracy of analysis results because of complexity and large amount of sample data of C^2R model and then compare the results.

5 Conclusion

We present a comprehensive evaluation model of regional independent innovation, design system indices, including transversal index and longitudinal index and then analyze the comprehensive evaluation indices by using transversal index and longitudinal index and evaluate the indices using transversal method (information entropy methods and Osculating value methods) and longitudinal evaluation (DEA methods). More of this study is to refine and decompose the model and our next work more focus on these.

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