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Study on the Coupling Development Between Higher Education and High-Tech Industry Innovation in China: An Empirical Study from Shandong Province

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Abstract: The purpose of this paper is to provide a comprehensive analysis of the relationship between higher education and high-tech industry innovation in China. Using the coupling theory and grey relational theory, this paper develops a evaluation model and research framework. Based on the statistical data of high-tech industry and higher education in Shandong province from 1995 to 2015, the empirical results show that there is a positive correlation between the high-tech industry innovation and higher education. In addition, personnel input and patent application are the key driving forces for the development of higher education and high technology industry.

Keywords: Higher Education, High-tech Industry Innovation, Coupling Coordination Model, Grey Relational Analysis

1. Introduction

In the current knowledge-based economy, higher education and high-tech industries are considered key to economic development. As the links between technology and development unfold, the potential role of higher education in contributing to the creation of high-tech industrial base is becoming a major policy focus [1]. At the same time, the world has observed that high-tech industry can emerge in a diverse set of countries including almost all OECD and those with limited industrial bases or low levels of economic development, such as China [2]. It is not surprising that innovation policies to create and support high-tech industries are a priority in China. In August 1999, the central government organized a National Innovation Congress and issued an act promoting commercialization of innovation and development of high-tech industry. Many local governments incorporated it into their local science policies [3]. Since then, higher education has become even more enthusiastic about transferring knowledge to industry [4]. In this context the relationship between high-tech industry and higher education become more important.

2. Literature Review

Since the first scientific research park was founded by Stanford University in 1950s in the United States, the internal relation between high-tech industry and higher education has enjoyed widespread popularity from scholars and they have achieved certain research results. A review of the relevant literature reveals that previous studies can be grouped into three research streams.

The first stream describes the influence of higher education on high-tech industry. The research in this area mainly analyzes the role of higher education in the development of high-tech industry. Their works suggest that higher education can promote knowledge transfer [5], increase the output [6], improve the efficiency of innovation [7], and also promote industrial development [8].

The second stream is concerned with the impact of high-tech industry on higher education, which focuses on the role of high-tech industry in absorbing talents and providing resources. These research suggest that high-tech industry can give a strong impetus to the employment of college students

[9], improve the quality of talents [10], impact the labor market talent demand [11-12], and promote the training of specialized personnel in higher education [13].

The third stream explores the interactive development between higher education and high-tech industry. In this area, researches mainly revolve the analysis, measurement and impact of the synergies between higher education and high-tech industry. Based on the the analysis of 2,457 Industry-University-Research projects, George (2002) found that the interaction between universities and high-tech industries can reduce the R&D cost and reap more innovative achievements [14]. Salazar (2003) discussed the management of knowledge flow between British biopharmaceutical industry and universities [15]. Yang (2010) analyzed the interactive mechanism and mode, links ways and problems between higher education and high-tech industry [16]. At the same time, many scholars used quantity methods to analyze the relationship. Xu (2012) examined the correlation between the number of institutions of higher learning and the added value of high-tech industries of Guangdong Province [17]. Spinesi et al. (2013) used mathematics model to study the interaction between universities and high-tech industry R&D [18].

Scholars from various disciplines have explored the relationship between higher education and high-tech industry from different perspectives. Although the aforementioned studies have lent support to the nature and importance of the university-industry relationship, there has been little written on how to evaluate this relationship and how to promote this relationship. Thus, this study uses coupling theory and grey relational theory to understand the internal mechanisms, and intends to contribute towards the theme's state-of-the-art.

3. Research Method

3.1. Coupling and Coordination Degree Model

Since the concept of coupling was proposed during the research on social livelihood [19], this method has been used in many fields.

3.1.1. Efficacy Function

We suppose $u_i(i=1,2,\cdots,n)$ is the ordering parameters of higher education and high-tech industry innovation, and μ_{ij} means indicator j of parameters i, its value is $X_{ij}(j=1,2,\cdots,m)$. α_{ij}, β_{ij} are maximum and minimum values of system critical points, respectively. The efficacy is

$$u_{ij}=\begin{cases}(X_{ij}-\beta_{ij})/(\alpha_{ij}-\beta_{ij}), u_{ij}\ has\ positive\ effect\\(\alpha_{ij}-X_{ij})/(\alpha_{ij}-\beta_{ij}), u_{ij}\ has\ negative\ effect\end{cases}$$
$$i=1,2,...,n;\ j=1,2,\ldots,m$$

In the above equation, u_{ij} is the level of satisfaction of the indicators $(0\le u_{ij}\le 1)$. The linear weighted sum method is used to calculate the total contribution of the order degree with each order parameter, that is: $u_i=\sum_{j=1}^{m}\lambda_{ij}u_{ij}$, $\sum_{j=1}^{m}\lambda_{ij}=1$, $i=1,2,...,n;\ j=1,2,\ldots,m$

In the formula above, λ_{ij} is the weight of the various indicators of subsystems and can be obtained by variation coefficient method.

3.1.2. Coupling Coordination Function

If the system includes only two elements, then the coupling degree model of multiple elements interplay is: $C=\left\{(u_1\times u_2)/[(u_1+u_2)^2]\right\}^{1/2}$

In this study u_1 is the higher education and u_2 is the high-tech industry innovation. Coupling degree (C) could be divided into three levels: the low level $(0<C\le 0.3)$, the moderator level $(0.3<C\le 0.7)$ and the high level $(0.7<C<1)$.

In order to reflect the effectiveness, we modify the coupling degree to evaluate the mutual coupling coordination degree (H), which is expressed as: $H=(C\times F)^{1/2}$, $F=\alpha u_1+\beta u_2$

F is the integrated harmonic index. α, β are undetermined coefficients. In this paper, we think that higher education has the more important role in the relationship, so α, β will be 0.6 and 0.4 respectively. Coupling coordination can be carried out four levels: the low level $(0<H\le 0.4)$, the moderate level $(0.4<H\le 0.6)$, the high level $(0.6<H\le 0.8)$ and the extreme level $(0.8<H<1)$.

3.2. Grey Relational Evaluation Method

The grey relational analysis has good effects on the uncertainty evaluation model of less data, fuzzy and difficult to quantify, etc. which avoids many human-made deviations caused by the knowledge level, cognitive ability and so on [20].

3.2.1. Reference Sequence

Assume that i is a serial number of evaluation unit $(i=1,2,\cdots,m)$; k is a serial number of evaluation index $(k=1,2,\cdots,n)$; v_{ik} is an evaluation value of i evaluation unit's k index.

Taking the best value v_{ok} of every index as the entity of the reference sequence V_o entities: $V_o=(v_{o1},v_{o2},..,v_{om})$, where: $v_{ok}=optimum(v_{ik})$, $i=1,2,..,m;\ k=1,2,...n$. For the system composed of m evaluation units and n evaluation indexes, there is a matrix as follows: $V=(V_{ik})_{m\times n}$. Selecting reference sequence is as follows: $V_O=(v_{o1},v_{o2},...,v_{on})$.

In order to make the comparison between indicators, each index needs to be subjected to standardized treatment: $X_{ik}=\dfrac{V_{ik}-\min\limits_{i}V_{ik}}{\max\limits_{i}V_{ik}-\min\limits_{i}V_{ik}}$

3.2.2. Relational Coefficient and Grade

Take the standardized sequence $X_o = (x_{o1}, x_{o2}, ..., x_{on})$ as the reference sequence and $X_i = (x_{i1}, x_{i2}, ..., x_{in})$ as the comparative sequence. The algorithm for the relational coefficient is as follows:

$$\xi_{ik} = \frac{\min_i \min_k |X_{ok} - X_{ik}| + \rho \max_i \max_k |X_{ok} - X_{ik}|}{|X_{ok} - X_{ik}| + \rho \max_i \max_k |X_{ok} - X_{ik}|},$$

$i = 1, 2, .., m;\ k = 1, 2, ...n$

where ρ is the distinguishing coefficient, usually, ρ =0.5.

Using the formula to calculate correlative coefficient ξ_{ik}, we can get a correlation coefficient matrix as follows: $E = (\xi_{ik})_{m\times n}$, where ξ_{ik} is the correlation coefficient of the k index and the k best index of the first evaluation unit.

The calculation of relational grade uses relational coefficient multiplying by weight. According to the subjective order relation index, we get all levels of index weights for: $W = (w_1, w_2, .., w_n)$, $\sum_{k=1}^{t} w_k = 1$, t shows the index quantity of this layer. The algorithm for relational grade is as follows: $R = (r_i)_{1\times m} = (r_1, r_2, ..., r_m) = WE^T$.

4. Empirical Analysis

4.1. Evaluation Index and Data Source

The establishment of the index system is the foundation of the assessment. It is a dialectical logic thinking process. Therefore, the scientific accuracy of the establishment of the index system is of key importance.

Different from other industries, high-tech industry emphasizes more on research and development (R&D). Past studies suggested that the evaluation index system of high-tech industry innovation should be divided into innovation input and innovation performance. Innovation input mainly evaluates the full-time equivalent of R&D personnel (I1), intramural expenditure on R&D (I2). Innovation performance is measured by the motivation of high-tech industry technological innovation, which means evaluating from the sales revenue of new products (I3), the number of patent applications (I4) and the number of patents in force (I5).

Similarly, some studies also analyze the index system of R&D of higher education from inputs and outputs. The evaluation index system of R&D of higher education is divided into two parts: innovation input and innovation performance. Innovation input evaluates the full-time equivalent of R&D personnel (E1) and intramural expenditure on R&D (E2). Innovation performance is measured by the scientific papers issued (E3), publication on science and technology (E4), and number of patent applications (E5).

4.2. Data Sources and Preprocessing

This study takes Shandong Province as the research object. The original data in this paper are derived from official statistics. The technological innovation indexes of high-tech industry are originated from China Statistics Yearbook on High Technology Industry. The indexes of higher education are derived from Compilation of Scientific and Technical Statistics of Colleges and Universities. These data range from 1995 to 2015.

Using the official statistics data, the original index data are showed in Table 1. By the use of formula to calculate the contribution of various subsystems for order system, this study mainly derived various order parameters and their evaluation indicators weight by using variation coefficient method. The results are shown in Table 2.

4.3. Coupling Coordination Degree Analysis

Using the formula to calculate the coupling and coupling coordination degree of various subsystems for order system, which are showed in Table 3. This study mainly derived the values to analyze the coupling situation and its change.

According to the changes of μ_1 and μ_2 in the table 3, Shandong Province attaches great importance to higher education, and the degree of attention gradually improved. The high-tech industry has not been widely developed before 2003. But since 2003, Shandong Province has laid claim to technology, and the effect of technological innovation has greatly increased.

Table 1. *The original data matrix.*

Year	I1	I2	I3	I4	I5	E1	E2	E3	E4	E5
1995	941	2279	238194	27	19	6916	120513	395	12268	245
1996	822	8164	231216	34	19	6655	143823	384	13639	199
1997	3329	20852	455167	81	32	6954	191777	408	14458	230
1998	3464	26047	60364	114	92	6688	217224	330	15256	197
1999	4009	35710	818737	141	63	6827	257094	310	14494	182
2000	3195	49329	1229598	155	97	5819	329540	374	13281	210
2001	3852	104919	1576624	259	57	6162	423316	411	14670	210
2002	3852	122772	2008160	421	157	6775	574290	366	17574	257
2003	5878	125808	2331377	589	85	7573	682931	867	19219	613
2004	4978	176439	4155318	789	180	8691	1048737	535	21976	755
2005	5836	267923	3971258	991	247	9308	1231029	553	24186	677
2006	7717	299790	4763455	1102	314	8252	1502111	561	27697	412
2007	9850	440205	7129663	1491	595	9193	1741491	516	29520	364
2008	13449	526931	8389480	2058	777	10067	2172991	600	34361	350
2009	17681	600638	9848807	3371	1758	9850	2325005	598	33711	1236
2010	15618	612385	11133363	3087	1268	9970	3033856	523	33741	287

Year	I1	I2	I3	I4	I5	E1	E2	E3	E4	E5
2011	29244	989971	15364345	5611	2375	11689	3667651	398	32890	332
2012	37499	1345637	17621221	6970	3912	11396	4274269	384	34229	406
2013	46887	1562172	18191965	8106	4667	12609	4701228	415	37464	367
2014	49122	1760079	19399769	9775	6883	14666	4777257	704	40926	452
2015	50774	2076753	26901847	11527	9569	14252	4883817	713	39667	338

Table 2. *The results of order parameters and indicators weight.*

Order parameters	Indicators	σ	$\bar{x}$	Weight
Higher Education (u_1)	Full-time R&D Personnel (E1)	0.367	0.297	0.161
	Allocate Funds for Science and Technology (E2)	0.358	0.361	0.257
	Number of Published Academic Works (E3)	0.328	0.260	0.149
	Number of Academic Papers Published (E4)	0.445	0.348	0.172
	Number of Technology Transfer Contracts (E5)	0.203	0.237	0.261
High-tech industry (u_2)	Full-time Equivalent of R&D Personnel (I1)	0.287	0.338	0.167
	Intramural Expenditure on R&D (I2)	0.255	0.308	0.181
	Sales Revenue of New Products (I3)	0.274	0.293	0.152
	Patent Applications (I4)	0.232	0.309	0.213
	Number of Patents in Force (I5)	0.163	0.272	0.286

Table 3. *Results of coupling coordination evaluation.*

Year	u_1	u_2	C	F	H
1995	0.058331	0.001407	0.303254	0.035561	0.085625
1996	0.048709	0.001614	0.35234	0.029871	0.084887
1997	0.07575	0.013635	0.719083	0.050904	0.166345
1998	0.048028	0.01471	0.847335	0.034701	0.154133
1999	0.039085	0.02131	0.955713	0.031975	0.164808
2000	0.041392	0.023389	0.960611	0.034191	0.171421
2001	0.070918	0.033144	0.931792	0.055809	0.212044
2002	0.107254	0.043153	0.904638	0.081613	0.249466
2003	0.359643	0.052982	0.669074	0.236978	0.342812
2004	0.362707	0.071301	0.74107	0.246145	0.373122
2005	0.382522	0.086877	0.776728	0.264264	0.399167
2006	0.335419	0.104511	0.851179	0.243056	0.409360
2007	0.352493	0.152973	0.9188	0.272685	0.462471
2008	0.439701	0.195699	0.923328	0.3421	0.520396
2009	0.659005	0.278307	0.913802	0.506726	0.627273
2010	0.444468	0.259777	0.964999	0.370592	0.567429
2011	0.482637	0.442307	0.999049	0.466505	0.676759
2012	0.532633	0.585055	0.998899	0.553602	0.750643
2013	0.595792	0.682292	0.997707	0.630392	0.803870
2014	0.756457	0.811265	0.999389	0.77838	0.888177
2015	0.721278	1.000000	0.986803	0.832767	0.936368

According to the results of table 3, the coupling degree between higher education and high-tech industry innovation in Shandong Province was in a state of imbalance from 1995 to 2007, which gradually changed from barely coordinated to high-quality coordination from 2007 to 2015. Coupling coordination degree increased over the study period, and had maintained a high level since 2013. These suggested that Shandong Province has always attached importance to the university-industry linkages.

4.4. Grey Relational Evaluation

In order to make a more objective and reasonable explanation for the deep relationship between high-tech industry innovation and higher education in Shandong Province, we use the gray correlation analysis method to calculate the relational coefficient and grey relational grade. The results are shown in Table 4, 5.

Table 4. *Influencing factors of High-tech industry.*

Index	I1	I2	I3	I4	I5
Grey Degree	0.7472	0.8513	0.7437	0.9091	0.7012
Gray Sequence	I4 > I2 > I1 > I3 > I5				

Table 4 shows that Patent Applications (I4) and Intramural Expenditure on R&D (I2) are most important force to promote the innovation activities of high-tech industry. If they can be used in industry innovation processes, they will realize the transformation of knowledge to practice and become stronger force to promote innovation.

Table 5. *Influencing factors of higher education.*

Index	E1	E2	E3	E4	E5
Grey Degree	0.8085	0.7642	0.7657	0.7486	0.7002
Gray Sequence	E1 > E3 > E2 > E4 > E5				

Table 5 shows that Full-time R&D Personnel (E1) and Number of Published Academic Works (I3) have the greatest impact on the level of education, while Number of Academic papers published and Number of Technology transfer contracts impact little. It corresponds to the situation of academic field in China. The ability of scientific and technological output of scholars is weak, and the ability of technology conversion is insufficient.

5. Conclusions and Policy Implications

Using the data from Shandong Province, this paper investigates the coupling development between higher education and high-tech industry innovation based on coupling coordination degree and grey relational evaluation, and draws the following conclusions:

Firstly, there is a positive correlation between innovation of higher technology industry and higher education in Shandong Province. So the promotion of higher education will lead to the improvement of the innovation level of high-tech industries and vice versa.

Secondly, the level of coupling coordination between the innovation of high-tech industry and higher education in Shandong Province only reached the first-time high-quality coordination in 2015, and there is still room for improvement in the development of the two systems.

Thirdly, according to the results of grey relational analysis, practical measures should be formulated. It is necessary to increase investment in R&D activities of high-tech industry, obtain more output, and enhance synergetic innovation. Meanwhile, it is also important to encourage the output of academic papers and realize more technology transfer activities.

Obviously, the paper has a number of limitations that call for future research. A promising avenue for future research could be a deep investigation of coupling development, which will be achieved by the use of case study. Furthermore, it could be interesting to further investigate the impact of regional institutional environment on the coupling relationship of the two systems.

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