Examination of the Interconnection and Coordination Degree between Higher Vocational Professional Groups and Industrial Structure, along with Spatiotemporal Dynamic Evolution

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Abstract: Professional clusters in higher vocational education help develop human capital in the manufacturing sector, working in harmony with the external industrial framework to advance social and economic growth. This study explores the spatial distribution patterns, sources of disparity, and spatio-temporal evolution trends of the two coupling coordination levels using panel data from 29 Chinese provinces from 2015 to 2022 and the coupling coordination model, Dagum Gini coefficient, kernel density function, and spatial Markov chain model. The analysis shows that coupling coordination gradually increased to 0.4413 in 2022. Positive global spatial autocorrelation shows a "high-high" agglomeration in the east and a "low-low" in the west. Positive regional spatial distribution of coupling coordination level. Eastern-western differences are the main cause of the growing regional gap. The developmental trajectory from low-order to high-order, with significant inter-regional nuclei. Geographic variables cause path dependency in the transition to coordinated development, defined by club convergence, making leapfrog development difficult in the short term. To advance the synergistic evolution of higher vocational education and industrial economic development, vocational education must be more adaptable, the inter-regional synergistic development strategy deepened, and a new framework for industrial innovation and integrated development must be created.

Keywords: Higher Vocational Professional Group; Industrial Structure; Coupling Coordination; Spatiotemporal Evolution

1. Introduction

Schultz's human capital theory from the 1960s emphasized that investment in human capital is a prospective investment and a crucial determinant of economic progress [1]. The research on higher vocational education and industrial economic development originated from this theory. Consequently, Denison employed established methodology to assess the economic benefit of education on the United States, determining it to be above 20% [2]. The accumulation of human capital and technology advancement are becoming increasingly essential for economic development, with Romer [3] and Lucas [4] introducing the concept of endogenous economic growth. These notions motivate other nations and have been substantiated inside their own countries: education cultivates human capital, while vocational education fosters technical and skilled laborers. The economic development of Germany and Japan is significantly influenced by vocational education [5-6]; the economies of Nepal and Indonesia are more productive as a result of vocational education [7-8]; and Nigeria's economic advancement is contingent upon the comprehensive adoption of vocational education[9]. Despite Arrow's presentation of divergent perspectives in the subsequent study [10], all nations concur that talent is the primary driving force for improving social and economic quality, and the professional training of talent is of utmost priority.

Chinese academics examine the impact of higher vocational education quality, hierarchical structure, and professional distribution on the optimization and upgrading of industrial structure, industrial transformation and relocation, and the coupling of regional economies [11-13]. Policy text analysis, geographical Durbin model, GMM model, baseline regression analysis, and additional methodologies are employed to analyze and quantify data from China as a whole, as well as from specific provinces and municipalities. The adaptability of higher vocational education to industrial development requires enhancement, as its intrinsic capacity is inadequate. It is recommended to increase investment in higher vocational education, improve the construction of professional groups, and establish a differentiated ecological framework and tiered development space [14-16]. In conclusion, the research on higher vocational education and industrial economic development, both domestically and internationally, is extensive and produces numerous valuable results.

The relationship between higher vocational professional groups and industrial structure is mostly overlooked, and the research methodologies employed are rather uniform, lacking a cross-disciplinary application of comprehensive approaches, and are insufficiently represented. Secondly, the origins of the issue are seldom analyzed in relation to the external environment and the evolving dynamics of social demand, complicating the formulation of policy solutions. The dynamic evolution features and developmental trends of the coupling coordination level have not been sufficiently explored, hindering the comprehension of vocational education and industry development as well as the principles of industry-education integration. This work scientifically constructs the index system for two typical higher vocational professional groups and industrial structures. The coupling coordination model and distribution map are employed to illustrate the coupling level of the two in each region of the country. The Moran index demonstrates the geographical correlation of the coupling coordination level between the two systems. The primary origins of coupling discrepancies are recognized. Ultimately, three-dimensional kernel density estimation and spatial Markov chain analyze the temporal distribution and geographic evolution trend of the coupling coordination degree. Consequently, findings and specific recommendations are offered to furnish empirical support for the merger of industry and education, as well as the advancement of high-quality vocational education.

2. Research Design

2.1 Construction of Indicator System and Data Sources

A three-tiered indicator system for higher vocational professional clusters and industrial structures was developed, grounded in the connotation and extension of these clusters, integration of industry and education, systematic nature, and data accessibility. Table 1 illustrates the resources, scale, and performance of this system. This research is based on the “China Higher Vocational Education Quality Report,” “China Education Statistical Yearbook,” “National Education Concise Statistical Analysis,” “China Population and Employment Statistical Yearbook,” provincial statistical yearbooks, and data from the National Bureau of Statistics. This study selected 29 provinces, in accordance with research aims and data accessibility. Missing data are supplemented by linear interpolation.

2.2 Research Methods

2.2.1 Entropy method and coupling coordination model

Entropy is an objective weighing technique that evaluates indicator information entropy and assigns weights according to their relative degree of volatility within the system. The extensive degree of higher vocational professional clusters and industrial framework is assessed. The coupling coordination model analyses the impacts of “interaction” and “synergy” to assess the coupling coordination status of higher vocational professional clusters and industrial structures. The equation for computation:

$$D=\sqrt{C\times T} \tag{1}$$

$$C=\sqrt{\frac{E(X)\times F(\mathrm{Y})}{\left(\frac{E(X)+F(\mathrm{Y})}{2}\right)^2}} \tag{2}$$

$$T=W_1\cdot E(X)+W_2\cdot F(\mathrm{Y}) \tag{3}$$

D, a quantitative measure of the degree of coupling coordination between systems, is present in the aforementioned equation. *C* represents the coupling degree between the higher vocational education program cluster and the industrial structure system, *T* denotes their comprehensive coordination index, *E(X)* and *E(Y)* signify their comprehensive evaluation indices, and W_1 and W_2 indicate their respective weights. It is commonly presumed that $W_1 = W_2 = 0.5$, indicating that both systems hold equal significance. Based on prior studies and the current context of this paper [17], the coupling coordination degree is categorized into eight levels, with the results presented in Table 2.

Table 1. Comprehensive Evaluation Index System of Higher Vocational Professional Groups and Industrial Structure

system	First level indicator	Secondary indicators	unit	Weight
Higher vocational professional group system	Professional Resources	The proportion of primary industry professional groups	percentage	0.0075
		Proportion of secondary industry professional groups	percentage	0.0259
		The proportion of tertiary industry professional groups	percentage	0.0080
		The proportion of professional course hours of part-time teachers in enterprises	percentage	0.0130
		Value of teaching and research equipment per student	Yuan/student	0.0936
	Professional scale	Student-teacher ratio in higher vocational colleges	percentage	0.0066
		Annual per capita financial allocation	Yuan	0.1996
		The proportion of full-time teachers with dual professional qualifications	percentage	0.0125
		Proportion of part-time teachers in off-campus industries	percentage	0.0176
	Professional performance	Number of graduates from higher vocational colleges	people	0.0544
		Employment rate of graduates in their province or city	percentage	0.0197
		Technology transaction amount	10,000 Yuan	0.2068
		Horizontal technical service amount	10,000 Yuan	0.1484
		Amount of vertical scientific research funds received	10,000 Yuan	0.1864
Industrial structure system	Industry resources	Number of employees	10,000 people	0.0165
		Number of enterprises above designated size	individual	0.0566
		Proportion of high-tech enterprises	percentage	0.0176
		Proportion of professional and technical personnel	percentage	0.0283
	Industry scale	The proportion of primary industry production	percentage	0.2046
		The proportion of secondary industry production	percentage	0.0144
		The proportion of tertiary industry production	percentage	0.4340
	Industry Performance	The proportion of employment in the primary industry	percentage	0.0274
		The proportion of employment in the secondary industry	percentage	0.0385
		The proportion of employment in the tertiary industry	percentage	0.1191
		Number of registered unemployed persons in urban areas	10,000 people	0.0431

Table 2. Coupling Coordination Degree and Classification

Coupling Coordination Level	Coupling Coordination Degree D	Coordination Level
1	$0.8<D\leq1.0$	High-Quality Coordination
2	$0.7<D\leq0.8$	Good Coordination
3	$0.6<D\leq0.7$	Intermediate Coordination
4	$0.5<D\leq0.6$	Primary Coordination
5	$0.4<D\leq0.5$	Barely Coordinated
6	$0.3<D\leq0.4$	Mild Disorder
7	$0.2<D\leq0.3$	Moderate Disorder
8	$0.0\leq D\leq0.2$	Serious Disorder

2.2.2 Moran index

Spatial correlation analysis employs a spatial weight matrix alongside the global and local Moran indices to examine spatial characteristics. This method is extensively used to discern spatial agglomeration characteristics, as the geographical context influences both a province's coupling coordination and that of its neighbouring regions. The global Moran index formula illustrates the spatial correlation and clustering of the coupling coordination degree among the 29 provinces in the nation.

$$G\text{-}I=\frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\left(X_i-\bar{X}\right)\left(X_j-\bar{X}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\sum_{i=1}^{n}\left(X_i-X_j\right)^2} \quad (4)$$

In this context, n represents the number of provinces, X_i and X_j denote the coupling coordination degrees of provinces i and j, $\bar{X}$ signifies the mean, and W_{ij} is the spatial weight matrix. I>0 signifies a positive spatial correlation in coupling coordination distribution, I<0 denotes a negative correlation, and I=0 represents the absence of correlation. The I range is from -1 to 1. The local Moran index is employed for a more detailed examination of the heterogeneity in provincial spatial distribution. The equation is:

$$L\text{-}I=\frac{X_i-\bar{X}}{\frac{1}{n}\sum_{i=1}^{n}\left(X_i-\bar{X}\right)^2}\sum_{j\neq i}^{n}W_{ij}\left(X_i-\bar{X}\right) \quad (5)$$

Current researchers [18] categorise each province's agglomeration types into four classifications: "high-high" agglomeration, "low-low" agglomeration, "low-high" agglomeration, and "high-low" agglomeration.

2.2.3 Dagum Gini coefficient and decomposition

The Dagum Gini coefficient is frequently employed to analyse regional and overall disparities and their underlying causes. It has distinct advantages in spatial imbalance analysis compared to the Gini coefficient. The Gini coefficient is divided into three components: the intra-regional difference contribution (Gw), the inter-regional difference contribution (Gnb), and the hypervariable density contribution. Hypervariable density denotes discrepancies in crossover effects among regions. In the absence of a crossover impact between regions, it is zero. Refer to research [19] for the formula.

2.2.4 Three-dimensional kernel density estimation

Nonparametric kernel density estimation is employed to analyse spatial non-equilibrium and dynamic evolution patterns. It examines the dynamic distribution of coupling coordination levels between higher vocational professional clusters and industrial structures [20]. This research employs a three-dimensional kernel density map to enhance data visualisation. Examine the density function of the random variable X:

$$f(x)=\frac{1}{Nh}\sum_{i=1}^{N}K\left(\frac{X_i-\bar{X}}{h}\right) \quad (6)$$

The coupling coordination degree density function is denoted as *f(x)*, the kernel density function as *K*, the independent and identically distributed observation values as X_i , the mean value as $\bar{X}$, the total number of observation values as N, and the bandwidth as *h*. The bandwidth escalates with *h*, enhancing the smoothness of the density function while diminishing estimation precision. The estimated results exhibit greater accuracy with a smaller *h*.

2.2.5 Spatial markov chain

A transfer matrix is employed in Markov chain analysis to ascertain the probability and direction of transitions between development types. This study utilises it to examine the internal dynamics and evolutionary patterns of coupling coordination. We categorise coupling coordination degree into N classifications and construct an NxN state transition probability matrix utilising the Markov chain [21-22]. Particular equation:

$$P_{ij}=\frac{n_{ij}}{n_i} \quad (7)$$

P_{ij} in the matrix denotes the transition probability of coupling coordination degree for a region of type i from period t to type j in period t+1. n_{ij} represents the number of provinces transitioning from type i to type j in period t+1; n_i denotes the number of provinces in state i throughout the study.A probability transition matrix of size N×N can be derived by computing all elements. Conventional Markov models overlook spatial correlation effects among regions, whereas the spatial Markov chain incorporates spatial lag conditions into the Markov probability transition matrix. The N×N transition probability matrix is decomposed into an N×N×N transition conditional probability matrix to examine the transition trends of coupling coordination degree under diverse neighbourhood background influences. The spatial lag value is determined by weighting the coupling coordination degree of geographically proximate units within a specified area, with the spatial weight matrix adhering to the boundary principle that assigns a value of 1 to adjacent regions and 0 to the non-adjacent areas.

3. Analysis of Empirical Results

3.1 Calculation and Analysis of the Level of Coupled Coordinated Development

3.1.1 The overall level of coupling coordination has been improved

A "fluctuating upward" trend in coupling coordination was observed, increasing by 10.44% from 0.3996 (mildly misaligned) in 2015 to 0.4413 (barely coordinated) in 2022. In 2022, provinces classified as "barely coordinated" progressively yielded to those in the "primary coordination" category for national coupling coordination. Eighteen provinces (62.07%) exhibited coupling coordination levels classified as "barely coordinated" or superior. Jiangsu and Zhejiang attained the "intermediate coordination" level, demonstrating considerable enhancement and a consistent upward trajectory. The overall coupling coordination remains inadequate and has not achieved "intermediate coordination."

Table 3. Coupling Coordination between Higher Vocational Professional Groups and Industrial Structure in Each Province

area	2015	2016	2017	2018	2019	2020	2021	2022
Fujian Province	0.4942	0.4306	0.4522	0.4552	0.4380	0.4207	0.4222	0.4293
Inner Mongolia	0.4149	0.3906	0.3944	0.3907	0.3916	0.5101	0.3853	0.3688
Heilongjiang	0.3420	0.3492	0.3555	0.3644	0.3420	0.3393	0.3377	0.3163
Shanghai	0.4283	0.4207	0.4325	0.4445	0.4545	0.4535	0.4641	0.4633
Hainan Province	0.3519	0.3534	0.3368	0.3537	0.3564	0.344 0	0.3623	0.328 0
Shanxi Province	0.3738	0.3734	0.3764	0.3998	0.3996	0.3945	0.3924	0.3591
Liaoning Province	0.3870	0.3913	0.3937	0.3996	0.4056	0.3787	0.3817	0.3891
Shaanxi Province	0.3916	0.4126	0.4376	0.4303	0.4304	0.3994	0.4191	0.3991
Chongqing	0.4000	0.4112	0.4372	0.4492	0.4631	0.5163	0.5304	0.4110
Ningxia	0.3855	0.4086	0.3991	0.4052	0.4073	0.3940	0.4065	0.3962
Yunnan Province	0.3341	0.3565	0.3939	0.393 0	0.3886	0.3681	0.3696	0.3486
Beijing	0.4959	0.5136	0.5200	0.5288	0.5326	0.5285	0.5309	0.5239
Qinghai Province	0.3874	0.3837	0.404	0.3975	0.3981	0.422 0	0.4301	0.4098
Hunan Province	0.4089	0.4126	0.4289	0.4623	0.5060	0.4686	0.4709	0.4439
Guangxi	0.3590	0.3697	0.3810	0.3841	0.3896	0.4004	0.4001	0.3898
Hubei Province	0.3883	0.4088	0.4308	0.4302	0.4524	0.4456	0.4729	0.4269
Guizhou Province	0.3305	0.3247	0.3653	0.3758	0.3761	0.3829	0.3845	0.3655
Gansu Province	0.3485	0.3549	0.3660	0.3797	0.3719	0.3699	0.3740	0.3871
Anhui Province	0.3846	0.3968	0.4096	0.4199	0.4364	0.4116	0.4569	0.4406
Hebei Province	0.3682	0.3992	0.4067	0.4381	0.4466	0.4405	0.4447	0.4249
Jiangxi Province	0.3720	0.3882	0.4013	0.4199	0.4243	0.4201	0.4379	0.4334
Jiangsu Province	0.5379	0.5339	0.5654	0.5862	0.6241	0.6162	0.6275	0.6328
Tianjin	0.4203	0.4244	0.439	0.4437	0.4509	0.4359	0.4379	0.5014
Shandong Province	0.4263	0.4350	0.4456	0.4748	0.4941	0.4906	0.5030	0.5150
Jilin Province	0.3436	0.3568	0.3856	0.3923	0.3931	0.3633	0.3703	0.4171
Guangdong Province	0.4606	0.4832	0.4907	0.5021	0.5141	0.5216	0.5560	0.5890
Sichuan Province	0.3983	0.4047	0.4158	0.4366	0.4791	0.4164	0.4344	0.5154
Zhejiang Province	0.4621	0.4825	0.5002	0.5219	0.5673	0.5539	0.5934	0.6042
Henan Province	0.3930	0.3975	0.4170	0.4253	0.4456	0.4657	0.4559	0.5670
National Average	0.3996	0.4058	0.4201	0.4312	0.4407	0.4370	0.4432	0.4413

3.1.2 The coupling coordination level and grade of each province have changed significantly

Various degrees of coupling coordination are present, and Figures 1-3 illustrate the spatial distribution of coupling coordination levels between higher vocational professional clusters and industrial structures throughout different Chinese provinces. In 2015, 20 provinces exhibited a moderate imbalance, representing 68.97% of all coordination alterations, followed by eight provinces with little coordinated development and one province with primary coordination (Jiangsu Province). The protracted effects of the global economic crisis impeded economic growth, diminished demand for skill, and constrained the advancement of vocational education. The mild imbalance decreased by 27.59% to 12 provinces, representing 41.38% by 2019. Conversely, 13 provinces exhibited minimal coordinated development; 3 provinces (Zhejiang, Beijing, and Hunan) demonstrated primary coordination, while one province (Jiangsu) achieved intermediate coordination. China's economy has entered a “new normal,” emphasising high-quality development and supply-side structural reform to enhance growth. The release of the “National Pilot Implementation Plan for Industry-Education Integration” has accelerated the progress of vocational education, underscoring the increasing social influence of higher vocational professional clusters. This expedited synchronised professional and industrial advancement. By 2022, the count of provinces exhibiting moderate imbalance decreased to 11, the number of scarcely coordinated provinces diminished to 10, while primary coordinated provinces increased to 6, and intermediate coordinated provinces ascended to 2. Nevertheless, the modifications were negligible and unremarkable. This signifies post-pandemic challenges and the emergence of intelligence. ChatGPT's generative artificial intelligence has transformed the societal distribution of labour and professions. Vocational education remains integral to economic development; nevertheless, intelligent production for technical skills has introduced new challenges to talent development. Secondly, the levels of higher vocational education and industrial structure development differ by province, exhibiting high coupling coordination in the east and low in the west. Table 3 indicates that provinces exhibiting high coupling coordination and rankings are located in the eastern region, including Jiangsu, Zhejiang, and Guangdong. These economically advanced provinces possess considerable resource advantages.

This indicates two primary attributes of the economic development of these provinces. The regional industrial structure is well-structured, industrial adjustments have been expedited, and vocational education has been enhanced, thereby improving coupling coordination. Secondly, with the backing of national policy, these regions have customised higher vocational professional clusters to align with local conditions, thereby diminishing the disparity between industry and education and demonstrating an increasing trend of integration. Guizhou, Yunnan, and Inner Mongolia encounter difficulties stemming from inadequate coupling coordination and ranking. These regions are experiencing industrial transformation and energy conversion, accompanied by a talent deficit and sluggish advancement in new materials, information technology, and biomedicine. Nonetheless, systemic economic decline and industrial transformation have hindered the progress of higher vocational education components, obstructing the alignment of higher vocational colleges' professional structures with local emerging industries and impeding industrial development. Consequently, industrial and educational resources are inadequately integrated.

3.2 Spatial Correlation Analysis of Coupling Coordination

3.2.1 Global moran index analysis

The levels of provincial coupling coordination exhibit significant variability. We assess coupling coordination spatial correlation by computing the global Moran index. Table 4 demonstrates that the Moran index from 2015 to 2022 consistently exceeds 0.1, signifying a spatial correlation in provincial coupling coordination. The spatial correlation between provinces is statistically significant, as indicated by a P value of less than 0.1. Coordinated development is essential in 2019, as the Moran index reaches a peak of 0.2804, signifying a high spatial correlation in coupling coordination. Nonetheless, spatial correlation has progressively diminished over time. The global Moran index fails to disclose local spatial aggregation characteristics; therefore, the local Moran index must be computed to analyse these patterns.

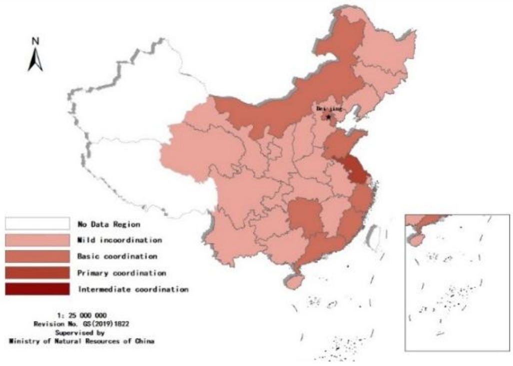

Figure 1. Spatial Distribution of Coupling Coordination Level across the Country in 2015

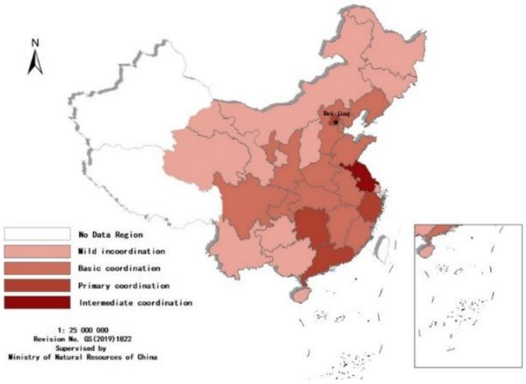

Figure 2. Spatial Distribution of Coupling Coordination Levels across the Country in 2019

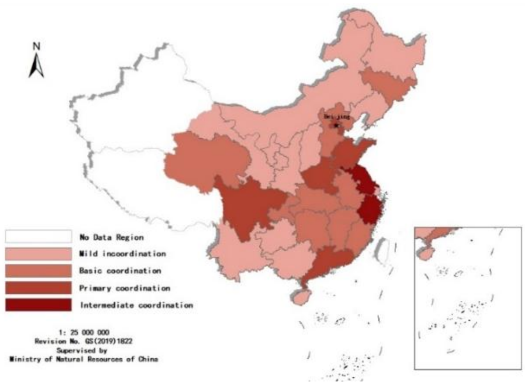

Figure 3. Spatial Distribution of Coupling Coordination Level across the Country in 2022

Table 4. Global Moran's I

Model parameters	2015	2019	2022
Moran's-I	0.1879	0.2804	0.1720
Z-score	2.8217	3.0810	2.5978
P-value	0.0048	0.0021	0.0094

3.2.2 Local moran index analysis

The global Moran index examines spatial agglomeration in its entirety, whereas the local index concentrates on particular regions. Table 5 indicates that the local Moran index analysis of coupling coordination degree reveals distinct spatial agglomeration between higher vocational professional groups and industrial structure. The significant category encompasses “high-high” agglomeration, “high-low” agglomeration, “low-high” agglomeration, and “low-low” agglomeration, whereas the other category comprises insignificant areas. The degree of main coupling coordination fluctuated from 2015 to 2022:

The “high-high” agglomeration persists in a stable manner in Hebei, Jiangsu, and Shandong. Developed regions prioritise the aggregation of beneficial resources to promote regional collective advancement. Nonetheless, “siphon weakening” may transpire. Secondly, China's economic growth centres, Jiangsu in the Yangtze River Delta and Guangdong in the Pearl River Delta, exhibit strong coupling coordination and are characterised as “high-low” agglomerations. Guangdong Province has spearheaded vocational education advancement by establishing pilot national industry-education integration cities such as Guangzhou and Shenzhen, formulating essential professional cluster development plans, and fostering industry-education integration within the Greater Bay Area. It is encircled by underdeveloped provinces due to its inability to positively influence adjacent regions. Third, as a global economic hub, Shanghai has consistently occupied a “low-high” agglomeration zone, necessitating the integration of advanced industry and education from other provinces. It must integrate these experiences with its urban regional context and enhance vocational education innovation. Fourth, no provinces are classified within the “low-low” agglomeration area, while the majority remain insignificant, increasing from 16 in 2015 to 18 in 2022. Tianjin and Ningxia transitioned from a state of prominence to insignificance. The reduction in coupling among neighbouring provinces has resulted in adverse radiation effects, underscoring the necessity to enhance interprovincial interactions. Nonetheless, it indicates that the siphoning effect and redundancy in production factors in high-level provinces have constrained the spillover effect. These provinces have experienced sluggish economic growth, leading to uneven development.

Table 5. Local Moran's I

Spatial aggregation type	2015	2019	2022
High-High Aggregate Area	Tianjin, Hebei, Shanxi, Shanghai, Jiangsu, Anhui, Shandong, Henan, Hubei, Shaanxi, Ningxia	Tianjin, Hebei, Shanxi, Jiangsu, Anhui, Shandong, Henan, Hubei, Shaanxi, Ningxia	Hebei, Jiangsu, Anhui, Shandong, Henan, Hubei, Shaanxi, Chongqing
High-low concentration area	Guangdong	Guangdong	Guangdong
Low-high concentration area	/	Shanghai	Shanxi, Shanghai
Low-low concentration area	/	/	/
Unnoticeable area	Beijing, Inner Mongolia Autonomous Region, Liaoning, Jilin, Heilongjiang, Zhejiang, Fujian, Jiangxi, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Gansu, Qinghai	Beijing, Inner Mongolia Autonomous Region, Liaoning, Jilin, Heilongjiang, Zhejiang, Fujian, Jiangxi, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Gansu, Qinghai	Beijing, Tianjin, Inner Mongolia Autonomous Region, Liaoning, Jilin, Heilongjiang, Zhejiang, Fujian, Jiangxi, Hunan, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Gansu, Qinghai, Ningxia

3.3 Regional Differences and Sources of Coupling Coordination

The coupling coordination levels for the eastern, northeastern, central, and western regions of China were assessed from 2015 to 2022. The analysis investigates intra-regional, inter-regional, and source variations in coupling coordination levels throughout China and within each region. Principal discoveries encompass:

The Gini coefficient consistently rose throughout the observation period, signifying considerable spatial disparities. Despite a minor reduction in the regional disparity in 2016, it has persisted in its expansion. Secondly, intra-regional disparities have been increasing. Figure 4-a indicates that the Gini coefficients for the eastern, northeastern, and western regions remained consistent. Their trends corresponded with the Gini coefficient, notwithstanding minor annual fluctuations. The eastern region exhibited the highest Gini coefficient, reflecting a modest increase yet surpassing the average. The western region exhibited the lowest Gini coefficient yet experienced the most significant increase, succeeded by the northeastern region. The Gini coefficient of the central region increased from 2015 to 2020, reaching a maximum of 0.0617 before experiencing a decline. This indicates that advancements in technology and the optimisation of industrial structures have mitigated uneven development in the central region, which is experiencing growth and propelling economic expansion. Third, inter-regional disparities varied throughout the study. Figure 4-b illustrates that the disparities among the east-west, northeast-west, and central-west regions increased and subsequently decreased, albeit at varying intervals. The potential of the West has been progressively realised in recent years; however, the disparity between the East and West persists as the most significant. National strategies such as western region development and elevation have contributed to reducing the disparity between the west and other regions. Nonetheless, regional disparities are increasing. The east-central region exhibited the greatest disparity, succeeded by the east-northeast and northeast-central regions. This indicates internal gradients in these areas. Certain provinces in these regions have undergone increased horizontal expansion, exacerbating internal disparities and uneven development. Fourth, contribution rates indicated that intra-regional differences (Gw) remained stable but diminished, whereas inter-regional differences (Gnb) and super-variable density (Gt) both decreased with recurrent fluctuations. Analysis of differential sources indicates that inter-regional disparities exerted a greater influence than intra-regional disparities, which in turn surpassed the impact of super-variable density. Disparities were predominantly attributed to interregional variations. Therefore, enhancing coupling coordination and regional collaborative development necessitates the rapid reduction of inter-regional disparities.

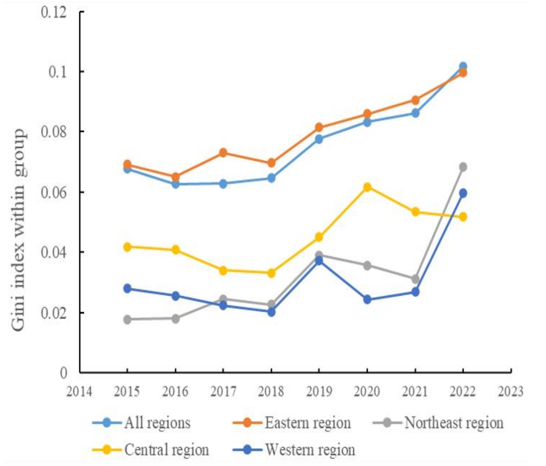

Figure 4-a Trends in Gini Coefficients within Groups

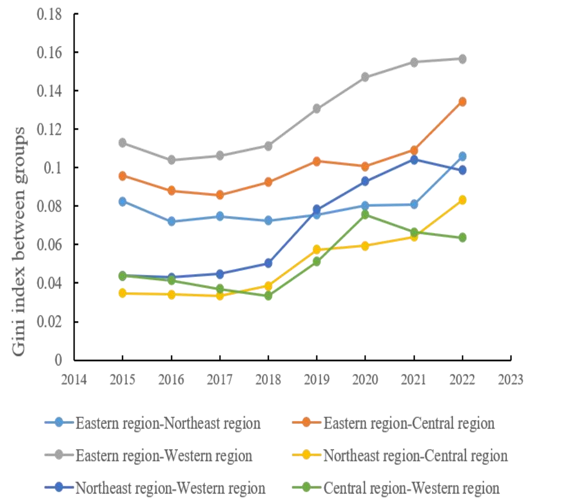

Figure 4-b Trend in Gini Coefficient between Groups

4. Analysis of Dynamic Evolution of Spatiotemporal Distribution of Coupling Coordination Degree

4.1 Analysis of the Time Distribution Evolution of Three-Dimensional Kernel Density Estimation

The coupling levels between China's higher vocational professional groups and industrial structure can be illustrated by the Dagum Gini coefficient. It does not elucidate the evolution at the provincial level. Consequently, three-dimensional Kernel density estimation is employed to examine the development trend, extensibility, and polarisation tendency of the coupling coordination coefficient at both the national level and within the four principal regions. Figure 5 illustrates the dynamic progression of the distribution of the national coupling coordination level: Initially, the kernel density distribution centre of the coupling coordination system shifts to the left, subsequently to the right, and ultimately to the right again. The "catch-up effect" among provinces is enhancing overall coupling coordination and accelerating progress. Secondly, the distribution peak shape of the coupling coordination level becomes narrower throughout the observation period, accompanied by a gradual decline in kurtosis. This indicates a broader disparity in the coordination speeds of provincial coupling. The Kernel density curve of the national coupling coordination level consistently exhibits an unimodal distribution, signifying minimal polarisation and an absence of multi-polarization trends. The distribution curve exhibits a pronounced right-tail characteristic and inadequate extended convergence, signifying a substantial disparity between extreme values and the mean. Furthermore, certain provinces have spearheaded development.

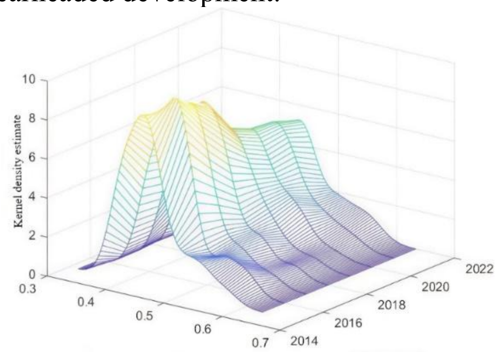

Figure 5. Development Trend of National Coupling Coordination Level

The distribution trends of coupled development levels across the four regions exhibit marked differences. In general, absolute disparities are diminishing. Figures 6-9 illustrate the principal characteristics: The Kernel density centres of the four regions exhibit varying degrees of rightward shift, signifying disparate enhancements in coupling coordination.

The northeastern and eastern peak shapes progressively broaden as kurtosis rises and subsequently falls. This signifies increasing dispersion among provinces in these two regions and notable disparities in path selection and high-level coupling challenges. The peak shapes in the central and western regions become increasingly narrow over time, with kurtosis exhibiting an N-shaped trajectory-initially increasing, subsequently decreasing, and then increasing once more-signifying a reduction in absolute disparities in coupled development levels among provinces. The eastern region exhibited an unimodal distribution characterised by mild kurtosis and an absence of tailing. This indicates that the region's development is equitable and not divisive. In the northeast, the number of peaks fluctuated from one to two and back to one, exhibiting a pronounced right-tail phenomenon. Notwithstanding diminishing polarisation, certain provinces in the region exhibited markedly superior levels of development compared to others. In 2015 and 2019, the central region exhibited an unimodal distribution, whereas in other years, it transitioned to bimodal and multimodal distributions. This illustrates an escalating “Matthew effect,” signifying multi-tiered differentiation and implying that barriers to the flow of production factors between provinces endure, exacerbating regional development disparities. In the western region, the distribution evolved from an unimodal form in 2015 to a bimodal form in 2018, with a reduction in side peak kurtosis signifying a decrease in polarization. In conclusion, the alignment of coordination levels between higher vocational professional groups and the industrial structure has enhanced, facilitating coordinated development and reducing inter-city disparities.

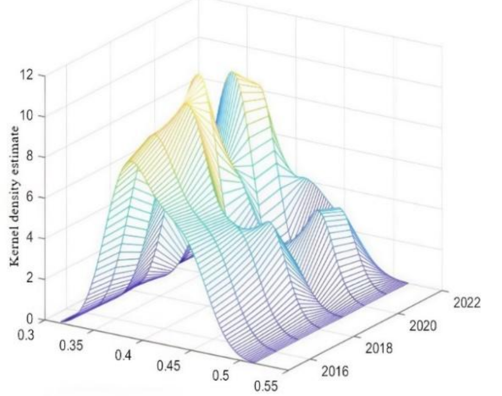

Figure 6. Development Trend of Coupling Coordination Level in Northeast China

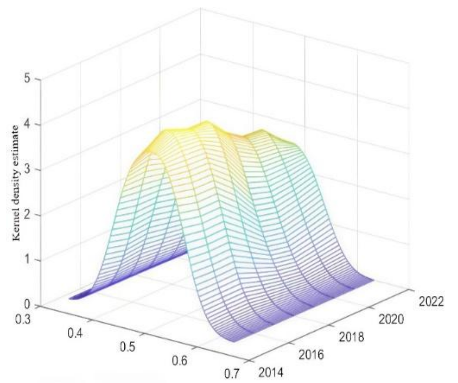

Figure 7. Development Trend of Coupling Coordination Level in the Eastern Region

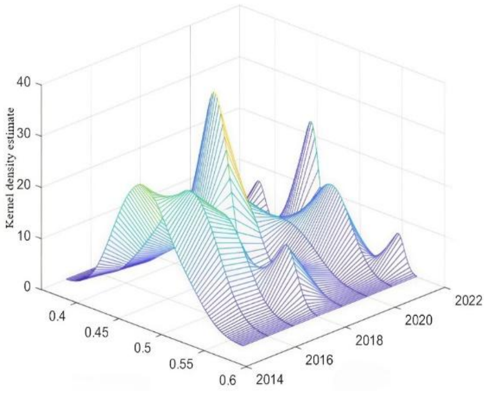

Figure 8. Development Trend of Coupling Coordination Level in the Central Region

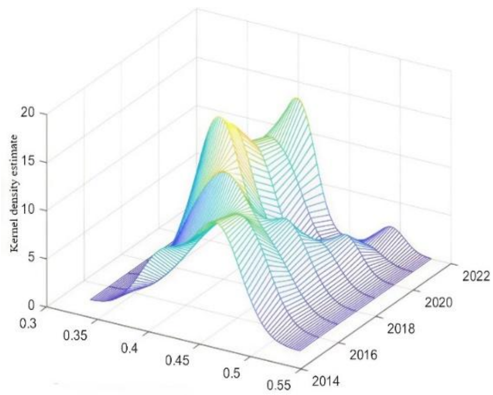

Figure 9. Development Trend of Coupling Coordination Level in Western China

4.2 Analysis of Dynamic Evolution of Markov Chain Space

Kernel density estimation is incapable of forecasting transitions in coupling coordination levels. Markov chain analysis is employed to augment kernel density estimation and illustrate internal dynamic evolution patterns, thereby addressing this limitation. A conventional Markov state transition probability matrix is established by Table 6, categorising the coupling coordination development levels into four quartiles using the quartile method: low (0-25%), relatively low (25%-50%), relatively high (50%-75%), and high (75%-100%). K equals 1, 2, 3, and 4, respectively. A higher (K) signifies increased regional coupling coordination. The outcomes are:

The diagonal probability values in the transition probability matrix exceed the off-diagonal values, signifying inertial and self-locking transitions in the coordinated development types of various provinces. The likelihood of preserving the original states for the low and high levels at both ends of the diagonal is 80.39% and 80%, respectively, resulting in a high-low agglomeration pattern and illustrating "club convergence." Secondly, elevated levels exhibit a 24.49% probability of upward transfer and a 6.12% probability of downward transfer. Lower levels exhibit upward transfer probabilities of 18.87% and downward transfer probabilities of 11.32%. The likelihood of advancement to higher levels is marginally greater than that of progression to lower levels. This indicates that industrial restructuring has produced certain advantages. Continued vigilance is essential to avert the "Matthew effect." Third, level transitions predominantly occur diagonally, while leapfrog transitions are infrequent. The maximum non-diagonal transfer probability is 0.2449, constituting 30.46% of the maximum diagonal transfer probability. Transfer probabilities on both sides of the diagonal are below 0.3. Transitions predominantly occur between levels, and immediate leapfrog development across categories is unfeasible.

Table 6. Traditional Markov Chain Transition Probability Matrix

t /t+1	n	1	2	3	4
1	51	0.8039	0.1765	0.0196	0
2	53	0.1132	0.6792	0.1887	0.0189
3	49	0	0.0612	0.6939	0.2449
4	50	0	0.0200	0.1800	0.8000

The spatial interconnection among industries across various regions is increasing, industrial factors are becoming more mobile, the industrial economy exhibits significant spatial spillover effects during development, and the surrounding environment influences the likelihood of transferring the coupled coordinated development level within the region. Consequently, the spatial Markov chain is formulated by integrating the conventional Markov chain with the spatial lag factor to examine the influence of neighbourhood context on the probability of coupled coordination transfer.

Table 7 illustrates the characteristics of spatial evolution: The geographical context significantly influences coupled coordinated development, with evident spatial spillover effects. When comparing the conventional Markov matrix with the spatial Markov matrix, it is evident that neglecting the spatial lag factor results in an upward transfer probability of 0.2449. However, when the geographical space factor is incorporated, with the neighbourhood background designated as state 4 (high level), it rises to 0.2727, demonstrating a significant increase in transfer probability and underscoring the necessity of considering the spatial lag factor. Secondly, varying neighbourhood backgrounds influence the state transfer probability of coupled coordinated development, distinguishing it from the conventional Markov chain at identical positions. The "neighbourhood effect" indicates that proximity to a high-level region will substantially enhance positive spillover effects and elevate the likelihood of upward transfer during the observation period. In contrast, closeness to a low-level area enhances downward transfer. In the conventional Markov probability matrix, the transition from higher to higher levels has a probability of 0.2449. The transfer probability rises to 0.3158 when adjacent to a higher-level region and diminishes to 0.125 when adjacent to a lower-level region ($P_{34/1}$ =0.125 < P_{34} =0.2449 < $P_{34/3}$ =0.3158). It can improve in all aspects when situated near a high-level area due to its beneficial radiation effect. The development will be adversely affected, while the adjacent high will be enhanced, and the adjacent low will be suppressed. The spatial spillover effect elucidates the club convergence phenomenon characterised by "high-high agglomeration and high-driving low" in the development of coupling coordination levels. A province adjacent to a high-level province will experience a favourable impact, enhancing the likelihood of upward transfer (P_{12} =0.1765 < $P_{12/4}$ = 0.1818) and diminishing the likelihood of downward transfer ($P_{32/4}$ =0 < P_{32} =0.0612). An adjacent low-level province will experience negative radiation, elevating the likelihood of downward transfer ($P_{32/3}$ =0.1818 > P_{32} =0.0612) and inhibiting upward transfer ($P_{34/1}$ =0.125 < P_{34} =0.2449), thereby demonstrating the "club convergence effect."

Table 7. Space Markov Chain Transition Probability Matrix

Field Type	t /t+1	n	1	2	3	4
1	1	11	0.7273	0.2727	0	0
	2	11	0	0.4545	0.5455	0
	3	8	0	0	0.875	0.125
	4	2	0	0	0.5	0.5
2	1	9	0.7778	0.222	0	0
	2	12	0.0833	0.8333	0.0833	0
	3	11	0	0.1818	0.6363	0.1818
	4	10	0	0	0.1	0.9
3	1	20	0.9	0.1	0	0
	2	25	0.12	0.72	0.12	0.04
	3	19	0	0.0526	0.6316	0.3158
	4	25	0	0.04	0.16	0.8
4	1	11	0.7273	0.1818	0.0909	0
	2	5	0.4	0.6	0	0
	3	11	0	0	0.7273	0.2727
	4	13	0	0	0.2308	0.7692

5. Conclusion and Recommendations

5.1 Conclusion

The coupling coordination between national higher vocational professional groups and the industrial structure has progressively enhanced from a slight imbalance (0.3996) in 2015 to a state of minimal coordination (0.4413) in 2022. Between 2015 and 2022, the percentage of provinces exhibiting slight imbalance declined from 68.97% (20 provinces) to 37.93% (11 provinces). In 2022, Beijing, Tianjin, Shandong, Guangdong, Sichuan, and Henan exhibited primary coordination, whereas Jiangsu and Zhejiang demonstrated intermediate coordination, indicating a notable transition from nonexistence to existence. The level of coordination has consistently improved, and coordinated development has progressed.

Secondly, a global spatial correlation exists in the coordination levels of provincial coupling, although it has marginally diminished from 2019 to 2022 due to spatial agglomeration challenges. The local spatial correlation indicates that "high-high" agglomeration diminished from 12 to 8 provinces, whereas "low-high" agglomeration rose from 0 to 2 provinces. The region with negligible spatial correlation comprises the largest share of provinces, increasing from 55.17% (16 provinces) in 2015 to 62.07% (18 provinces) in 2022, signifying persistent imbalance challenges.

Third, regional disparity increases as the Gini coefficient reaches a maximum of 0.1017 in 2022. The east-west disparity is the primary factor contributing to regional variations in coupling coordination. The western region is advancing, reducing the disparity with other regions. Ranking of the Gini coefficient by region: East, Central, Northeast, West. The Northeast and Western regions exhibit a lower Gini coefficient; however, both have experienced substantial growth since 2021, prompting concerns regarding regional segmentation and the resultant imbalance in regional development.

The coupling coordination polarisation is weak on a national level but robust regionally. The four principal regions exhibit distinct trends in the distribution of coupling development levels, with the central region demonstrating an evolutionary pattern of "aggregation-dispersion-greater dispersion." This indicates that regional development disparities are increasing. Geographic and spatial factors constrain the coordinated development types of provinces into distinct patterns, demonstrating significant path dependency. The convergence of clubs in the distribution range indicates that leapfrog development will require time.

5.2 Suggestions

5.2.1 Effectively enhance the adaptability of vocational education and ignite the dual engines of integration, symbiosis, and resonance

Research indicates that although coupling coordination in the country is enhancing, it remains subpar in quality. Certain provinces exhibit subpar coupling coordination. Consequently, the coupling coordination between the two systems must be perpetually enhanced. Enhancing the quality of higher vocational education fosters improved coupling coordination. It is essential to enhance the integration of vocational and general education, industry and education, as well as science and education, to rejuvenate high-quality vocational education. Develop pertinent platforms to align and synchronise industry talent demand reports, talent supply-demand inventories, and academic majors, courses, and textbooks from colleges and universities. Moreover, talent teams ought to enhance their scientific research competencies, establish scientific research exchange platforms, facilitate communication between educational institutions and enterprises, expedite the industrialisation of scientific and technological advancements, implement the “four-chain integration,” cultivate an open innovation ecosystem, and promote high-quality higher vocational education. Nonetheless, supply-side structural reforms must be intensified to enhance the adaptability of vocational education. Vocational colleges, as the principal providers of vocational education, are essential to this process. The professional development of vocational colleges should adhere to demand orientation, integration of industry and education, and distinctive growth. Investigate methods to establish advanced, unique, and dynamic vocational education professional clusters aligned with regional industrial clusters, incorporate professional cluster development into regional economic progress, and efficiently support the expansion of industrial clusters.

5.2.2 Deepen the inter-regional coordinated development strategy and create a resource-sharing community with complementary advantages

Inter-regional disparities primarily induce variations in coupling coordination. Therefore, it is essential to promote cross-regional higher vocational education development alliances, college alliances, and industry alliances to maximise the leadership and exemplary roles of provinces with high-quality development. These initiatives should concentrate on leveraging regional advantages to assist underdeveloped provinces, sharing resources and complementary strengths, and fostering coordinated collaboration. Regions with lower development should leverage their comparative advantages to cultivate an optimal economic, social, and cultural milieu to attract productive resources. These regions can attain competitive advantages, attract superior resources, mitigate local resource structure deficiencies, and expedite economic and social development by implementing such strategies. This mitigates “depression convergence” and averts “siphon weakening.”

5.2.3 Improve the level of regional economic integration and build a new pattern of industrial innovation and integrated development

Regional economic development must proactively “respond” and “adapt” to changes while overcoming inertia and path dependence. Taking the initiative to “alter the cage and substitute the bird” by promptly transitioning or phasing out obsolete traditional industries and those that no longer align with developmental objectives facilitates the optimisation of industrial structure and configuration. Prioritising the removal of regional administrative, technical, and informational barriers, facilitating the seamless flow of resources and factors across regions, establishing an open and dynamic innovation network, and executing scientific resource and industrial configurations aligned with local developmental stages and resource endowments are essential. To enhance the “triple helix” innovation mechanism, the government ought to refrain from excessive administrative interference and uniform strategies. It should promote innovation and embrace failure while “establishing connections" and "creating frameworks". Businesses, as demand and supply entities, should engage proactively in the initial phases of talent training. Vocational colleges should utilise professional groups and networks as frameworks, integrating into the regional relational network of institutions and organisations instead of employing fragmented models. Collaborating with government, businesses, and universities facilitates the circulation and cross-integration of vocational colleges, thereby enhancing regional economic integration.

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