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Contradiction-driven "one body, two wings" model of modern vocational education based on three-dimensional coupling calculation

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Abstract This paper constructs a "one body, two wings" model for modern vocational education and explores the status of industry-education integration in the implementation of this model, specifically the coupling and coordination mechanism between higher education and industrial development. Using the entropy method, a system evaluation indicator system for higher education and industrial development was constructed. Methods such as the global Moran index, Dagum Gini coefficient, kernel density method, and Tobit regression model were employed to investigate the characteristics and influencing factors of the coupling and coordination level between higher education and industrial development. The coupling degree between the two systems has remained stable, consistently maintaining a high coupling range of 0.9–1.0 since 2018, indicating a strong association between the higher vocational education system and the industrial development system. At the same time, the degree of coordination between the two systems basically showed a phased trend of first declining and then rebounding, falling from 0.673 in 2018 to 0.571 in 2021, and then rising to 0.683 in 2024. In addition, there are obvious spatial agglomeration and spatial heterogeneity in the coupling and coordination degree of China's higher vocational education and industrial development systems, which shows a gradient development pattern from southeast to northwest on the whole, and the coupling and coordinated development gradually evolves to multipolarization. There is a significant positive correlation between industrial structure upgrading, regional economic development level, and coupling coordination degree, while there is a significant negative correlation between local employment rate and coupling coordination degree.

Index Terms entropy method, kernel density method, Tobit regression model, Dagum Gini coefficient, vocational education, coupling coordination degree

I. Introduction

How to cultivate high-quality, multi-skilled technical and vocational talent is an unavoidable issue for higher vocational colleges and universities, and it is also a critical question that modern vocational education must address to ensure its survival and improve the quality of talent cultivation [1], [2]. However, as digital transformation has imposed new requirements on the cultivation of high-quality technical and vocational talent needed for industrial upgrading, it has also presented new challenges to vocational education talent cultivation, making reforms to talent cultivation models imperative [3]-[5]. A talent cultivation model generally refers to the overall process of implementing talent education under the guidance of certain educational theories and ideas, in accordance with specific cultivation objectives and talent specifications, using relatively stable teaching content and curriculum systems, management systems, and assessment methods [6]-[9].

To better address the fundamental question of "what kind of people to cultivate, how to cultivate them, and for whom to cultivate them," China's vocational education system has widely adopted the "one core, two wings" talent cultivation model [10], [11]. The "core" refers to the educational objectives and standards. Specifically, it aims to cultivate high-end, composite technical and skilled talent with innovative and entrepreneurial spirit and capabilities, fostering truly innovative and entrepreneurial "craftsman-style" high-level vocational talent. This represents the educational objectives and core philosophy of modern vocational education [12]-[15]. The "two wings" refer to the implementation pathways and measures. One "wing" is the cultivation of moral character, which involves adhering to the principle of cultivating virtue and fostering talent, integrating quasi-military education into the entire talent cultivation process, and closely combining it with the '5G' experiential classroom for ideological and political education, thereby forming a new framework of "all-round education" that organically integrates ideological and political education with military-style training [16]-[19]. This approach aims to deeply integrate moral education with the spirit of craftsmanship, innovation, and military qualities, combining moral cultivation with practical action to enable students to develop a perfect personality characterized by the unity of knowledge and action [20]-[22]. The other “wing” is academic cultivation, adhering to the principle of “education determined by industry,” implementing a distinctive credit system, and creating an integrated research, education, and entrepreneurship platform. This achieves a new framework centered on student development, with education and teaching seamlessly integrated with enterprise entrepreneurship platforms, realizing true industry-academia integration [23]-[26].

This paper explores the contradiction-driven “one body, two wings” model of modern vocational education based on three-dimensional coupling calculations. It constructs an evaluation index system for the two systems of higher education and industrial development, and uses the entropy method to determine the weights of the indicators. Subsequently, by integrating the coupling degree model, coordination degree model, and global Moran index, the study examines the temporal changes, spatial characteristics, dynamic evolution, and spatial correlations of the coupling coordination levels between higher education and industrial development. Additionally, the Tobit regression model is employed to analyze the influencing factors of coupling coordination, while the Dagum Gini coefficient is used to assess regional disparities in coupling coordination.

II. Building a “one body, two wings” model for modern vocational education

This chapter explores the construction of a modern vocational education model based on three-dimensional coupling calculations, and analyzes the coupling and coordination mechanisms between the two wings of this model, namely higher education and industrial development.

II. A. The “One Body, Two Wings” Model of Modern Vocational Education

In the “one body, two wings” teaching model of modern vocational education, “one body” refers to modern vocational education with the “National Standards” as its core and college students as its main body, while “two wings” refer to higher education and industrial development, respectively. The construction of the “one body, two wings” teaching model of modern vocational education mainly aims to solve two problems:

(1) Guiding students to engage in practical operations, experience the industrial development process, and understand the difficulties and problems of industrial development.

(2) Addressing issues related to the selection of practical training fields in modern vocational education, the costs of industrial practice, and student participation in the design of industrial practice programs.

II. B. Coupling and coordination mechanism between higher education and industrial development

Coupling refers to the phenomenon where multiple independent systems interact and influence one another. Coordination refers to the degree of close cooperation between multiple systems, reflecting the overall effectiveness and synergistic effects of their interactive development. The interplay between the higher education system and the industrial development system can be characterized by coupling and coordination. Both systems serve as the cornerstones of socio-economic development, mutually driving one another. The coupling and coordination mechanism between the two systems is illustrated in Figure 1.

Higher education serves as the driving force for high-quality industrial development. As an integral part of the social system, the higher education system primarily promotes industrial development through talent cultivation, scientific research, and social services. With the overall slowdown in global economic growth, cutting-edge technologies such as new energy and artificial intelligence have emerged as new economic growth points and have become key areas of competition in national economic strategies. This has placed higher demands on countries' technological innovation capabilities. Against this backdrop, the synergistic innovation between higher education and industry has become the “main theme” of international competition. Higher education institutions closely align with national key industries and major projects, and relevant research findings are applied to production through forms of technology transfer such as industry-education integration and government-industry-academia-research collaboration, effectively promoting technological innovation in industries.

Industrial development is driving the high-quality development of higher education. In the era of economic digitalization, higher education must enhance the quality of talent cultivation, deepen scientific and technological innovation, and achieve coordinated development among government, industry, academia, research, and application. This cannot be achieved without the support of industrial development. The status of industrial development significantly influences the scale of higher education, the intensity of educational funding, and research conditions, thereby exerting a pivotal role in shaping universities' innovative capabilities. Under the backdrop of the new technological revolution, the evolving technological structure imposes new demands on the structure of talent needs, while industrial support will increasingly tilt toward new technologies. This will guide higher education to align with industrial development needs, integrating cutting-edge industrial concepts with scientific research to cultivate a cohort of high-level talent capable of meeting enterprises' new requirements.

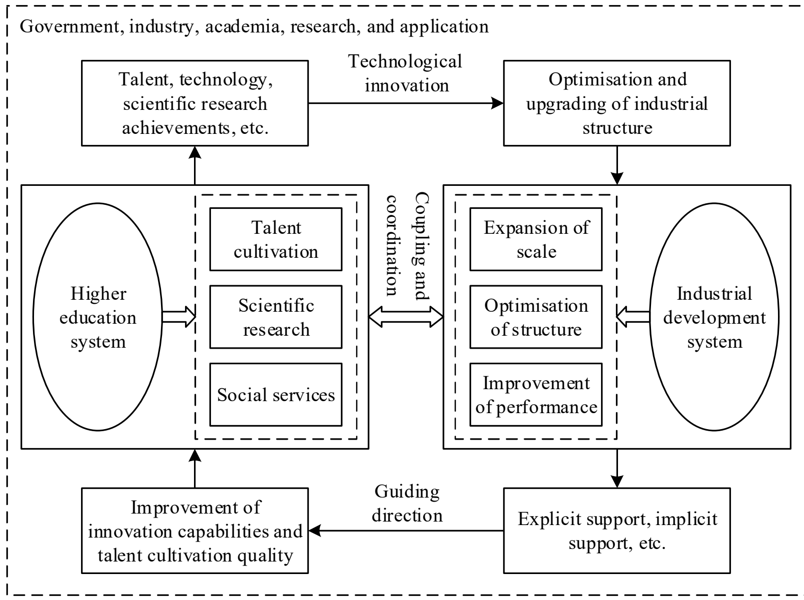

Figure 1: Higher education and industrial development are coupled and coordinated

III. Research design

III. A. Construction of the indicator system

To accurately reveal the multidimensional and multilevel coupling and coordination relationship between the higher education system and the industrial development system, this paper draws on previous research findings to construct an evaluation indicator system for the higher education system from three aspects: education scale, education support, and education output. Nine indicators, including the number of general higher education institutions, are selected for measurement. Additionally, an evaluation indicator system for the industrial development system is constructed from three aspects: economic level, industrial structure, and industrial performance. Nine indicators, including per capita GDP, are selected for measurement. The comprehensive evaluation indicator system is shown in Table 1, with the weights of each indicator assigned using the entropy method.

Table 1: Evaluation index system for higher education and industrial development

First-level indicator	Secondary indicators	Third-level indicators	U_{ij}	Weight	Type
Higher education system U_1	Education scale	The number of regular institutions of higher learning	U_{11}	0.1702	+
		The number of students in regular colleges and universities per 10,000 people	U_{12}	0.0548	+
		The proportion of postgraduate students among the total students on campus	U_{13}	0.1705	+
	Education support	The proportion of full-time teachers in regular higher education	U_{14}	0.1054	+
		Per capita public finance expenditure for students in regular higher education	U_{15}	0.1293	+
		The proportion of public finance expenditure on regular higher education in GDP	U_{16}	0.0517	+
		The growth rate of internal expenditure on research and development in regular higher education	U_{17}	0.0829	+
	Education output	The number of new graduates per 10,000 people	U_{18}	0.0365	+
		The average number of patent applications per teacher and student in regular colleges and universities	U_{19}	0.1987	+
Industrial development system U_2	Economic level	Per capita GDP	U_{21}	0.1375	+
		Social capital	U_{22}	0.0944	+
		Per capita fiscal revenue	U_{23}	0.1582	+
		The proportion of added value of the primary industry in GDP	U_{24}	0.0751	-

	Industrial structure	The proportion of added value of the secondary industry in GDP.	U_{25}	0.1205	+
		The proportion of the added value of the tertiary industry in GDP	U_{26}	0.0913	+
	Industrial performance	Green GDP	U_{27}	0.0546	-
		The proportion of high-tech exports in manufactured goods exports	U_{28}	0.1311	+
		Labor productivity per employee	U_{29}	0.1373	+

III. B. Data Sources

The higher education development data in this study is sourced from the “Annual Quality Report on Higher Vocational Education” of more than 1,200 higher vocational colleges in China from 2018 to 2024, and is summarized and calculated according to the location of the schools. The industrial development data comes from panel data from 31 provincial capitals in China from 2018 to 2024, specifically including the “China Statistical Yearbook,” “China Education Statistics Yearbook,” and “China Science and Technology Statistics Yearbook.” Missing values in the data are filled in using linear interpolation.

III. C. Research Methods

III. C. 1) Entropy Method

To avoid the non-objectivity and bias introduced by subjective weighting methods such as the Analytic Hierarchy Process (AHP), Principal Component Analysis (PCA), and expert scoring, which can affect measurement results, this paper adopts the widely used entropy method [27] to determine the weights of each indicator, thereby enhancing the objectivity and stability of the measurements. The specific steps are as follows: Let the variable $x_{ij}\left(i=1,2,\cdots,n, j=1,2,\cdots,m\right)$ represent the data for the j th indicator in the i th year, with a total of n years and m indicators.

(1) Standardization of indicators. The extreme value method is used to perform dimensionless processing on the original data. Let H_j be the maximum value of the sample for the j th indicator, and h_j be the minimum value of the sample for the j th indicator. The calculation formula is as follows:

Positive indicators:

$$x_{ij}^{*}=\frac{x_{ij}-h_j}{H_j-h_j}\times 0.95+0.05 \tag{1}$$

Negative indicators:

$$x_{ij}^{*}=\frac{H_j-x_{ij}}{H_j-h_j}\times 0.95+0.05 \tag{2}$$

(2) Calculate the entropy of the j th indicator:

$$e_j=-\frac{1}{\ln n}\left(\sum_{i=1}^{n}p_{ij}^{*}\ln p_{ij}\right) \tag{3}$$

$$p_{ij}=\frac{x_{ij}^{*}}{\sum_{i=1}^{n}x_{ij}^{*}} \tag{4}$$

(3) Calculate the coefficient of variation for the j th indicator:

$$g_j=1-e_j \tag{5}$$

(4) Calculate the weighting coefficients for each indicator:

$$w_j=g_j\Big/\sqrt{\sum_{j=1}^{m}g_j} \tag{6}$$

(5) Calculate the overall contribution of the system:

$$U_{\gamma}=\sum_{j=1}^{m}w_j x_{ij}^{*} \tag{7}$$

$\gamma = 1,2$, $0 < U_\gamma < 1$, the higher the comprehensive contribution, the higher the comprehensive development level of the system.

III. C. 2) Coupling Degree Model

Coupling degree is mainly used to measure the strength of interaction between different systems, but there is no distinction between good and bad. The higher the coupling degree, the better the coordination and integration between the elements of the systems. The traditional coupling degree function for two systems is:

$$C = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2} \tag{8}$$

Due to the high C value of traditional coupling degree function calculations and low discrimination, especially in the field of social sciences, the explanatory validity of the model is low. Therefore, this study draws on existing research results and adopts a modified coupling degree formula:

$$C = \sqrt{\left[1 - \frac{\sum_{i>j j=1}^{n} \sqrt{\left(U_i - U_j\right)^2}}{\sum_{n=1}^{n-1} m}\right] \times \left(\prod_{i=1}^{n} \frac{U_i}{\max U_i}\right)^{\frac{1}{n-1}}} \tag{9}$$

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In the formula: U_1 represents the comprehensive contribution of the higher education system, U_2 represents the comprehensive contribution of the industrial development system, n is the number of systems, $U_i \in [0,1]$, and $C \in [0,1]$. The revised model distributes C as widely as possible within $[0,1]$, increasing the distinction between C values, thereby achieving greater efficiency in the social sciences.

The degree of coupling can be evaluated based on the size of the coupling value, with the coupling degree evaluation criteria shown in Table 2.

Table 2: Evaluation criteria for coupling degree

C value	Coupling stage
0<*C*≤0.3	Low-level coupling stage
0.3<*C*≤0.5	Antagonistic stage
0.5<*C*≤0.8	The running-in stage
0.8<*C*≤1	High-level coupling stage

III. C. 3) Coordination Model

Since coupling degree only reflects the strength of interaction between systems and cannot reflect the overall effectiveness and synergistic effects of interaction between systems, if the development levels of two systems are both low, a false high coupling degree may be calculated. Therefore, a coordination degree model for two systems is constructed to measure the degree of coordination between them. The coordination degree has high stability because it combines the coupling degree C and the development degree T. The formula is as follows:

$$D = \sqrt{C \times T} \tag{10}$$

$$T = \alpha U_1 + \beta U_2, \alpha + \beta = 1 \tag{11}$$

In the formula: D is the coordination degree, and T is the comprehensive evaluation index. α and β represent the contribution of the two systems to the entire system. Considering the need for the coordinated development of regional industries and higher education, this study sets $\alpha = 0.5$ and $\beta = 0.5$.

Based on the value of the coordination degree, the degree of coordination can be evaluated. The coordination degree standards are shown in Table 3.

Table 3: Evaluation criteria for coordination degree

Serial number	Coordination degree range	Coupling stage	Serial number	Coordination degree range	Coupling stage
*D*1	0≤*D*<0.1	Extreme imbalance	*D*6	0.5≤*D*<0.6	Barely coordinated
*D*2	0.1≤*D*<0.2	Highly dysregulated	*D*7	0.6≤*D*<0.7	Primary coordination
*D*3	0.2≤*D*<0.3	Moderate dysregulation	*D*8	0.7≤*D*<0.8	Intermediate coordination
*D*4	0.3≤*D*<0.4	Mild disorder	*D*9	0.8≤*D*<0.9	Benign coordination
*D*5	0.4≤*D*<0.5	On the verge of imbalance	*D*10	0.9≤*D*<0.1	High-quality coordination

III. C. 4) Global Moran Index

Spatial autocorrelation is an important tool for analyzing the spatial correlation between variables in neighboring locations, mainly including global and local Moran indices. This paper uses the global Moran index to analyze the spatial differentiation of the coupling and coordination between higher vocational education and industrial development in each province and region of China, and determines whether spatial autocorrelation exists. Its expression is:

$$I=\frac{N\sum_{i=1}^{N}\sum_{j=1}^{N}W_{i,j}\left(D_i-\bar{D}\right)\left(D_j-\bar{D}\right)}{\left(\sum_{i=1}^{N}\sum_{j=1}^{N}W_{i,j}\right)\sum_{i=1}^{N}\left(D_i-\bar{D}\right)^2} \tag{12}$$

In the formula: I represents the global Moran index, N represents the number of provinces/regions, $W_{i,j}$ represents the adjacency weight matrix between the i th and j th provinces/regions, D_i represents the coupling coordination degree of the i th province/region, D_j represents the coupling coordination degree of the j th province or region; $\bar{D}$ is the average coupling coordination degree of all provinces and regions in China.

The global Moran's I index ranges between $[-1,1]$. The closer it is to 1, the higher the spatial positive correlation. The closer it is to -1, the higher the spatial negative correlation. When it equals 0, it indicates spatial independence, with a random distribution.

III. C. 5) Dagum Gini coefficient

The Dagum Gini coefficient [28] takes into account the phenomenon of overlap between groups and can accurately determine the relative differences between regions and their main sources. Its expression is:

$$G=\frac{\sum_{p=1}^{m}\sum_{q=1}^{m}\sum_{i=1}^{N_p}\sum_{j=1}^{N_q}\left|y_{p,i}-y_{q,j}\right|}{2N^2\bar{y}} \tag{13}$$

In the equation: m represents the number of regions, N_p is the number of provinces in the p th region, N_q denotes the number of provinces in the q th region, $y_{p,i}$ denotes the coupling coordination degree of the i th province in the p th region, $y_{q,j}$ denotes the coupling coordination degree of the j th province in the q th region, and $\bar{y}$ denotes the average coupling coordination degree of all provinces. G represents the overall gap in coupling coordination, composed of the contribution from intra-regional differences (G_w), the net contribution from inter-regional differences (G_{nb}), and the super-variability density (G_t).

III. C. 6) Kernel Density Estimation Method

The kernel density estimation method [29] is a nonparametric estimation method that uses probability density functions to fit smooth curves based on the data itself, and solves problems by analyzing the peaks and extensibility of the curves. Its expression is:

$$f(x)=\frac{1}{Nh}\sum_{i=1}^{N}K\left(\frac{x_i-x}{h}\right) \tag{14}$$

In the formula: $f(x)$ represents the density function, h represents the bandwidth, x_i is the independent and identically distributed observation value of the i th province or region, and $K(x)$ represents the kernel function. This paper selects the Gaussian kernel function, whose expression is as follows:

$$K(x)=\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right) \tag{15}$$

III. C. 7) Tobit regression model

This study selected relevant factors influencing the coupling coordination degree of the two systems for regression analysis. The factors affecting the level of industry-education integration in modern higher vocational education, i.e., the coupling coordination degree, primarily originate from the coupling subsystem itself. Therefore, this study identifies core explanatory variables from within the coupling coordination system, selecting the primary factors influencing coupling coordination from the vocational education development system and the industrial development system as core explanatory variables, and choosing secondary factors affecting the coupling coordination degree of the two systems from outside the coupling coordination system as control variables. Since the estimation results of the coupling coordination model are non-negative random variables in the range [0,1], they do not satisfy the assumption of normal distribution of the explained variable in linear regression (OLS). Therefore, this study adopts the Tobit model [30] to construct the regression equation:

$$D_{it} = \alpha + \beta_1 F_1 + \beta_2 F_2 + \varepsilon_{it} \tag{16}$$

Among these, D_{it} represents the level of industry-education integration in higher vocational education across Chinese provinces from 2018 to 2024, denoted as the coupling coordination degree (Y). F_1 denotes the explanatory variables influencing the coupling coordination degree, including the number of graduates employed within the province (X1), the employment rate of graduates within the province (X2), the rationalization of industrial structure (X3), and the upgrading of industrial structure (X4). F_2 is the control variable, including regional economic development level (C1), government macro-level investment (C2), scientific and technological innovation capability (C3), labor productivity (C4), and school-enterprise investment level (C5). ε_{it} is the random error term, and α, β_1, and β_2 are the coefficients of each variable.

Among these, the number of graduates employed within the province and the employment rate are calculated. The levels of industrial structure rationalization and industrial structure upgrading are estimated based on relevant research. The control variables selected include regional economic development level, government macro-level investment, technological innovation capability, and overall labor efficiency level. Regional economic development level influences industrial development and the mobility of vocational and technical talent, so regional GDP is used as a measure. Government macro-level investment directly impacts the scale and quality of vocational education development, and the study uses per-student fiscal allocation as a measure. Technological innovation capacity reflects the core competitiveness of regional industries, and the study uses the proportion of total research expenditure to GDP as a measure. Labor productivity is an important factor in industrial development, and high-quality labor productivity facilitates industrial upgrading and transformation. The study uses regional GDP divided by regional employment population as a measure.

IV. Empirical analysis

IV. A. Analysis of Coupling Coordination Level Sequential Changes

Based on provincial panel data from 2018 to 2024, using the indicator system constructed in the preceding section, the comprehensive evaluation values, coupling degrees, and coupling coordination degrees of China's higher vocational education and industrial development systems were calculated separately, as shown in Figure 2.

Overall, in terms of comprehensive evaluation value, the national-level higher vocational education system's comprehensive evaluation value U1 shows a slow upward trend, increasing from 0.323 in 2018 to 0.392 in 2024, indicating that higher vocational education continues to make steady progress and develop steadily upward. However, the comprehensive evaluation value U2 of the national-level industrial development system shows a significant downward trend, decreasing slightly from 0.526 in 2018-2019 to 0.491, and then plummeting to 0.387 in 2020-2021. The possible reasons for this outcome include the intensification of global trade frictions and the outbreak of the COVID-19 pandemic after 2018, particularly the significant impact of the pandemic on manufacturing, services, and other economic activities, severely hindering industrial development. However, the comprehensive evaluation value U1 of the higher vocational education system has consistently been lower than that of the industrial development system U2, indicating that China's higher vocational education has long lagged behind industrial development and fails to meet the market demands of industrial development. In the future, it is necessary to further enhance the adaptability of higher vocational education to industrial development. In terms of coupling degree, the coupling degree C value of the two systems has shown minimal fluctuations and a stable trend, maintaining a high coupling level between 0.9 and 1.0 since 2018. This indicates that the higher vocational education system and the industrial development system are strongly interconnected, with the two systems closely interdependent and mutually influencing each other. In terms of coupling coordination, the coupling coordination value D of the two systems has generally shown a phased trend of first declining and then recovering, dropping from 0.673 in 2018 to 0.571 in 2021, and then rising to 0.683 in 2024. The coordination level of the two systems has dropped from the primary coordination level to the barely coordinated level. This may be attributed to the industrial development crisis caused by the COVID-19 pandemic in 2020, which prevented higher vocational education from fulfilling its role in adapting to changes, making it difficult for the two systems to form a good synergistic relationship. Overall, the coupling coordination level of the two systems remains in a transitional development stage at the intermediate level, and their positive interaction requires further strengthening in the future.

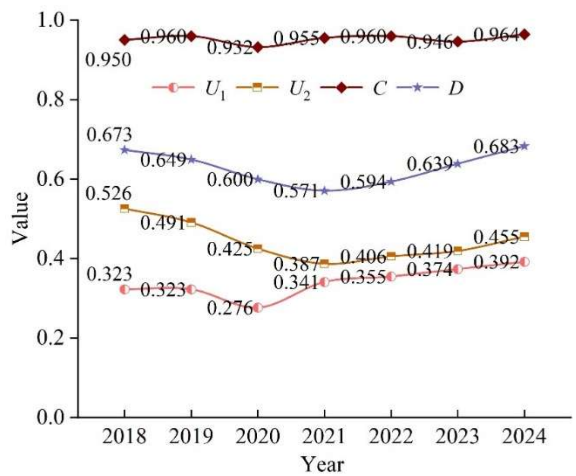


Figure 2: Coupling and coordinating the temporal variations of the horizontal sequence

The coupling coordination degree between the higher vocational education system and the industrial development system in different regions across the country is shown in Figure 3. It can be observed that the eastern, central, and western regions of China generally align with the national development trend, having all undergone three distinct phases in their temporal development patterns: a slow rise from 2018 to 2019, a sharp decline from 2020 to 2021, and a sustained recovery from 2022 to 2024. During the first phase, the coupling coordination degree of the eastern region increased slightly from 0.688 to 0.697, while that of the central region rose from 0.667 to 0.672. while the initial coupling coordination level of the western region increased from 0.604 to 0.608. During this phase, the development of all three regions remained stable at the primary coordination level, failing to achieve a transition between coupling coordination levels. In the second phase, the coupling coordination levels of the eastern, central, and western regions all dropped from the primary coordination level to the barely coordinated level, with decreases of 14.92%, 15.33%, and 16.78%, respectively. In the third stage, the coupling coordination levels of the eastern and central regions both achieved a leap, rising from the barely coordinated level to the intermediate coordinated level and the primary coordinated level, respectively, while the western region increased from 0.506 to 0.590, a rise of 16.60%, but did not achieve a leap in coupling coordination levels. Overall, the significant impact of the COVID-19 pandemic on the evolution of coupling and coordination between higher vocational education and industrial development led to a substantial decline in coupling and coordination levels across all three regions, with each region's coupling and coordination level dropping by one tier.

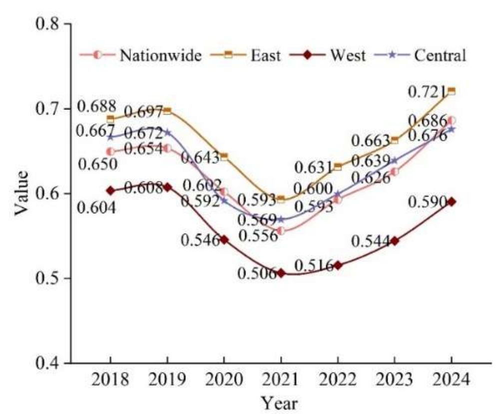


Figure 3: Changes of the coupling and coordination degree in different regions

IV. B. Analysis of Coupling Coordination Level Spatial Characteristics

To further explore the spatial evolution and differentiation characteristics of the coupling coordination degree between China's higher vocational education system and industrial development system, stages were defined based on the results of the previous temporal analysis. The years 2018 and 2021, and 2024 as key observation points for in-depth analysis. The coupling coordination model was used to calculate the coupling coordination degree of China's 30 provinces and municipalities, and ArcGIS 10.8 spatial analysis software was employed for visualization. The spatial distribution of the coupling coordination degree between the higher vocational education system and the industrial development system in 2018, 2021, and 2024 is shown in Table 4.

It can be seen that there is obvious spatial agglomeration and spatial heterogeneity in the coupling coordination degree of the two systems of higher vocational education and industrial development in China, the coupling coordination degree of the eastern region is slightly higher than that of the central region, while the coupling coordination degree of the western region is significantly lower than that of the eastern and central regions, and the coupling coordination degree of the coastal region is higher than that of the inland region, so the overall development pattern shows a gradient development pattern from southeast to northwest. The reason for this phenomenon is the imbalance of regional economic development, the southeast region is relatively developed economically, and the development in many fields is at the forefront, and there is enough economic strength to invest in higher vocational education and promote the transformation and upgrading of the industrial structure, thus forming a virtuous circle in which the two promote each other. On the contrary, the economic development level of the western region is relatively backward, the quality of higher vocational education supply is low, and the industrial structure is irrational.

During the first sample observation period from 2018 to 2021, the coupling coordination levels of provinces across China saw a significant decline, with a large expansion of regions nearing imbalance and barely coordinated. In 2021, over half of the provinces in the western region fell into the nearly imbalanced category. In the eastern and central regions, only Beijing, Shandong, and Henan maintained the primary coordination level, while most other provinces deteriorated to the barely coordinated state. During the second sample observation period from 2021 to 2024, the areas nearing imbalance and barely coordinated regions contracted significantly, the primary coordination regions expanded rapidly, and the intermediate and good coordination regions developed steadily. Overall, during this phase, accompanied by the steady upward development of higher vocational education and the continuous optimization of industrial structure, the coupling coordination level between China's higher vocational education system and industrial development system has improved.

In contrast, external uncertainties dominated by the COVID-19 pandemic severely disrupted the steady upward trend in the coupling coordination between the higher vocational education and industrial development systems. Focusing on individual provinces and municipalities, Jilin's coupling coordination level has consistently lagged behind other provinces and municipalities in the central region and exhibits significant inertia, indicating that both the quality of higher vocational education and the level of industrial development in Jilin urgently need improvement. Jiangsu leads the nation in coupling coordination level and is the only province to have entered the good coordination tier. Future efforts should focus on thoroughly analyzing the underlying causes behind Jiangsu's outstanding performance and fully leveraging its "pioneering" role. Additionally, compared to 2019, only Beijing, Tianjin, Shandong, Henan, and Xinjiang did not exhibit a decline in coupling coordination in 2021, indicating that the higher vocational education and industrial development in these five provinces and municipalities are relatively stable and possess a certain ability to withstand uncertain risks.

Table 4: Spatial distribution of coupling coordination degree of the two systems

Coupling coordination level	2018	2021	2024
On the verge of imbalance (0.4-0.5)		Hainan (1), Shanxi (2), Hubei (2), Jilin (2), Inner Mongolia (3), Guizhou (3), Yunnan (3), Gansu (3), (3), Qinghai (3), Ningxia (3)	Ningxia (3)
Barely coordinated (0.5-0.6)	Tianjin (1), Hainan (1), Jilin (2), Yunnan (3), Gansu (3), Qinghai (3), Ningxia (3), Xinjiang (3)	Tianjin (1), Hebei (1), Shanghai (1), Jiangsu (1), Zhejiang (1), Guangdong (1), Fujian (1), Liaoning (1), Heilongjiang (2), Anhui (2) Jiangxi (2) Hunan (2) Guangxi (3) Chongqing (3) Sichuan (3) Shaanxi (3) Xinjiang (3)	Hainan (1), Jilin (2) Guangxi (3), Chongqing (3), Sichuan (3), Guizhou (3), Yunnan (3), Shaanxi (3), Qinghai (3), Xinjiang (3)
Primary coordination (0.6-0.7)	Beijing (1), Hebei (1), Shanghai (1), Liaoning (1), Shandong (1),	Beijing (1), Shandong (1), Henan (2)	Beijing (1), Tianjin (1), Hebei (1), Shanghai (1), Shandong (1),

	Heilongjiang (2), Shanxi (2), Jiangxi (2), Henan (2), Hubei (2), Hunan (2), Inner Mongolia (3), Guangxi (3), Chongqing (3), Sichuan (3), Guizhou (3), Shaanxi (3)		Guangdong (1), Shanxi (2), Jiangxi (2), Henan (2), Hubei (2), Hunan (2), Heilongjiang (2), Inner Mongolia (3)
Intermediate coordination (0.7-0.8)	Zhejiang (1) Fujian (1), Guangdong (1), Anhui (2)		Zhejiang (1), Fujian (1), Liaoning (1), Anhui (2)
Benign coordination (0.8-0.9)	Jiangsu (1)		Jiangsu (1)

IV. C. Dynamic evolution analysis of coupling coordination

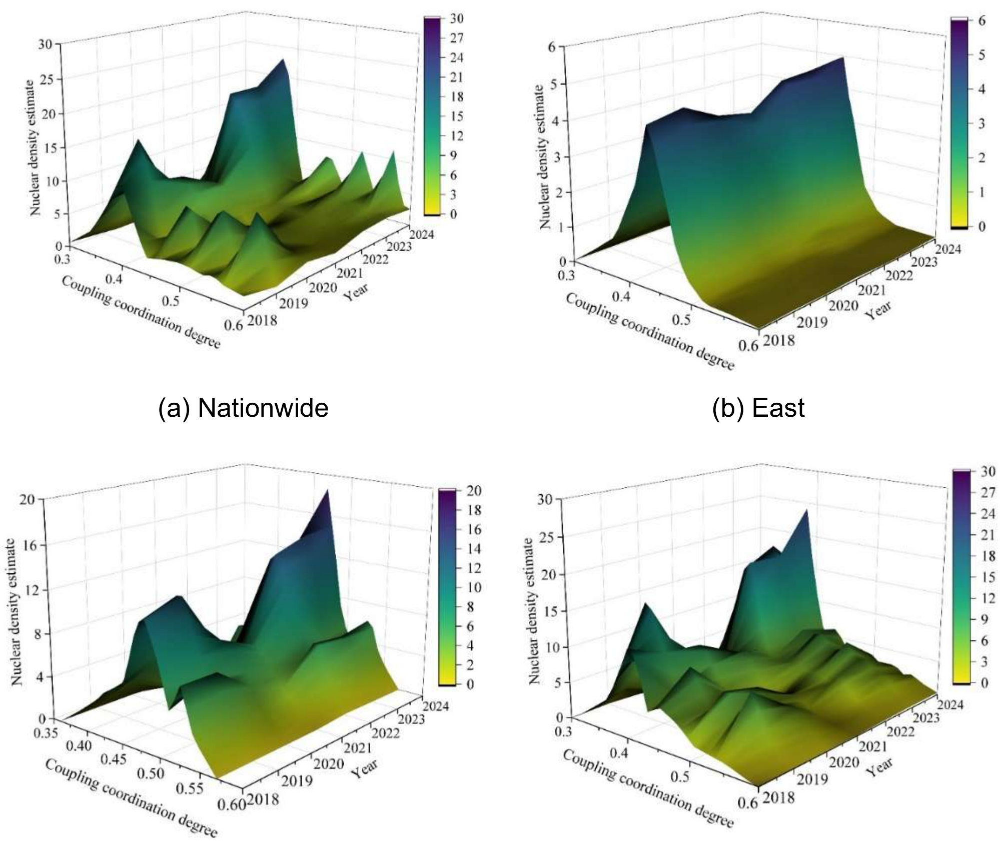
This section employs kernel density estimation to analyze the dynamic evolution trends of the coupling and coordination between higher education and industrial development within the "one core, two wings" model of modern vocational education. The dynamic evolution trends and patterns of the coupling and coordination levels between higher education development and industrial development in the national, eastern, central, and western regions are respectively illustrated in Figures 4(a) to (d).

At the national level, the center of the kernel density curve distribution shows a leftward shift, indicating a significant improvement in the coupling and coordination level between higher education development and industrial development from 2018 to 2024. The peak has risen and the wave peaks have narrowed, reflecting a transition from a broad peak to a sharp peak, suggesting that the absolute gap in coupling and coordination between higher education and industrial development across provinces has narrowed during the study period. The presence of a right-tailing phenomenon that has been lengthening annually indicates that certain regions have maintained an absolute leading position in the development of the coupling and coordination between higher education and industrial development, such as Beijing and Jiangsu, whose levels of coupling and coordination far exceed those of other provincial-level administrative regions. From the analysis of the number of peaks, the kernel density curve has consistently maintained a single main peak from 2018 to 2024, with no minor side peaks, indicating that the development of higher education and industrial development in China has not exhibited a multipolarization trend. Overall, the kernel density curve exhibits a right-skewed distribution, with provincial-level administrative regions with low levels of coupling and coordination having higher kernel density function values, while those with high levels of coupling and coordination have lower values. This suggests that currently, there are few provinces or municipalities in China where higher education and industrial development are at a high level of coupling and coordination, and the majority of provincial-level administrative regions still have relatively low levels of coupling and coordination.

The center of the nuclear density curve distribution in the eastern region has shifted significantly to the left, indicating that the level of coupling and coordination between higher education development and provincial-level administrative regions has significantly improved during the study period. From 2018 to 2021, the peak decreased and the wave peak widened, evolving from a sharp peak to a broad peak, indicating that the absolute gap in inter-provincial coupling coordination levels is widening. From 2021 to 2024, the peak gradually rose again, evolving from a broad peak to a sharp peak. The kernel density curve has consistently maintained a single-peak shape, indicating that the coupling and coordination between higher education and industrial development in the eastern region have not yet exhibited polarized characteristics. Throughout the study period, the kernel density curve exhibits a symmetrical distribution with no tailing features, indicating that the likelihood of extreme values in the coupling and coordination level between higher education development and industrial development in the eastern region is decreasing, with the coupling and coordination development level remaining relatively balanced.

The central region's nuclear density function distribution center shifted significantly to the left, indicating that the level of coordination between higher education development and industrial development in the central region improved rapidly from 2018 to 2024. From 2018 to 2021, the main peak decreased, the wave peaks widened, and the peak evolved from a sharp peak to a broad peak, meaning that the absolute gap between provinces in the central region in terms of the level of coordination between higher education development and industrial development is widening. From 2021 to 2024, the peak of the nuclear density curve rose in a stair-step pattern, the wave peaks narrowed, and there were side peaks on both sides, indicating that the gaps in the coordination and development of higher education and industrial development between provinces are gradually narrowing, and the phenomenon of multipolarization is becoming increasingly evident.

During the study period, the distribution center of the nuclear density curve in the western region also shifted overall to the left, with the peak undergoing a "decline-rise" evolution process and the peak following a "widening-narrowing" evolution path. 2021 serves as a turning point, with the peak declining in a stepwise manner before that year and rising in a stepwise manner afterward. Between 2018 and 2019, the nuclear density curve exhibited one main peak and one small side peak, while between 2021 and 2024, multiple side peaks emerged, indicating that the coordinated development of higher education and industrial development is evolving from a bipolar to a multipolar structure. In 2024, the nuclear density curve exhibits a relatively long right-tail phenomenon.



(a) Nationwide (b) East

(c) Central (d) West

Figure 4: The kernel density curve of coupling coordination degree

IV. D. Spatial correlation analysis

IV. D. 1) Global spatial autocorrelation

The results of the calculation of the global Moran's I index for coupling coordination are shown in Table 5. Overall, the global Moran's I index is significantly positive, indicating that the level of industry-education integration in higher vocational education has spatial autocorrelation and spatial agglomeration effects. From a temporal perspective, the global Moran's I index based on the geographical adjacency matrix shows a slight fluctuation trend, with spatial agglomeration effects exhibiting volatility over time.

Table 5: Global index of coupling coordination degree from 2018 to 2024

Year	Moran's I index	Expect E (I)	Standard deviation sd (I)	*z* value	*p* value
2018	0.392	-0.029	0.117	3.685	0.001
2019	0.338	-0.029	0.119	3.213	0.000
2020	0.364	-0.029	0.121	3.407	0.001
2021	0.331	-0.029	0.128	3.162	0.000
2022	0.367	-0.029	0.112	3.441	0.000
2023	0.379	-0.029	0.125	3.584	0.000
2024	0.273	-0.029	0.124	2.739	0.005

IV. D. 2) Local spatial autocorrelation

By calculating the local Moran's I index of coupling coordination, we can conduct an in-depth analysis of the spatial clustering characteristics of the integration of industry and education in China's higher vocational education. The results of the local spatial autocorrelation of the integration of industry and education in higher vocational education in various regions in 2018 and 2024 are shown in Table 6.

It can be seen that most regions in China exhibit a “low-high” or “low-low” clustering state, indicating a strong spatial clustering effect. “High-high clustering” primarily occurs in the economically more developed eastern and central regions, where the level of industry-education integration in higher vocational education is relatively high, and the spatial spillover effects are strong, positively driving the development of industry-education integration in surrounding regions. In contrast, regions with “low-high clustering” have lower coupling coordination levels, but the coupling coordination levels of their surrounding regions are higher. This phenomenon reflects the lagging development of vocational education industry-education integration in these regions, as well as the influence of surrounding high-level regions. “Low-low clustering” regions are primarily located in western and northeastern regions, where the level of vocational education industry-education integration is generally low, and there is a lack of obvious growth momentum, resulting in a relatively backward spatial clustering pattern. It is worth noting that the “high-low clustering” phenomenon primarily occurs in regions such as Beijing, Guangdong, and Sichuan. These regions exhibit high levels of coupling coordination, but the surrounding provinces have lower levels of coupling coordination, exhibiting a “polarization” characteristic. This polarization may stem from the advantages these regions hold in terms of resources and policies, but it may also exacerbate imbalances in regional development.

Table 6: The level of industry-education integration is locally spatially autocorrelated

Aggregation form	2018	2024
HH	Tianjin, Shanghai, Jiangsu, Zhejiang, Anhui, Shandong, Hubei, Hunan, Chongqing	Hebei, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Henan, Hubei, Hunan, Chongqing
LH	Hebei, Liaoning, Fujian, Jiangxi, Henan, Guangxi, Hainan	Tianjin, Liaoning, Shanghai, Jiangxi, Guangxi, Hainan, Guizhou, Shaanxi
LL	Shanxi, Inner Mongolia, Jilin, Heilongjiang, Guizhou, Yunnan, Xizang, Gansu, Qinghai, Ningxia, Xinjiang	Shanxi, Inner Mongolia, Jilin, Heilongjiang, Yunnan, Xizang, Gansu, Qinghai, Ningxia, Xinjiang
HL	Beijing, Guangdong, Sichuan, Shaanxi	Beijing, Guangdong, Sichuan

In addition, the level of industry-education integration in China's higher vocational education is constantly evolving, reflecting the trend toward regional integration. For example, Hebei, Fujian, Henan, and other provinces that were in the “low-high concentration” category in 2018 have entered the “high-high concentration” category in 2024, demonstrating significant progress in industry-education integration in higher vocational education and a positive trend toward regional coordination and development in these areas. Conversely, regions such as Tianjin and Shanghai, which were in the “high-high aggregation” category in 2018, have fallen into the “low-high aggregation” category by 2024. This may be influenced by various factors, such as policy adjustments and changes in resource allocation.

In the HH zone, the number of regions has increased by one province and is clustering toward the eastern coastal and central regions. These regions and their surrounding areas are generally high-value zones with active economic development, sustainable industrial growth, and a concentration of high-quality vocational colleges. In the LH zone, the number of regions has also increased by one, but only Liaoning, Jiangxi, Guangxi, and Hainan have not seen changes, indicating that their positive influence from surrounding regions is beginning to grow. In 2024, Tianjin and Shanghai fell into the LH zone, indicating that while their coordination levels have improved, the gap with surrounding regions has widened, and they are less influenced by the pull effect of surrounding regions. Guizhou's entry into the LH zone indicates that its coordination level has improved, not only narrowing the gap with surrounding regions but also beginning to exert a positive pull effect on them, thereby influencing the coordinated development of surrounding regions. The provinces in the LL zone are relatively stable, with most concentrated in western and northeastern regions. However, Guizhou's entry into the LH zone in 2024 indicates that its driving effect on surrounding areas is emerging, and its own coordinated development is beginning to influence surrounding regions. Provinces in the HL zone are dispersed, with strong higher vocational education and industrial development capabilities and relatively high coordination levels, but their radiating effect on surrounding areas is limited, to some extent reflecting a polarization effect.

IV. E. Analysis of influencing factors based on the Tobit regression model

A Tobit regression analysis was conducted using Stata 18.0 to examine the development level of industry-education integration in China's higher vocational education from 2018 to 2024. The results of the Tobit regression analysis are shown in Table 7. Among the nine selected variables, only industrial structure rationalization (X3) failed to pass the significance test. The remaining eight variables all passed the significance test at least at the 5% statistical level, indicating that the selected variables are crucial for the integration of industry and education in higher vocational education.

Table 7: Tobit regression results

Variable	Regression coefficient	Standard error	*t* value	*p* value
Local employment number (X1)	9.52e-07***	7.65e-08	13.42	0.000
Local employment rate (X2)	-0.0007142***	0.000152	-4.85	0.000
Rationalization of industrial structure (X3)	0.0375238	0.0284735	1.41	0.192
The upgrading of the industrial structure (X4)	0.023143***	0.0041593	5.92	0.000
The level of regional economic development (C1)	0.0547692***	0.0112647	5.37	0.000
The level of government macro investment (C2)	9.89e-08**	4.38e-08	2.35	0.027
Capacity for scientific and technological innovation (C3)	0.0381463***	0.0059437	6.07	0.000
Labor productivity (C4)	0.00120375***	0.0002034	5.79	0.000
Level of investment from schools and enterprises (C5)	6.14e-10***	1.62e-10	4.02	0.000
_cons	-0.3516249***	0.0978946	-3.59	0.000
LR chi2(8) =468.85				
prob>chi2=0.0000				
Pseudo R2=-0.9764				
Note: ***p<0.01, **p<0.05, *p<0.1				

Among the core explanatory variables, the upgrading of industrial structure (X4) has the greatest impact on the level of industry-education integration in higher vocational education, with a regression coefficient of 0.023143. This indicates that the more advanced the industrial structure, the higher the level of industry-education integration in higher vocational education. This is because the upgrading of industrial structure promotes higher vocational colleges to adjust their professional layout, cultivate technical and skilled talents that meet industrial development needs, and adapt to industrial development demands. Local employment rate (X2) is significantly negative, meaning that the higher the local employment rate, the lower the level of industry-education integration in vocational education. This may be attributed to four factors:

First, resource allocation. Overemphasizing short-term employment skills training may neglect deep integration with industries and long-term development, leading to mismatches between vocational education content and industrial needs, thereby reducing the level of industry-education integration.

Second, educational quality. Schools may prioritize rapid training of students to meet short-term employment needs, which could weaken the connection between vocational education and industry, thereby affecting the level of industry-education integration.

Third, changes in market demand. If the pace and intensity of curriculum adjustments at vocational colleges fail to keep pace with dynamic changes in the market, this may lead to a decline in the level of industry-education integration.

Fourth, policy orientation. Overemphasizing short-term employment indicators rather than long-term industry-education integration may also lead vocational colleges to prioritize increasing local employment rates over deepening cooperation with enterprises to provide suitable talent for industrial upgrading and transformation.

Among the control variables, regional economic development level (C1) has the greatest impact on the level of industry-education integration in vocational education, with a regression coefficient of 0.0547692. The reasons are as follows: First, government policies play a crucial role in promoting the development of industry-education integration in higher vocational education. Second, economic development typically drives industrial structure upgrading and transformation. Third, growth in per capita GDP will facilitate deeper integration between higher vocational education and industries, enhancing the relevance and timeliness of talent cultivation.

IV. F. Regional differences analysis based on the Dagum Gini coefficient

The degree of variation and contribution rate in the development level of industry-education integration in higher vocational education are shown in Table 8. The overall Gini coefficient for the level of industry-education integration in higher vocational education shows a slight upward trend, rising from 0.095 in 2018 to 0.115 in 2024, indicating that the disparity in the level of industry-education integration in China's higher vocational education is gradually widening. Meanwhile, the intra-group Gini coefficient has slightly increased, while the inter-group Gini coefficient shows a downward trend, suggesting that the disparities in the level of industry-education integration within and between regions are also undergoing changes. By comparing the contribution rates of each component of the Dagum Gini coefficient, it can be seen that although the inter-group contribution rate has decreased during the study period, it remains relatively high, maintaining a level above 59%. Meanwhile, the intra-group contribution rate and the hyper-variability density contribution rate are relatively low, indicating that the differences in the level of industry-education integration in China's higher vocational education primarily stem from inter-regional differences, while differences within regions and between regions that overlap are relatively minor.

Table 8: Dagum Gini coefficient and contribution rate results

Year	Gini coefficient				Contribution rate (%)		
	Overall	within the group	Inter-group	supervariable density	within the group	Inter-group	Supervariable density
2018	0.095	0.021	0.075	0.009	20.015	71.243	8.742
2019	0.099	0.024	0.072	0.009	21.824	69.584	8.592
2020	0.099	0.025	0.071	0.014	22.043	66.852	11.105
2021	0.113	0.027	0.069	0.017	22.705	65.171	12.124
2022	0.124	0.028	0.078	0.015	22.384	67.025	10.591
2023	0.127	0.029	0.077	0.019	22.542	64.837	12.621
2024	0.115	0.029	0.063	0.020	23.978	59.364	16.658

The results of the decomposition of the Gini coefficient differences for Dagum are shown in Table 9. It can be seen that the intra-regional Gini coefficients for all four major regions generally show an upward trend, indicating that the differences in the level of vocational education-industry integration development among various regions within the four major regions have increased. From the perspective of the mean values of intra-regional Gini coefficients, the eastern region has the highest Gini coefficient, indicating the greatest disparity in the level of vocational education industry-education integration development between the eastern region and its internal areas. The western region ranks second, the central region ranks third with a significantly higher Gini coefficient than the northeastern region, and the northeastern region has the lowest Gini coefficient, meaning the disparity in the level of vocational education industry-education integration development among the three northeastern provinces is the smallest. From the perspective of the mean values of inter-regional Gini coefficients, the average Gini coefficient between the eastern and western regions is 0.161, significantly higher than that between other regions, indicating that the differences in the level of integration between vocational education and industry in the eastern and western regions are relatively large. Meanwhile, the average Gini coefficient between the western and northeastern regions is 0.069, lower than that between other regions, also indicating that the differences in the level of integration between vocational education and industry in the western and northeastern regions are relatively small.

Table 9: The difference decomposition result of Dagum Gini coefficient

Gini coefficient	Region	Year							Mean value
		2018	2019	2020	2021	2022	2023	2024	
Gini coefficient within the group	Northeast	0.036	0.035	0.034	0.032	0.027	0.056	0.041	0.037
	East	0.085	0.093	0.087	0.095	0.102	0.105	0.107	0.096
	Central	0.054	0.062	0.063	0.081	0.075	0.083	0.078	0.071
	West	0.072	0.075	0.082	0.077	0.086	0.095	0.091	0.083
Gini coefficient between groups	East & Northeast	0.139	0.132	0.142	0.147	0.162	0.165	0.151	0.148
	East & Central	0.103	0.096	0.091	0.093	0.107	0.112	0.105	0.101
	East & West	0.164	0.161	0.157	0.152	0.172	0.175	0.148	0.161
	Central & Northeast	0.071	0.074	0.086	0.116	0.095	0.108	0.114	0.095
	Central & West	0.095	0.103	0.105	0.124	0.116	0.125	0.112	0.111
	West & Northeast	0.064	0.067	0.067	0.062	0.068	0.081	0.075	0.069

V. Conclusion

This paper explores the temporal changes, spatial characteristics, dynamic evolution, spatial correlation, influencing factors, and regional differences in the coupling and coordination levels between higher education and industrial development based on the “one body, two wings” model of modern vocational education.

In terms of comprehensive evaluation values, the national-level higher vocational education system shows a slow upward trend, while the industrial development system exhibits a significant downward trend, with the former consistently lagging behind the latter. This indicates that China's higher vocational education has long been lagging behind industrial development, and future efforts should focus on enhancing the adaptability of higher vocational education to industrial development. In terms of coupling degree, the coupling degree of the two systems fluctuates little and remains stable, maintaining a high coupling range of 0.9–1.0 during the 2018–2024 period. In terms of coupling coordination degree, the coupling coordination degree of the two systems generally exhibits a phased trend of first declining and then recovering, with a tendency toward multipolar development.

The coupling coordination degree of China's higher vocational education and industrial development systems, from high to low, is as follows: eastern regions, central regions, and western regions. Coastal regions have a higher coupling coordination degree than inland regions, with an overall gradient development pattern decreasing from southeast to northwest. Most regions in China exhibit a "low-high" or "low-low" clustering state. "High-high clustering" primarily occurs in the economically developed eastern and central regions, while "low-low clustering" regions are predominantly located in the western and northeastern regions.

Among the core explanatory variables in the Tobit regression model, the upgrading of industrial structure has the greatest impact on the development level of vocational education industry-education integration, while local employment rates have a significant negative impact. Among the control variables, regional economic development levels have the greatest impact on the development level of vocational education industry-education integration.

In terms of regional differences, the disparities in the development level of vocational education industry-education integration in China primarily stem from inter-group differences between regions, while differences within regions and between regions are relatively minor. The Gini coefficients, from highest to lowest, are for the eastern region, western region, central region, and northeastern region, indicating that the northeastern provinces have the smallest differences in the level of integration between vocational education and industry. In terms of intergroup differences, the intergroup Gini coefficient is highest between the eastern and western regions, and lowest between the western and northeastern regions.

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