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Research Article

Evaluation of the Production-Education Integration Performance of the High-Tech Industry: An Empirical Comparison between Three Urban Agglomerations in China

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Deepening production-education integration (PEI) is a major strategy of China to reinforce education reform and promote industry transformation. Different from the traditional research perspective of colleges on the supple side, this paper chooses to evaluate the PEI performance of the high-tech industry from the angle of industry on the demand side. Firstly, the action mechanisms of the education system and industry system in PEI were expounded, and the design framework of the evaluation index system (EIS) was derived from the interactions between two elements (technologies and talents) and two market relationships (supply and demand), forming a two-dimensional four-quadrant EIS. On this basis, the correlation-entropy composite matter-element (CECME) model and coupling coordination degree (CCD) model were introduced to empirically compare the PEI performance of the high-tech industry between Guangdong-Hong Kong-Macao (GHKM) Greater Bay Area, Beijing-Tianjin-Hebei (BTH) Urban Agglomeration, and Yangtze River Delta (YRD) Urban Agglomeration. The main conclusions are as follows: (1) the GHKM Greater Bay Area is far better in education and industry development than YRD Urban Agglomeration and BTH Urban Agglomeration; (2) the PEI performance of the high-tech industry in GHKM Greater Bay Area was evaluated as high level with industry in lead, that in YRD Urban Agglomeration as moderate level with education in lead, and that in BTH Urban Agglomeration high-tech industry PEI as moderate level with industry in lag. Finally, several countermeasures were proposed for the urban agglomerations to further enhance the PEI performance of the high-tech industry: GHKM Greater Bay Area should improve the weak link of education development; YRD Urban Agglomeration should give full play to its advantages in higher education; BTH Urban Agglomeration should focus on high-quality industry development. From the practical level, this paper objectively evaluates the actual performance of PEI and provides a reference for scientific policymaking of PEI development.

1. Introduction

Originating from practical productions in human society, education and industry gradually evolve into independent systems, as production gets more and more complicated, and the division of labor becomes more refined. The education system is responsible for summarizing and imparting practical knowledge of production, while the industrial system is the main source of education knowledge system. The interaction and integration between the two systems could bring huge economic and social benefits [1]. In the era of knowledge economy, the two independent systems slowly intermingle. It is an inevitable trend for education and industry to realize resource-based coupling development [2], which contributes greatly to the health and sustainable development of the economy [3]. However, the supply side of scientific research and talent training in Chinese colleges is not fully compatible with the demand side of the industry, in terms of structure, quality, and level. The supply-side reform of human resources must deepen production-education integration (PEI) and enhance the organic cohesion between education chain, talent chain, industry chain, and innovation chain.

Against this backdrop, China has recently regarded the deepening of PEI as an important direction and effective means to promote industrial transformation and education reform and formulated and enacted a series of policies on PEI promotion. On the 19th National Congress, the ruling party clearly proposed the task of deepening PEI reform. After that, several leading departments of the Chinese government rolled out policies on the top-level design and implementation scheme of PEI deepening, such as *Several Opinions Regarding PEI Deepening*, *Implementation Measures for Construction of PEI Enterprises (Trial)*, *Implementation Plan for National Pilot Programs of PEI Construction*, and *Work Plan for National Pilot Programs of Construction of PEI Enterprises*. These policies elevate PEI to a key support strategy for innovation-driven development. In July, 2021, China official released *List of National PEI Enterprises* and *List of National Pilot Cities for PEI*, which specify 21 national PEI pilot cities, including Shenzhen and Guangzhou, as well as 63 national PEI enterprises, such as China General Nuclear (CGN) Power Group and Tencent. The pilot and demonstration programs in these cities and enterprises speed up the reform and innovation of PEI, a sign of marked progress and positive results of PEI deepening in China.

Nevertheless, China still faces a string of theoretical and practical problems in PEI: the absence of a complete set of evaluation criteria and methods for PEI effect; the structural conflict of the detachment between education and industry supply/demand. The scientific evaluation of PEI performance helps to identify the evaluation indices and mechanism of PEI performance, reasonably evaluate the actual PEI effect, and improve the integration quality through monitoring and regulation [2]. To deepen PEI, China must solve this key theoretical and practical problem, i.e., the scientific evaluation of PEI performance. Like practitioners, theorists also attach great importance to PEI. Focusing on colleges, the relevant scholars have discussed the main measures of PEI promotion from the aspects of discipline construction, organizational innovation, and education structure.

As the leading promoters of PEI, colleges should design and adjust disciplines in strict accordance with the philosophy, goals, and requirements of PEI, trying to integrate PEI in the whole education process of disciplines like geology and medicine [4, 5]. During the promotion of discipline construction, colleges could choose between multiple modes according to the topology and internal links between disciplines and industries: the docking mode between discipline cluster and industry cluster, the docking mode between discipline chain and industry chain, and the driving mode of emerging and frontier disciplines [6]. Compared to traditional education modes, PEI requires college development to reach higher goals (e.g., emphasizing the capabilities of practical application and market adaptation over the number of students), posing a new challenge to the management mode of colleges. While promoting PEI, colleges should accelerate organizational innovation and adapt better to external system and internal culture [7], thereby enhancing the PEI effect.

In the higher education system, different types of colleges have different statuses and thus take varied measures of PEI promotion. Application-oriented colleges maintain a closer relationship with the industry and undertake greater responsibilities in PEI, than other education entities. However, application-oriented colleges are often marginalized, unlike their research-oriented counterparts. During the PEI, they generally lack education fund, high-quality teachers, and a well-established discipline system. Considering the core-periphery structure of higher education system, application-oriented colleges should join forces with research-oriented colleges to promote PEI, highlight their comparative advantages and unique features, and try to realize corner overtaking as underdogs [1]. Meanwhile, the government should optimize the allocation of higher education resources, grant application-oriented colleges greater authority, and create a good external environment.

Apart from integration measures, some scholars have explored the evaluation model and indices of PEI entities. The government plays an important role in PEI through public policymaking [8]. Wang et al. [9] established an analysis framework of policy coordination and quantified the coordination of China's PEI policies, laying an important basis for the government to design scientific and effective public policies. College-Enterprise Cooperation Research Center (CECRC) provides colleges and enterprises with a key platform to advance PEI. Based on the functional goals of PEI, CECRC can be evaluated by analytic hierarchy process (AHP), under a multilevel objective system, which includes pursuit of research, producing graduates, and accelerating knowledge and technology transfer [10, 11]. Partnership evaluation is another core issue in PEI entity evaluation. The partnership between entities can be evaluated in reference to the European Foundation for Quality Management (EFQM) model [12], supported by a comprehensive evaluation system of micro-, meso-, and macrolevel indices [13]. To judge the satisfaction with the partnership between entities, Suh et al. [14] constructed satisfaction index, dissatisfaction index, and potential customer satisfaction improvement (PCSI) index and carried out evaluation by the Kano model.

The existing research stresses the important role of colleges in PEI and discusses the measures for the colleges to promote PEI. In addition, PEI evaluation is examined from the angle of entity partnership. Many PEI evaluation models and indices have been developed, providing an important reference for our research. PEI mainly covers two major systems: education and industry. On market supply and demand, the education system is the main supplier of PEI, while the industry system is the main demander. The two systems complement each other, forming a complete system of PEI. As the core entities of education, colleges have attracted much attention from PEI researchers. By contrast, enterprises, as the representatives of industry, have been largely ignored. There is virtually no report on PEI from the perspective of enterprises, leaving a huge gap in PEI research. Furthermore, the promotion of PEI mainly aims to enhance the matching between industry and education resources; that is, the actual utility of talents and technologies from the education system must be evaluated through the market inspection of the industry system. This is the starting point of PEI performance evaluation. However, few scholars have discussed the theoretical results of PEI performance evaluation from the angle of industry entities. This paper attempts to innovatively make up for the above two gaps.

The remainder of this paper is organized as follows: Section 2 designs an evaluation index system (EIS) for PEI performance of high-tech industry; Section 3 constructs an evaluation model for PEI performance of high-tech industry; Section 4 empirically analyzes the PEI performance evaluation of high-tech industry; Section 5 draws the conclusions and presents several suggestions.

2. EIS Design

2.1. Theoretical Bases. From the perspective of systems theory, PEI is a large system formed by the integrated development of education system and industry system. In the education system, schools, especially colleges, are the core education entities. They are responsible for talent training, scientific research, social service, and cultural inheritance. In the industry system, enterprises, especially high-tech enterprises, are the core market entities. They are responsible for technological innovation, production development, job creation, and text contribution.

Despite their difference in function orientation, the two systems are inherently consistent in function implementation under PEI conditions. Through scientific research and talent training, colleges provide important technologies and talents to enterprises, enabling them to realize technological innovation and production development. Whether colleges have implemented functions like scientific research and talent training needs to be inspected and evaluated in the market. The market inspection checks if the talents trained by colleges meet the needs of industry development, and the scientific research in colleges could be transformed into productivity. Through market feedbacks, the enterprise demand for talents and technologies will influence the direction and method of scientific research and talent training in colleges.

In the PEI, education system and industry system are bridged up by talents and technologies, forming a complementary intrinsic correlation via the market supply and demand (Figure 1). Accordingly, the connotation of "PEI of high-tech industry" is defined as a cooperation mode in which colleges and high-tech enterprises conduct deep cooperation in technological innovation and talent training under the guidance of the demand in high-tech industry and then gradually form a benign coupling relationship, based on the organizational function positioning and market supply and demand relationship. The intrinsic correlation lays the theoretical basis for setting up the EIS for PEI performance of high-tech industry.

2.2. Index Screening. According to the intrinsic correlation between education system and industry system in PEI, the following structural relationships should be emphasized in the evaluation of PEI performance of high-tech industry: in the PEI, the two types of entities, namely, colleges and high-tech enterprises, generate two basic market relationships, i.e., supply and demand, relying on two core elements, i.e., technologies and talents. Based on the two elements and two market relationships, this paper builds up a two-dimensional four-quadrant EIS, including the technology supply and talent supply of colleges, and the technology demand and talent demand of high-tech industry (Figure 2).

Under the EIS, four primary evaluation indices were defined for PEI performance of high-tech industry: technology supply, talent supply, technology demand, and talent demand. The secondary indices were screened, referring to the EISs for PEI performance proposed by HellstrÖm and Jacob [15], Chen et al. [2], etc. Considering index completeness and data availability, this paper presents an EIS for PEI performance of high-tech industry. Under the entities of colleges, the primary index of technology supply contains three secondary indices: technical project supply, technical patent supply, and technical results supply; the primary index of talent supply contains three secondary indices: research and development (R&D) personnel supply, college student supply, and college students' working ability. Under the entities of high-tech enterprises, the primary index of technology demand contains three secondary indices: technology purchase demand, technology introduction demand, and technology cooperation demand; the primary index of talent demand contains three secondary indices: talent quantity demand, talent quality demand, and talent demand structure (Table 1).

3. Model Construction

3.1. Basic Ideas. The evaluation of PEI performance intends to measure and analyze the level of integrated development between industry system and education system in PEI, that is, assessing the coupling coordination degree (CCD) between the two systems. The CCD refers to the degree of benign coupling of each system during mutual coupling and reflects the coordination between systems. According to the calculation model of the CCD model, the CCD between industry system and education system needs to be measured with the development levels of the two systems as independent variables. Therefore, this paper decides to evaluate the PEI performance of high-tech industry in two steps: first, setting up a mathematical model for the development levels of education system and industry system, based on the proposed EIS, and second, substituting the development levels of the two systems into the CCD model as independent variables, outputting the PEI performance level of high-tech industry.

(1) Constructing composite matter-element model for evaluation the development level of education system or industry system:

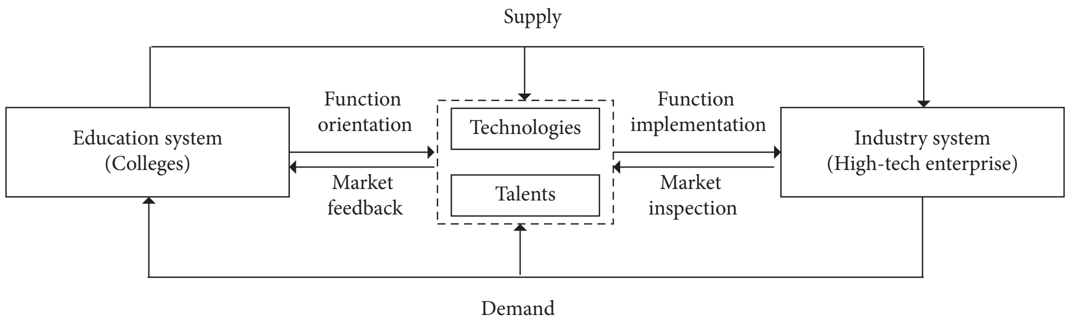

FIGURE 1: Intrinsic correlation between the education system and industry system in PEI.

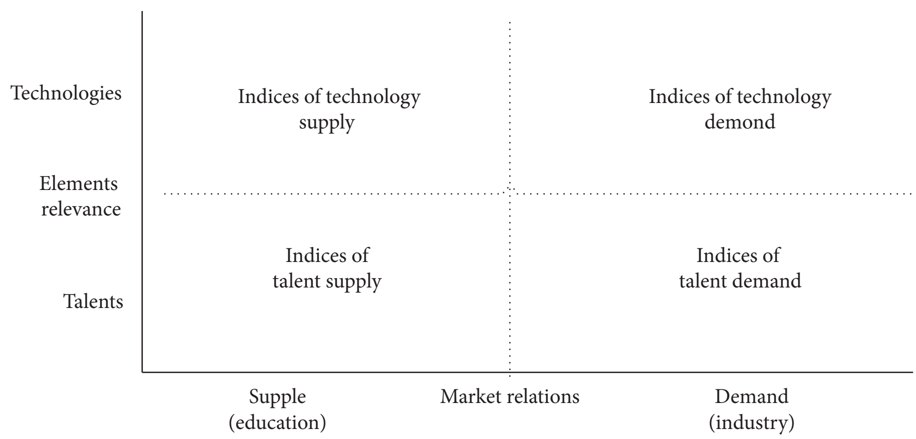

FIGURE 2: Two-dimensional four-quadrant EIS for the PEI performance in the high-tech industry.

TABLE 1: EIS for PEI performance in the high-tech industry.

PEI entity	Primary index	Secondary index	Measurement	Source
Colleges	Technology supply	Technical project supply	Expenditure on R&D results and scientific services (10,000 yuan)	*Statistical Compilation of Higher Education Science and Technology*
		Technical patent supply	Total patent sales (10,000 yuan)	
		Technical results supply	Amount of technology transformation contracts (10,000 yuan)	
	Talent supply	R&D personnel supply	Number of R&D personnel in colleges (10,000 people)	
		College student supply	Number of college graduates (10,000 people)	Local statistical yearbooks
		College students' working ability	Employer satisfaction with graduates (%)	Sample investigation
High-tech enterprises	Technology demand	Technology purchase demand	Expenditure on domestic technologies (10,000 yuan)	*China Statistical Yearbook on Science and Technology*
		Technology introduction demand	Expenditure on foreign technologies (10,000 yuan)	
		Technology cooperation demand	Proportion of cooperative R&D projects in enterprise R&D projects (%)	Sample investigation
	Talent demand	Talent quantity demand	Number of new jobs (10,000 people)	Local statistical yearbooks
		Talent quality demand	Proportion of local employment in local college graduates (%)	Regional reports on employment of college graduates
		Talent demand structure	Proportion of immigrants in local permanent residents (%)	Local statistical yearbooks

If there are M areas with N measure indices, it is called N dimensional composite matter-element of M areas, denoted as R_{mn}.

$$R_{mn} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ C_1 & x_{11} & x_{21} & \cdots & x_{m1} \\ C_2 & x_{12} & x_{22} & \cdots & x_{m2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & x_{1n} & x_{2n} & \cdots & x_{mn} \end{bmatrix}. \quad (1)$$

In the formula, M_i is the ith measure sample, C_j is the jth measure index, and its corresponding value is x_{ij}.

(2) Standardizing the index value:

In order to eliminate the dimension to keep the consistency and comparability of measurement data, indices values should be standardized.

Let $J^+ = \{\text{benefit indices}\}$, $J^- = \{\text{cost indices}\}$, and $J^{\text{interval}} = \{\text{interval indices}\}$; then,

$$\begin{gathered} \mu_{ij} = \frac{\left(x_{ij} - \min_{1\le i\le n} x_{ij}\right)}{\left(\max_{1\le i\le n} x_{ij} - \min_{1\le i\le n} x_{ij}\right)}, \quad \left(i = 1, 2, \ldots, n;\ j \in J^+\right), \\ \mu_{ij} = \frac{\left(\max_{1\le i\le n} x_{ij} - x_{ij}\right)}{\left(\max_{1\le i\le n} x_{ij} - \min_{1\le i\le n} x_{ij}\right)}, \quad \left(i = 1, 2, \ldots, n;\ j \in J^-\right), \\ J^+ = \{\text{benefit indices}\}, J^- = \{\text{cost indices}\}, J^{\text{interval}} = \{\text{interval indices}\}, \\ \mu_{ij} = \begin{cases} 1 - \left[\dfrac{\max\left\{c_1^j - x_{ij}, x_{ij} - c_2^j\right\}}{\max\left\{c_1^j - \min_{1\le i\le n} x_{ij}, \max_{1\le i\le n} x_{ij} - c_2^j\right\}}\right], & v_{ij} \notin \left[c_1^j, c_2^j\right], \\ 1, & v_{ij} \in \left[c_1^j, c_2^j\right], \end{cases} \\ \left(i = 1, 2, \ldots, n;\ j \in J^{\text{interval}}\right). \end{gathered} \quad (2)$$

After standardization, R_{mn} is

$$\underset{\sim}{R}_{mn} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ C_1 & \mu_{11} & \mu_{21} & \cdots & \mu_{m1} \\ C_2 & \mu_{12} & \mu_{22} & \cdots & \mu_{m2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & \mu_{1n} & \mu_{2n} & \cdots & \mu_{mn} \end{bmatrix}. \quad (3)$$

(3) Calculating the weight of evaluation indices with correlation-entropy method:

Firstly, calculate the grey correlation coefficient of $\underset{\sim}{R}_{mn}$. The grey correlation coefficient of C_j is

$$\zeta_{ij} = \frac{\min_i \min_j \Delta_i + \rho \min_i \min_j \Delta_i}{\left|\mu_{ij} - y_j\right| + \rho \max_i \max_j \Delta_i}, \quad (4)$$

where ρ is resolution coefficient, under normal conditions, $\rho = 0.5$.

Then, calculate entropy of measure indices. The entropy of C_j is

$$\begin{gathered} F_j = -(\ln m)^{-1} \sum_{i=1}^{m} \frac{\zeta_{ij}}{\sum_{i=1}^{m} \zeta_{ij}} \ln \frac{\zeta_{ij}}{\sum_{i=1}^{m} \zeta_{ij}}, \\ (= 1, 2, \ldots, m;\ j = 1, 2, \ldots, n). \end{gathered} \quad (5)$$

Finally, determine the weight of measure indices. According to deviation degree $k_j = 1 - F_j$, the weight of C_j is $\omega_j = k_j / \sum_{j=1}^{n} k_j$. Then construct the complex matter-element model of evaluation indices weight:

$$R_{\omega j} = \begin{bmatrix} & C_1 & C_2 & \cdots & C_n \\ \omega_j & \omega_1 & \omega_2 & \cdots & \omega_n \end{bmatrix}. \quad (6)$$

(4) Evaluating the results of development level:

$\underset{\sim}{R}_{mn}$ and $R_{\omega j}$ constitute complex correlation-entropy matter-element $\underset{\sim}{R}_{mH}$:

$$\underset{\sim}{R}_{mH} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ H_i & H_1 & H_2 & \cdots & H_m \end{bmatrix}$$
$$= \begin{bmatrix} & M_1 & \cdots & M_i & \cdots & M_m \\ H_i & -\sum_{j=1}^{n} P\left(\omega_j \mu_{1j}\right) \ln P\left(\omega_j \mu_{1j}\right) & \cdots & -\sum_{j=1}^{n} P\left(\omega_j \mu_{ij}\right) \ln P\left(\omega_j \mu_{ij}\right) & \cdots & -\sum_{j=1}^{n} P\left(\omega_j \mu_{mj}\right) \ln P\left(\omega_j \mu_{mj}\right) \end{bmatrix}, \quad (7)$$

where $P(\omega_j \mu_{ij}) = \omega_j \mu_{ij} / \sum_{j=1}^{n} \omega_j \mu_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$, and H_i is the measure value of item ith zone. The bigger the value, the better the development level.

3.2. Correlation-Entropy Composite Matter-Element (CECME) Model. PEI research started relatively late. As a result, there is not yet a perfect evaluation criterion, or a unified statistical caliber. Therefore, it is relatively fuzzy to fully evaluate the development levels of education and industry systems in PEI. The fuzziness can be dealt with by the grey system theory.

The education system outputs technologies and talents and imports them to the industry system through the market supply system. Relying on the elements of technologies and talents, the two systems transmit information to each other and mutually influence each other. The interaction between the two systems carries the basic features of the information theory. In that theory, the amount of information is measured by entropy. If an index has a high entropy, then it must contain lots of information and should be assigned a large weight.

Drawing on the above features and the results of Zhang et al. [16], this paper combines information theory, entropy theory, and the correlation degree method of grey system theory and evaluates the development levels of the systems in PEI with improved CECME model. The construction of the CECME model is introduced below.

3.3. CCD Model. Referring to the physical model of capacity coupling coefficient, this paper firstly constructs a coupling degree model for PEI system evaluation in high-tech industry:

$$C = \sqrt{4U_1U_2 / \left(U_1 + U_2\right)^2}, \quad (8)$$

where C is the coupling degree and U_1 and U_2 are the development levels of education system and industry system, respectively. C falls in the interval of [0, 1]. The greater the C value, the more intense the mutual influence between the two systems.

However, the coupling degree cannot effectively differentiate between high-level coupling and low-level coupling. The education system and industry system might be strongly coupled, when both of them are on low levels, putting the evaluation accuracy at stake. Inspired by Liu et al. [17], this paper introduces the CCD model to evaluate the coupling quality between systems:

$$D = \sqrt{C \times T}, \quad T = \alpha U_1 + \beta U_2, \quad (9)$$

where D is the CCD, T is the evaluation index for the development level of each system, and α and β are parameters to be determined ($\alpha + \beta = 1$). Since education and industry are the supply subject and demand subject of the core elements of PEI, respectively, which are the two sides of the coin of PEI in market competition, thus the education system is of equal importance as industry system in PEI system; this paper sets both α and β to 0.5. D falls in the interval of [0, 1]. The greater the D value, the better the coordination between the two systems, and the higher the PEI performance of high-tech industry.

4. Empirical Analysis

4.1. Object Selection and Data Sources. This paper chooses three urban agglomerations in China for comparative analysis, namely, Guangdong-Hong Kong-Macao (GHKM) Greater Bay Area, Beijing-Tianjin-Hebei (BTH) Urban Agglomeration, and Yangtze River Delta (YRD) Urban Agglomeration [18,19]. These regions were selected for the following advantages: the three urban agglomerations boast the earliest integrated development, most advanced economy, and most mature collaboration networks in China. In 2019, the three regions created a gross domestic product (GDP) as high as 42.95 trillion yuan (excluding Hong Kong and Macao), about 43.5% of China's total GDP. Suffice it to say, the three regions are the pillars of China's economic growth and regional coordinated development.

The three urban agglomerations have the most developed higher education resources and high-tech industry in China. In 2019, GHKM Greater Bay Area, BTH Urban Agglomeration, and YRD Urban Agglomeration owned 184, 280, and 413 colleges, and 13,000 (excluding Hong Kong and Macao), 43,000, and 61,000 high-tech enterprises, respectively. Overall, the three regions are home to 30% of colleges and 52% of high-tech enterprises in China. Owing to advanced higher education system and high-tech industry, the three urban agglomerations are key pilot regions of PEI in China. Three cities and 27 enterprises (76% of the national total) are among the first batch of PEI promotion.

Nonetheless, the development data on Hong Kong and Macao are not available in China's national statistical data. To ensure availability of data and consistency between comparative objects, the core regions of the three urban agglomerations were taken for empirical comparison: Guangdong, Beijing, and Shanghai were chosen as the representative regions of GHKM Greater Bay Area, BTH Urban Agglomeration, and YRD Urban Agglomeration, respectively, for empirical comparison of PEI performance of high-tech industry, in which the main reasons were as follows: the PEI of high-tech industry mainly involves two types of systems of knowledge and technology intensive, that is, higher education and high-tech industry. In China, the elements of knowledge and technology intensive have the typical characteristics of central-city agglomeration. As the science and education center and the economic center of China, Beijing and Shanghai occupy the undisputed central-city status in the urban agglomerations of BTH and YRD, respectively. In the GHKM Greater Bay Area, the scale of higher education and high-tech industry in Guangdong far exceeds that of Hong Kong and Macao. Considering the special systems in Hong Kong and Macao, it is scientific and feasible to represent the GHKM Greater Bay Area by Guangdong. The relevant data were mainly collected from official statistical data in 2020, including *Statistical Compilation of Higher Education Science and Technology, 2020*, *China Statistical Yearbook on Science and Technology, 2020*, as well as the local statistical yearbooks issued by Guangdong, Beijing, and Shanghai in 2020. Due to the lack of statistical caliber, some data were obtained through sample investigation on representative colleges and high-tech enterprises in the three urban agglomerations.

4.2. Evaluation Process and Results

4.2.1. Weight Calculation. Following the construction steps of CECME model, this paper assigns weights to indices on each level of education and industry systems by entropy method, based on the data on education and industry development in the three urban agglomerations. The assigned weights are recorded in Table 2. It can be seen that the two primary indices, namely, technology supply and talent supply, of education system had very close weights, indicating that the two indices are of equal importance. In the industry system, the weight of technology demand was 0.0922 greater than that of talent demand, suggesting the former is relatively more important in the evaluation of industry system.

Table 2: Weights of evaluation indices.

Primary index	Weight	Secondary index	Weight
Technology supply	0.4901	Technical project supply	0.2975
		Technical patent supply	0.4227
		Technical results' supply	0.2798
Talent supply	0.5099	R&D personnel supply	0.2880
		College student supply	0.3973
		College students' working ability	0.3147
Technology demand	0.5461	Technology purchase demand	0.3826
		Technology introduction demand	0.3643
		Technology cooperation demand	0.2531
Talent demand	0.4539	Talent quantity demand	0.4023
		Talent quality demand	0.3254
		Talent demand structure	0.2724

4.2.2. Development Levels of the Two Systems. Under the above indices and model, the data on education and industry development in Guangdong, Beijing, and Shanghai were imported to the CECME model to evaluate the development levels of education and industry systems in the three urban agglomerations (Table 3).

Based on the data in Table 3, this paper compares the development levels of the two systems in high-tech industry of the three urban agglomerations.

The first is to compare the development levels of education system between the three regions. The development level of education system in Guangdong in 2019 achieved a score of 0.7689, which is 0.1803 and 0.2998 higher than those of Shanghai and Beijing, respectively. Besides, Guangdong had an obvious superiority in technology supply and talent supply. The advantage in talent supply was particularly prominent, whose score was 0.2259 and 0.3710 higher than that in Shanghai and Beijing, respectively. Therefore, the GHKM Greater Bay Area, which is represented by Guangdong, is far better in education system development than YRD Urban Agglomeration, which is represented by Shanghai, and BTH Urban Agglomeration, which is represented by Beijing. Although Beijing and Shanghai possess more high-level colleges (e.g., Double First-Class colleges), the number of college and the number of college graduates in Guangzhou almost equal those of Beijing and Shanghai combined. In 2019, there were 154 colleges and 539,200 college graduates in Guangdong, far more than those in Shanghai (64; 175,600) and Beijing (93; 237,000). Colleges and their graduates are the most important organization entities and individual entities of PEI. Every year, GHKM Greater Bay Area trains over 500,000 college graduates, which provides a constant intelligent flow to the high-tech industry development in the region. Furthermore, Guangdong colleges are more active in patent transfer than their counterparts in Beijing and Shanghai. In 2019, the patent sales of Guangdong colleges amounted to 604.146 million yuan, eight and four times that of Beijing and Shanghai, respectively. Therefore, Guangdong colleges offer richer technology resources for high-tech industry development, which in turn promotes regional PEI.

The second is to compare the development levels of industry system between the three regions. The development level of industry system in Guangdong in 2019 achieved a score of 0.9176, which is 0.4308 and 0.5412 higher than that in Shanghai and Beijing, respectively. Besides, Guangdong had an obvious superiority in technology demand and talent demand. The advantage in technology demand was particularly prominent, whose score was 2.5 times and 3 times that of Shanghai and Beijing, respectively. This means GHKM Greater Bay Area far exceeds YRD Urban Agglomeration and BTH Urban Agglomeration, in the development level of industry system. Guangdong enjoys the most developed high-tech industry in China. In 2019, Guangdong spent a total of 22.53307 billion yuan on domestic technologies, 28 times and 19 times those of Beijing and Shanghai, respectively, and 7.56216 billion yuan on

Table 3: Evaluated development levels of the two systems.

Core region	Education system	Technology supply	Talent supply	Industry system	Technology demand	Talent demand
Guangdong	0.7680	0.7182	0.8158	0.9176	1.0000	0.8184
Beijing	0.4682	0.4926	0.4448	0.3764	0.3333	0.4282
Shanghai	0.5877	0.5854	0.5899	0.4868	0.3982	0.5934

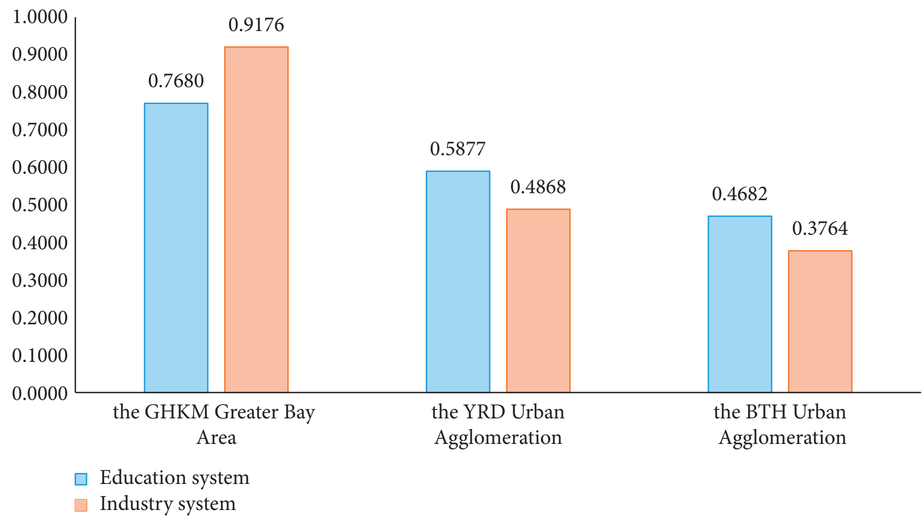

Figure 3: The development levels of two systems in three urban agglomerations.

foreign technologies, 18 times and 7 times those of Beijing and Shanghai, respectively. Therefore, the internal technology innovation of high-tech industry in GHKM Greater Bay Area falls short of the industry development demand, creating a huge demand for technology resources from external sources like colleges. The frequent technology transactions in high-tech industry significantly promote the regional PEI. In the meantime, GHKM Greater Bay Area had stronger attraction to talents than the other two urban agglomerations. About 71.85% of college students trained in GHKM Greater Bay Area eventually work in this region, far higher than the proportions of Beijing (42.69%) and Shanghai (57.34%). Each year, the local colleges in GHKM Greater Bay Area alone cultivate 286,000 high-quality talents than those in BTH Urban Agglomeration and YRD Urban Agglomeration. In each year, 387,400 college students join the labor force of GHKM Greater Bay Area and work hard to promote the development of the local economy. These talents not only offer high-quality labor for regional high-tech industry development but also enhance regional PEI.

The third is to compare the development levels of education system and industry system. In Guangdong, the development level of education system in 2019 was 0.1496 lower than that of industry system. On the contrary, development level of education system in 2019 was 0.0918 higher than that of industry system in Beijing, and 0.1009 higher than the latter in Shanghai. In terms of PEI, industry development surpasses education development in GHKM Greater Bay Area, and the opposite occurs in BTH Urban Agglomeration and YRD Urban Agglomeration (as shown in Figure 3). Thus, the three urban agglomerations should adopt differential strategies for PEI promotion. GHKM Greater Bay Area should improve the weak link of education development, trying to provide more technology support and intelligent resources to high-tech industry development. Meanwhile, BTH Urban Agglomeration and YRD Urban Agglomeration should promote the application of scientific education resources, solve the "last mile problem" of scientific results transformation, and turn the advantages of science and education resources into industrial and economic advantages.

4.2.3. CCD Measurement and Analysis. The development levels of the two systems in each region were imported to the coupling degree model and CCD model to obtain the coupling degree and CCD for the PEI of high-tech industry in each region (Table 4). Despite having slight differences, the coupling degrees of the PEI of high-tech industry in the three urban agglomerations in 2019 were all around 0.995, belonging to the same level. However, the CCDs of Guangdong, Shanghai, and Beijing were 0.9162, 0.7314, and 0.6479, respectively. Therefore, the high-tech industry in GHKM Greater Bay Area performed well in PEI, doing better than that in YRD Urban Agglomeration and BTH Urban Agglomeration.

To divide the PEI performance of high-tech industry in the three urban agglomerations into different levels, this paper defines five levels of system CCD, using the method of equal appearing intervals (Table 5). Against the defined standard, Guangdong belongs to the level of high coordination; Shanghai and Beijing belong to the level of moderate coordination. Based on these levels and the scores of the two systems, the PEI performance of high-tech industry in

Table 4: CCD of the PEI of the high-tech industry in each region.

Core region	Coupling degree	CCD
Guangdong	0.9961	0.9162
Beijing	0.9941	0.6479
Shanghai	0.9956	0.7314

Table 5: Classification standard for system CCD.

CCD	[0, 0.2]	(0.2, 0.4]	(0.4, 0.6]	(0.6, 0.8]	(0.8, 1]
Level	High incoordination	Moderate incoordination	Low coordination	Moderate coordination	High coordination

GHKM Greater Bay Area was evaluated as high level with industry in lead, that in YRD Urban Agglomeration as moderate level with education in lead, and that in BTH Urban Agglomeration high-tech industry PEI as moderate level with industry in lag.

5. Conclusions

Deepening PEI is a major strategy of China to reinforce education reform and promote industry transformation. PEI promotion helps to improve the overall quality of education quality and cultivate new drivers of economy. PEI performance offers an important yardstick of PEI development level. The actual performance of PEI can be more practically reflected by evaluating PEI performance of high-tech industry from the angle of PEI demander(s). Through empirical comparison, this paper establishes the evaluation indices and model for PEI performance of high-tech industry and chooses three regions with the most advanced education and industry resources in China, namely, GHKM Greater Bay Area, BTH Urban Agglomeration, and YRD Urban Agglomeration. Focusing on the core regions of the three urban agglomerations, the PEI performance of high-tech industry of each urban agglomeration in 2019 was contrasted and deliberated, before developing suitable countermeasures for each region. The main conclusions are as follows:

(1) This paper designs an EIS for PEI performance of high-tech industry. The systems theory was adopted to analyze the complementary intrinsic correlation between education and industry systems in PEI. The two systems are bridged up by talents and technologies and weaved together by market supply and demand. On this basis, a two-dimensional four-quadrant EIS was established, which covers interactive factors like the technology supply and talent supply of colleges, and the technology demand and talent demand of high-tech industry. The established EIS consists of four primary indices, namely, technology supply, talent supply, technology demand, and talent demand, and twelve secondary indices, laying a solid basis for the scientific evaluation of the PEI performance of high-tech industry in the three urban agglomerations.

(2) This paper further compares the levels of PEI performance of high-tech industry between the three urban agglomerations. First, the CECME model was introduced to evaluate the development levels of education and industry systems in each urban agglomeration. Externally, the GHKM Greater Bay Area, which is represented by Guangdong, is far better in education and industry development than YRD Urban Agglomeration, which is represented by Shanghai, and BTH Urban Agglomeration, which is represented by Beijing. Internally, industry development surpasses education development in GHKM Greater Bay Area, and the opposite occurs in BTH Urban Agglomeration and YRD Urban Agglomeration. Next, CCD model was adopted to measure the CCD of the PEI of high-tech industry in each urban agglomeration. Based on the scores of education and industry systems, the PEI performance of high-tech industry in GHKM Greater Bay Area was evaluated as high level with industry in lead, that in YRD Urban Agglomeration as moderate level with education in lead, and that in BTH Urban Agglomeration high-tech industry PEI as moderate level with industry in lag.

(3) Several countermeasures were designed for the three urban agglomerations to enhance the PEI performance of high-tech industry. First, the PEI performance of high-tech industry in GHKM Greater Bay Area belongs to the high level with industry in lead. To enhance PEI performance, this region needs to improve the weak link of education development. This region is recommended to speed up the investment, introduction, and integration of higher education resources. According to the actual demand of local high-tech industry for talents and technologies, the region should build a number of higher vocational and technical colleges with unique features, introduce a batch of high-quality colleges from higher education hubs like Beijing, Shanghai, Nanjing, and Wuhan, and work with these colleges to set up graduate colleges or industry-university-research collaborative innovation bases in this region. By integrating the local higher education resources, GHKM Greater Bay Area should accelerate the cultivation of First-Class Colleges and teachers with both theoretical and practical abilities and thus boost the higher education quality and technological innovation capability of colleges in the region. Second, the PEI performance of high-tech industry in YRD Urban Agglomeration belongs to

moderate level with education in lead. To enhance PEI performance, this region needs to give full play to its advantages in higher education. YRD Urban Agglomeration is advised to strengthen the transformation of scientific results and the cultivation of applied talents in colleges and take integrated measures like building transformation platforms, improving incentive mechanisms, and protecting intellectual property rights. These would solve the solve the "last mile problem" of scientific results transformation and turn the advantages of science and education resources into industrial and economic advantages. In addition, the region should fully consider the demand of local high-tech industry and thoroughly reform the education system in local colleges from the aspects of discipline adjustment, training scheme design, and curriculum configuration. The reform intends to boost the practical ability of college students and train them into high-quality applied talents for high-tech industry development. Third, the PEI performance of high-tech industry in BTH Urban Agglomeration belongs to moderate level with industry in lag. To improve PEI performance, this region needs to focus on high-quality industry development. BTH Urban Agglomeration is suggested to support regional high-tech enterprises more forcefully, encourage colleges to incubate high-tech enterprises, relying on scientific results like invention patents, and guide high-tech enterprises to improve innovation capability and market competitiveness through technology cooperation with colleges. Furthermore, this region needs to provide integrated supports to high-tech enterprises, in terms of business registration, financing guarantee, tax incentives, listing guidance, and first product procurement, trying to fully optimize the business environment for high-tech industry in the region.

In this paper, research perspective selection is the main innovation. Different from the existing studies mainly focusing on colleges, which are the supply subject of PEI, this paper tries to expand the ideas of PEI from the perspective of high-tech industry as a demand subject. At the same time, the framework of two-dimensional four-quadrant EIS designed in this paper is also innovative, which enriches the guiding tools for the construction of EIS in PEI performance.

However, this paper also has some limitations. The evaluation indices of PEI constructed in this paper need to be further improved. Only the cross-section data of 2019 were used in the empirical analysis, and the temporal trend characteristics were not depicted. The quantitative analysis of the reasons for different types of PEI in the three urban agglomerations is absent. In subsequent studies, the above deficiencies will be mainly supplemented.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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