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Dynamic Coupling Coordination of Higher Vocational Education and Digital Economy: A Spatial-temporal Analysis of China

Ying Yang[a] Yexin Liu[b] Weiwei Wu[c] Pengbin Gao[d] and Yifan Zhang[e]

[a] School of Finance and Economics, Shenzhen University of Information Technology, China

[b] School of Economics and Management, Northeast Forest University, China

[c] Business School, Harbin Institute of Technology, China

[d] School of Economics and Management, Harbin Institute of Technology (Weihai), China

[e] Business School, Harbin Institute of Technology, China

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Abstract

Purpose – The purpose of this paper is to explore the coupling coordination between higher vocational education and the digital economy.

Design/Methodology/Approach – Based on panel data from 31 provincial regions in China from 2013 to 2022, this paper studies the interdependence between higher vocational education and the digital economy.

Findings – Results show that the national coupling coordination degree increases gradually with a "high coupling with low coordination" pattern. Spatial differentiation follows the hierarchy of eastern > central > western regions. Key drivers undergo staged transitions from infrastructure factors (instructional research investment, R&D investment, digital infrastructure) to quality-oriented enablers (training services, education quality, industry digitization).

Research Implications – Policy simulation suggests tiered strategies: fostering industry-education consortia in advanced eastern regions while promoting targeted digital upskilling in western provinces.

Keywords: higher vocational education; digital economy; coupling coordination; interaction

JEL Classifications: I21, O33, R12, O15

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[a] First Author, E-mail:miaowww2056@126.com

[b] Corresponding Author, E-mail: liuyexin1990@163.com

[c] Co-Author, E-mail: wuweiwei@hit.edu.cn

[d] Co-Author, E-mail: gaopengbin@hit.edu.cn

[e] Co-Author, E-mail: yifanzhang@hit.edu.cn

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I. Introduction

The rise of innovative digital technologies, including big data, cloud computing, and artificial intelligence, has marked a new era of accelerated innovation, and this surge has led to digital industries and the promotion of digital transformation in traditional industries. In this context, many countries are prioritizing the development of the digital economy (Ran et al., 2023). And the workforce's skill and competencies are redefined (Achtenhagen et al., 2019). New unconventional, cross-sectoral high-level skills related to digitalization are replacing the need for manual and conventional lower-level skills and qualifications. Consequently, training skilled workforce with advanced competencies is crucial for economic growth and social advancement through digital transformation (Acemoglu and Autor, 2011). Higher vocational education, as the primary provider of higher-skilled talent (Kambourov, 2009), has been recognized as a significant factor in the context of digital economy development and has become a key topic on the agenda of governments (UNESCO, 2021). Various countries have introduced policies to guide their development, such as the EU's "2018-2020 Digital Education Action Plan" and “2021-2027 Digital Education Plan”, aimed at restructuring the vocational education talent training system and encouraging enterprises to participate in the digital transformation of vocational education. These measures aim to enhance employees' digital capabilities to meet the demands of the digital economy era. The vocational education and training (VET) system in China has proven its effectiveness in improving labor market outcomes. The vocational education and training (VET) system in China has demonstrated its effectiveness in improving labor market outcomes. According to the "Annual Report on Employment of Chinese Three Year Vocational College Graduates (2023)", in 2023, there were 2951 vocational colleges in China, with a total of 5.597 million graduates employed and an employment rate of 98.34%. In addition, the salary of graduates of higher vocational colleges has been growing steadily. The average starting salary of graduates in 2023 will reach 4082.2 yuan, an increase of 11.13% over 2021 (China Vocational Education Quality Annual Report Data Collection Platform). Especially in new occupations related to digital technology, such as live broadcast sales, industrial robots and industrial Internet, the salary advantage is more obvious. However, the World Economic Forum has also pointed out that vocational schools' service capabilities may struggle to keep pace with the changing labor market demands and that there may be limitations in the scope for reform and innovation. Therefore, the suitability of higher vocational education for the development needs of the digital economy and the potential for coordinated development between the two have become critical issues for the advancement of the digital economy.

In China, rapid digital economy growth has led to an increase in the demand for high-skilled workers, this question is particularly pressing. The government has acknowledged the pivotal role of vocational education in the nation's digitalization strategy and released a series of policies to support the reformation and modernization of vocational education, such as "Opinions on Promoting High-Quality Development of Modern Vocational Education" in 2021 and "Opinions on Deepening the Reform of the Modern Vocational Education System" in 2022 aim to support reformation and modernization of vocational education. According to the "China Vocational Education Development Report 2024," in 2023, there were 11,133 vocational colleges and schools

in China, producing approximately 10 million skilled graduates annually, and providing over 70% of the new employees in sectors such as modern manufacturing, strategic emerging industries, and modern services (Vocational Education Development Center, Ministry of Education, 2023). Thus, necessitating further inquiry into the outcomes of higher vocational education adapting to the digital economy. Has higher vocational education, propelled by the digital economy, realized high-quality development? Have the digital reforms in higher vocational education addressed the talent requirements of the digital economy? Is there a harmonious and coordinated development between vocational education and the digital economy? Answering these questions is a critical first step to drive rapid growth in the digital economy.

Existing literature has discussed the complex and multifaceted relationship between digital economy and vocational education. On the one hand, digital economy introduces shifts in the workforce's skill diversity and structure of employment, which driven the transformation of vocational education. Zhang et al. (2003) and Huaping et al. (2022) found that digital economy introduces shifts in the workforce's skill diversity and structure of employment, and Wang et al. (2023) also illustrated that digital economy equips higher vocational education with enhanced teaching services, resources, methodologies, platforms, and online tools, thus drive digital transformation within higher vocational education. However, Woolf et al. (2013) also pointed out that the drive to align talent cultivation with the accelerated demands of the digital economy may lead higher vocational education to diverge from its foundational mission of nurturing individuals who are well-rounded and comprehensive in their development. On the other hand, higher vocational education can facilitate the digital economy by nurturing technical and skilled talents, providing persistent technical vocational training, and engaging in educational and research initiatives. Poschauko et al. (2024), Zheng et al. (2024) and Tada et al. (2023) reported that higher vocational education can facilitate the digital economy by nurturing technical and skilled talents, providing persistent technical vocational training, and engaging in educational and research initiatives; nevertheless, Kerroum et al. (2020), Gkrimpizi et al. (2023) point out that education generally retains traditional ways and patterns and is slow in initiating and adopting swift changes in digital technology, such as the lag in building intelligent platforms for industry-education integration and the occurrence of the "information island" phenomenon (Sun et al., 2024) . In addition, there are significant regional differences in the contribution of higher vocational education to the digital economy. Wang et al. (2021) calculated the contribution rate of higher vocational education to economic growth and found that the contribution rate in the eastern region was 1.39%, higher than the 1.31% in the central region.

To date, the existing research has provided only a one-sided assessment of the contributions vocational education makes to the digital economy and the driving force the digital economy offers for the reform of vocational education. There has not been an in-depth analysis of the coordination mechanisms between higher vocational education and the digital economy, and appropriate indicators for accurate evaluation are lacking. Consequently, these studies have not provided a complete understanding of the relationship between higher vocational education and the digital economy. Moreover, few studies focus on their dynamic coupling coordination interactions with both temporal and spatial comparisons through quantitative analysis and case studies; let alone the exploration of factors influencing these interactions and strategies for coordination to

achieve a better state. Thus, it is necessary to use different new multivariate statistical analyses to explore their coupling coordination interaction mechanism, analyze the current coordinated development state, and explore their influencing factors, which will help us to take appropriate measures to achieve coordinated development of higher vocational education and the digital economy.

Given this, this study utilizes data from 31 provinces across China from 2013 to 2022, and adopts integrated Coupling Coordination Degree Model (CCDM) and gray correlation model to measure the interaction spatiotemporal heterogeneity between higher vocational education and digital economy and depict the main influencing factors of this interaction mechanism. Compared with other analytical methods like Structural Equation Model (SEM), CCDM in combination with grey correlation model can capture the dynamic changes in the coupling and coordination degrees of the two systems over time and space and identify the main factors affecting the coupling coordination degree, as demonstrated in recent studies of Liu Y et. al (2023) . Thus, with the combination of two models, this study mainly has the following three innovations and contributions. (1) Different from previous studies mainly focusing on the unilateral influence between higher vocational education and the digital economy, this paper emphasized the coupling coordination interaction of higher vocational education and the digital economy. Such discussion enriches the relationship between higher vocational education and the digital economy. (2) This paper explored the coupling coordination relationship between higher vocational education and the digital economy, bridging the research gap concerning their synergistic development, and more clearly defining the pivotal role that higher vocational education plays in facilitating the transformation and innovation within the digital economy. (3) Based on temporal-spatial comparisons and influencing factor analysis, we explored potential causes of better coordination in spatiotemporal heterogeneity between higher vocational education and the digital economy in China, which benefits policymakers to make more scientific strategic decisions to promote the coordinated growth of higher vocational education and digital economy according to the specific circumstances.

II. Conceptual background

1. The impact of higher vocational education on digital economy

As a type of education closely related to various levels of education and various aspects of society, vocational education can provide increasingly qualified graduates and professional technicians to facilitate digital economy development and upgradation. Previous studies prove that higher vocational education both positively and negatively affects the digital economy.

From a positive perspective, as the important cultivator of high-quality technical and skilled talents, higher vocational education plays a crucial role in fostering a digital economy (Mikheev et al., 2021) . Specifically, higher vocational education elevated the development of the digital economy through its multifaceted roles in talent cultivation, innovative research, and social vocational training. Firstly, from the aspect of talent

cultivation, higher vocational education can provide courses, practices, and internship opportunities to teach and train graduates and talents with advanced technical skills and a robust understanding of digital technologies (zhang X et al., 2024). The result not only elevated the knowledge and skill levels of the educated related to the digital economy, who become well-attuned to the demands of the digital economy (Wu and Liu, 2021); but also aided in the evolution of regional human capital structures from a primary to a more advanced configuration through knowledge spillover, which would foster to facilitate the substitution of advanced digital technologies for primitive ones, as well as accelerated application refinement, and innovation of digital technologies within the region (Hasanefendic et al., 2016). Goedhuys et al. (2014) demonstrated that an increase in the provision of high-quality skilled personnel by higher vocational education while reducing skill premiums, motivates enterprises to increase investments in skill-complementary machinery. This, in turn, accelerates the trend of skill-biased technological progress, thereby amplifying the functional and intrinsic value of digital economy initiatives. Secondly, higher vocational education includes research activities, some of which promote the advancements in key disciplines such as information technology are essential for understanding and managing information and for the successful application of digital technologies. As Such research pursuits accelerate the integration of digital technologies into traditional industry sectors. Kang (2024) showed that higher vocational education has fostered "integration of industry and education" programs that have led to collaborative efforts that have not only fostered the cultivation of highly skilled professionals but also breakthroughs in vital digital technologies, thereby expeditiously advancing the shift towards a digital economy. Thirdly, higher vocational institutes conduct social vocational training activities, such as non-academic vocational training and educational programs, and the quality and technical skills of the regional workforce would be enhanced. As Findeisen et al. (2022) pointed out, the result will help to expand the market for digital technology services within the region and furnish local enterprises with technical support. Such support is instrumental in facilitating the iterative updates of digital technologies, thereby accelerating the progression of the digital economy.

Higher vocational education also exerts negative influences on the digital economy. Firstly, compared to the rapidly evolving demands for talent during the digital economy, the curriculum design and course contents of higher vocational education exhibit a degree of inertia, resulting in a mismatch between the talents cultivation and digital economy's development requirements and status (Lund and Karlsen, 2022). For example, curriculum updates in higher vocational education are not keeping pace with the development of the digital economy, which leads to the graduates being less compatible with the actual digital economy needs. Makgato's (2020) study found that the VET needs to meet workplace expectations regarding practical skill training and vocational pedagogy, which places VET graduates in a dire position regarding employability. Secondly, as lack of long-term industry engagement partnerships, the scholarly and practical output of higher vocational education are less industry-focused or practice-oriented, consequently impeding the acceleration of the digital economy in the short term. For instance, as Rujira et al. (2020) argued, some higher vocational education faculties are unfamiliar with regional digital transform-related knowledge or lack regional digital transform-related practical experiences, making it challenging to keep up with the regional digital transform's current focus. Their research achievements and cultivation contribution are lagging compared with the market demands, thus reducing digital

economy efficiency.

2. The impact of digital economy on vocational education

The digital economy also has positive effects on higher vocational education. Firstly, the digital economy increased investment in educational funding and the construction of core digital infrastructures, such as information networks and platform systems, which would expand the coverage and application of digital construction within higher vocational education (Guo et al., 2023).

For example, García-Hernández et al. (2022) suggest that optimizing the infrastructure of higher vocational education can achieve precise allocation and rational matching of effective educational resources between different colleges, disciplines, and majors, ensuring continuity of investment in vocational institutions and promoting their efficient development. Secondly, digital transformation aims to reform the allocation of educational resources, educational structure, and teaching models, innovate higher vocational education, accelerate the transformation and innovation of the vocational education system, and improve the efficiency of vocational education development. Breaz et al. (2022) demonstrated that by collaborating with digital enterprises, higher vocational education departments can use digital technology to update electronic education platforms, explore new online teaching models, and enhance the competitiveness of local higher education departments from the perspective of infrastructure. In addition, the digital economy has enriched higher vocational education resources, promoted knowledge sharing, and improved students' learning efficiency. As shown by Xiao (2022), digital technologies such as "intelligent workshops" and "VR virtual scenes" provide technical support for practical training, which is conducive to the cultivation of practical skills for graduates. And Thomann et al. (2024) emphasized that significant potential in knowledge gains to employ IVR technology in vocational education. Thirdly, the extensive connectivity and low-cost transactions facilitated by the digital economy have enhanced the potential for cross-sector collaboration and cooperative development between vocational education and others. The research of Muammar et al. (2023) and Stephen (2020) confirmed that, with some new digital tools, higher vocational institutions can easily know the frontiers of the discipline domains and grasp industry needs and trends, develop appropriate educational strategies and curriculum designs, and help students adapt more effectively to career demands and market fluctuations, thereby accelerating the growth of higher vocational education (Jiang et al., 2024). Magagula et al.(2024) pointed that digital technology promoted the VET sector collaborating with labour industry, accepting 4IR technology as a learning tool in South Africa.

Meanwhile, the digital economy has also had a negative impact on higher vocational education. The more online educational content brought by the digital economy will increase the search cost for vocational college students. According to Geng et al. (2023), students often spend a lot of time searching for online resources during their self-directed learning process, which may lower their academic performance. In addition, there may be differences between the goals of the digital economy and higher vocational education, with the former primarily focusing on profits and market share, while the latter is dedicated to long-term educational outcomes

and student success. As demonstrated by Li et al. (2023) the pursuit of commercial interests in the digital economy has accelerated technological innovation, leading to continuous updates of digital tools and platforms. This dynamic undermines the creation of a stable and sustainable educational environment, which is a goal that higher vocational colleges are earnestly seeking to achieve. The necessity of quickly adapting to the constantly changing demands of new technologies may deviate from the basic education tasks of higher vocational colleges and may lead to improper allocation of resources for other key educational goals, thereby affecting the high-quality development of higher vocational education.

3. Mechanism for interaction of higher vocational education and digital economy

In conclusion, we can find from previous literature that higher vocational education and the digital economy affect each other positively and negatively, in other words, they have complex interactions (As shown in Fig. 1), moreover, the interactions between the two are nonlinear. On the one hand, the transformative effects of the digital economy have reshaped the traditional market ecosystem, resulting in a significant scarcity of high-quality technical and skilled talents within the labor market of the digital economy era, and promoting the digital transformation of higher vocational education. On the other hand, the economic benefits derived from the digital economy offer a robust driving force for the digital development of higher vocational education, and the continuous cultivation of digital talents in higher vocational education would be facilitated which would fulfill the needs of the digital economy. The mutually beneficial relationship between the two propels a deeper integration and collaborative development between the digital economy and higher vocational education. Therefore, we should explore the coordination relationship and internal mechanism between the two, and clarify what measures we can take to enhance their mutual positive influence and balance growth.

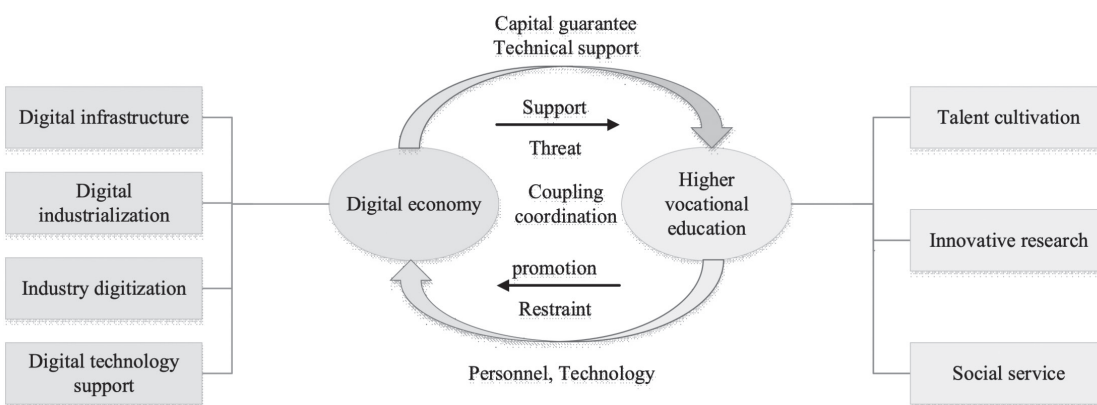

Fig. 1. The Conceptual framework of higher vocational education and digital economy

III. Research design

1. Construction of the indicator system

We construct a comprehensive evaluation system to evaluate the above two subsystem's development and coupling coordination status. The evaluation follows the following principles: first, indicators selected reflect critical dimenstions of higher vocational education and digital economy (su et.al, 2022; Wang et al.,2023; Sun et al,2023); second, metrics were sourced from widely cited studies or government report, such as Annual Report on the Quality of Higher Vocational Education, China Digital Economy Development Index Report, China's official Statistical Classification of the Digital Economy ; third, all indicators use publicly reported statistics from national yearbooks. We select the indicators through literature screening and qualitative analysis and thus construct the comprehensive evaluation system (See Table 1). In this comprehensive evaluation system, the higher vocational education subsystem has three dimensions and 8 indicators, and the digital economy has four dimensions and 10 indicators.

Specifically, based on the perspective of societal demand, we use talent cultivation, innovative research, and social vocational training as the control layers to comprehensively evaluate the development of the higher vocational education subsystem. Talent cultivation reflects the input in higher vocational education and its potential impact on nurturing graduates outcomes, including three index layers: "Education scale", "Education Quality" and "construction of teacher team". Innovation research demonstrates that higher vocational institutions engage in research activities that have direct relevance to industry needs, which are composed of two specific index layers: "R&D investment" and "Instructional Research investment". social vocational training represents higher vocational institutions that serve the social community by offering continuing education courses for both non-academic training and professional guidance to foster educational enhancement of lifelong learning and skill refinement in local members. And three specific index layers are selected: "Vocational skills cultivation", "Vocational skills cultivation" and "Continuing Education for the Employed Workforce".

Following the research of Bukht et al. (2017) and Zhang et al. (2024), and the "Statistical Classification of the Digital Economy and Its Core Industries (2021)" (National Bureau of Statistics, 2021) in National Bureau of Statistics, we finally selected ten indicators to measure digital economy from four control layers: digital infrastructure, digital industrialization, industrial digitization, and digital technology support. Among them, digital infrastructure represents the status of infrastructure and digital network that support the development of the digital economy, and three index layers are selected: "Internet Penetration Rate", "Mobile Telephony Services" and "Telecommunications Infrastructure". Digital economy comprises two major components: digital industrialization and industrial digitization, according to China Digital Economy Development White Paper (2017)(CAICT, 2017). The dimension of digital industrialization measures the technological industries that underpin digital transformation, which reflects the process of converting digital technologies into industries and services, encompassing all economic activities related to the provision of digital technologies, products, and

services. Specific indicators include the "ICT Workforce" and "Information Services Revenue". Meanwhile, the dimension of Industrial Digitization captures the new business models and economic activities enabled by digital transformation, which demonstrates the upgrading, transformation, and reengineering of traditional industries across their upstream and downstream chains, driven by next-generation digital science and technology. Key indicators include "Corporate Digitalization Level", "E-commerce", and "Digital Inclusive Finance Index". Digital technology support measures the updates and innovations in digital technology, which is composed of two index layers: "Technology Market Turnover" and "Technological Innovation" (Peng et al., 2025; Ding et al., 2024; Zhou, 2024; Guo et al.,2024).

2. Data sources

In this study, we choose the data from 31 provinces in China from 2013-2022 as the research sample to conduct in-depth explorations on the coupling coordination mechanism between higher vocational education and digital economy. The data used in this paper mainly come from the China Statistical Yearbook, China Educational Finance Statistical Yearbook, China Statistical Yearbook on Science and Technology, China Labor Statistical Yearbook, and the statistics on the official website of the Ministry of Education of China. The data related to the digital financial inclusion index comes from the Digital Finance Research Center of Peking University and the digital innovation index from the Enterprise Big Data Research Center of Peking University. These data are from the national authority, which shares high accuracy and reliability, making the results more convincing. We used the random forest algorithm to calculate the very few missing values.

Table 1. Evaluation index system of higher vocational education and digital economy.

System	Control layer	Index layer	Explanation of Index	Unit
digital economy system	Digital infrastructure D1	Internet Penetration Rate D11	The ratio of Internet broadband access subscribers to permanent resident	number/ person
		Mobile Telephony Services D12	Mobile internet users	Ten thousand households
		Telecommunications Infrastructure D13	Length of optic cables	Km
	Digital industrialization D2	ICT Workforce D21	Proportion of employees in information transmission, software, and information technology services to employed persons	%
		Information Services revenue D22	Software business revenue from subsectors classified under the digital core industry	Billion yuan

System	Control layer	Index layer	Explanation of Index	Unit
digital economy system	Industry digitization D3	Corporate Digitalization Level D31	Number of websites per 100 enterprises	number
		E-commerce D32	Ratio of E-commerce sales volume to local GDP	%
		Digital Financial Inclusion Index D33	Digital Inclusive Finance Index	/
	Digital technology support D4	Technology Market turnover D41	Technology Market Turnovers	Billion yuan
		Technological Innovation D42	Number of valid invention patents of ICT industries	patent
Higher vocational education system	Talent cultivation V1	Education scale V11	Number of higher vocational students at colleges	person
		Education Quality V12	Per Capita Expenditure on General Public Budget for Educational Undertakings	Yuan
		Construction of teacher team V13	Student-teacher ratio	%
	Innovative research V2	R&D investment V21	expenditure on R&D expenses	Million yuan
		Instructional Research investment V22	Value of teaching and research equipment per student	Million yuan
	social vocational training V3	Vocational skills cultivation V31	Funds Received for Non-academic Training	%
		Training Services V32	Funds Received for Non-academic Training	Million yuan
		Continuing Education for the Employed Workforce V33	Ratio of vocational enrollment to employment	%

3. Research methodology

3.1. The improved entropy method

The entropy method is an objective weighting method, which determines the weights according to the information provided by observed values of each index. When the traditional entropy weighting method is used to calculate the weights, when the entropy value tends to 1, a small difference in the entropy value will cause the weights to change exponentially, making the weights of some indicators incompatible with their importance. Some scholars, like Tian et al.(2021), have improved on the traditional entropy method while retaining its ability to widen the gap of index weights and makes up for the shortcomings of the traditional entropy method (Deng and Hu, 2024). And this paper draws lessons from the methods used by existing scholars to calculate index weights, the process is as follows:

(1) Standardize data. As the evaluation index data have different magnitudes and index attributes, we use the normalization method to standardize the data to enhance comparability between different indicators and mark the new standardized matrix as Zij. However, the data may be 0 after standardization. The standardized data are shifted by 0.0001 units to avoid such as meaningless situation.

The formulas are equations (1) and (2):

Positive indicators:

$$Z_{ij} = \frac{X_{ij} - Min(X_{ij})}{Max\left(X_{ij}\right) - Min(X_{ij})} + 0.0001, (i = 1,2,3\cdots n; j = 1,2,3\cdots m) \quad (1)$$

Negative indicators:

$$Z_{ij} = \frac{Max\left(X_{ij}\right) - X_{ij}}{Max\left(X_{ij}\right) - Min(X_{ij})} + 0.0001, \left(i = 1,2,3\cdots n; j = 1,2,3\cdots m\right) \quad (2)$$

Where Xij is the value of the j index in the i year, and Zij is the standardized data.

(2) Calculate the entropy value of each index. To avoid the influence of subjective elements, we use the entropy value method to determine the index weights and derive the comprehensive score of the digital economy and vocational education.

Y_{ij} represents the weight of the jth index in the ith year, and the formula is equation (3).

$$Y_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{m} Z_{ij}} \ (i = 1,2,3\cdots n; j = 1,2,3\cdots m) \quad (3)$$

And H_j represents the entropy value of indicator j.

$$H_j = -\frac{1}{\ln n}\sum_{i=1}^{n} Y_{ij} lnY_{ij} \ \ (i = 1,2,3\cdots n, j = 1,2,3\cdots m) \quad (4)$$

(3) Calculate the weight of each index.

$$W_j = \frac{1 - H_j}{n - \sum_{j=1}^{n}(1 - H_j)} \quad (5)$$

3.2. Coupling coordination degree model

Coupling is based on the concept of coupling physics and describes the level of interaction between different systems (Cai et al., 2021). With the complexity of research problems, it has been gradually introduced into the field of social sciences. The coupling degree calculation is a way to measure the degree of correlation between systems. When there exists a relationship of mutual integration and promotion between the two systems, the coupling between the two systems is good. When there exist mutual constraints and restrictions between the two systems, the coupling between the two systems is poor (Ma, 2022). This paper used the model of coupling coordination degree to analyze the higher vocational education system and the digital economy system.

(1) Calculation of the combined score. The weight of each index and the weighted sum of each standardized value are used to calculate the combined score of the higher vocational education system and digital economy system.

$$V_i = \sum_{j=1}^{m} Z_{ij}^{V} W_j^{V}, \quad D_i = \sum_{j=1}^{m} Z_{ij}^{D} W_j^{D} \tag{6}$$

Where Vi and Di are the composite scores of the vocational education system and digital economy system, respectively. Z_{ij}^{V} Vand Z_{ij}^{D} D are the standardized values of each indicator of the vocational education system and digital economy system, respectively. W_j^{V} Vand W_j^{D} are the weights of each indicator of the vocational education system and digital economy system, respectively.

(2) Calculation of C. C is the coupling degree between higher vocational education and digital economy, C ∈ [0,1], and the value of is determined by the combined scores of the two systems of vocational education system and digital economy system.

$$C = \frac{\sqrt[2]{Z_i D_i}}{\left(Z_i + D_i\right)/2} \tag{7}$$

Where, the Z_i and D_i represent the combined scores of the vocational education system and digital economy, respectively. The greater the value of C, the stronger the interaction and influence between the two systems. Calculation of T. T is the degree of comprehensive coordination index between the vocational education system and the digital economy.

$$T = \alpha Z_i + \beta D_i \tag{8}$$

Where α and β are coefficients to be determined. Referring to the relevant literature, considering the mutual promotion and equally importance of higher vocational educational system and the digital economy, this paper assigns α and β are set at 0.5 respectively.

(3) Calculation of D. D is the degree of coupling and coordination development parameter between the vocational education system and digital economy, taking [0,1]. The larger the scale, the more coordinated the development level of the two systems, on the contrary, the lower degree of cooperation between the two systems.

$$D = \sqrt{C \times T} \tag{9}$$

To directly reflect the coordinated development degree of higher vocational education and digital economy,

the coupling coordination degree is subdivided into ten levels by referring to the research results of existing scholars, as shown in Table 2.

Table 2. Evaluation criteria of coupling coordination level (D).

Value	Grade	Value	Grade
0.00-0.09	Extreme imbalance	0.50-0.59	Barely coordination
0.10-0.19	Severe imbalance	0.60-0.69	Primary coordination
0.20-0.29	Moderate imbalance	0.70-0.79	Moderate coordination
0.30-0.39	Slight imbalance	0.80-0.89	Good coordination
0.40-0.49	Close to imbalance	0.90-1.00	Superior coordination

3.3. Influencing factor analysis

Gray correlation analysis is a statistical method to evaluate the relations of factors or indicators using gray correlation degree (GCD). It compares the similarity between the comparison and reference data columns and then determines the correlations between factors or indicators (Jiao et al.,2022). The consistency of the factors' changes means that GCD is close to 1; the inconsistency makes GCD closer to 0 (Zhou et al., 2022). The detailed procedures of influencing factor analysis are as follows.

(1) Determine the reference column and the comparison column. We aim to calculate the gray correlation between the higher vocational education system and the digital economy system, so we set the indicators of the higher vocational education system as the comparison series S_q, where q is the comparison sequence; we also set the indicators of the digital economy system as the reference series , where g is the reference sequence.

$$S_q = \left(S_q(1), S_q(2), S_q(3), \cdots, S_q(n),\right). q = 1,2,3, \cdots a \quad (10)$$

$$S_g = \left(S_g(1), S_g(2), S_g(3), \cdots, S_g(n),\right). g = 1,2,3, \cdots b \quad (11)$$

(2) Calculate the correlation degree $\rho maxmax\left|S_g(t) - S_q(t)\right|$ of the two series. The ρ is defined as 0.5.

$$\zeta_{gq}(t) = \frac{minmin\left|S_g(t) - S_q(t)\right| + \rho maxmax\left|S_g(t) - S_q(t)\right|}{\left|S_g(t) - S_q(t)\right| + \rho maxmax\left|S_g(t) - S_q(t)\right|} \quad (12)$$

(3) Define the new series by integrating the correlations of observed values to better depict the correlation between the series.

$$b^{(1)}(t) = \frac{b^{(1)}(t) + b^{(1)}(t-1)}{2}, t = 2,3, \cdots, n \quad (13)$$

(4) Calculate GCD of the two series (r_{gq})

$$r_{gq} = \frac{1}{n}\sum_{t=1}^{n} \zeta_{gq}(t) \tag{14}$$

(5) Arrange GCD between S_q and S_g in the form of a matrix.

IV. Empirical results and analysis

1. Comprehensive score and evolution of higher vocational education and digital economy

1.1. Comprehensive score and evolution of higher vocational education

According to formulas (6), the comprehensive score of higher vocational education of 31 provinces (cities) in China from 2013 to 2022 can be calculated, and the results are shown in Table 3.

From the perspective of temporal trends, the comprehensive score of higher vocational education across various provincial-level administrative regions in 2013 ranged from 0.149 to 0.287, which exhibited that the development of higher vocational education is at low levels, imbalance, and insufficiency. The comprehensive score of higher vocational education in 2022 increased to between 0.1514 and 3.560, which shows that higher vocational education in China is generally on the rise. And this is correlated to the background of the times when China has been attaching great importance to the development of higher vocational education in recent years. Firstly, since 2005, China successively enacted a series of policies, such as the Decision of the State Council on Vigorously Developing Vocational Education (The State Council [2005] No. 35), Decision of the State Council on Accelerating the Development of Modern Vocational Education (The State Council [2014] No. 19), National Vocational Education Reform Implementation Plan (The State Council [2019] No. 4), and Opinions on Promoting the High-Quality Development of Modern Vocational Education (The State Council [2021] NO. 30). These policies defined the legal status and well-defined developmental path for higher vocational education, which ascribed a more salient role to vocational education in the spheres of educational reform, innovation, and in driving economic and social progress. Moreover, policies have engendered a strong sense of confidence among investors. As an illustration, the year 2023 witnessed a total of 19 investment and financing occurrences within the vocational education sector, including 6 involving tens of millions and 8 in the hundreds of millions. The influx of this capital has provided the necessary material basis for the development of higher vocational education, promoting the improvement of educational facilities and the enrichment of educational resources. Hence, under the joint influence of policy guidance and capital investment, the caliber of higher vocational education in China has achieved significant enhancement. For example, driven by policies and economic development, Guangdong Province continues to deepen vocational education reform.

At present, higher vocational education accounts for about 50% of higher education in Guangdong Province. The number of students in vocational colleges has increased from 737,000 in 2017 to 2.805 million in 2022. From 2012 to 2022, these institutions have trained and delivered approximately 7.69 million technical elites to society, making significant contributions to Guangdong Province's consecutive ranking as the country's largest economy for many years. Secondly, China's higher vocational education actively adapts to regional industrial restructuring and transformation through measures such as adjusting professional settings, strengthening the integration of industry and education, innovating educational methods, and enhancing the construction of teaching staff. These measures not only promote the sustainable development of higher vocational education, but also significantly improve the quality of educational outcomes.

Table 3. Comprehensive score of higher vocational education

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	mean
Beijing	0.243	0.203	0.239	0.265	0.255	0.257	0.279	0.280	0.278	0.294	0.259
Tianjin	0.222	0.258	0.238	0.258	0.250	0.233	0.270	0.300	0.297	0.284	0.261
Hebei	0.273	0.206	0.220	0.236	0.241	0.253	0.299	0.302	0.294	0.279	0.260
Shanxi	0.217	0.248	0.225	0.215	0.214	0.239	0.280	0.284	0.332	0.345	0.260
Inner Mongolia	0.196	0.196	0.217	0.202	0.215	0.190	0.219	0.216	0.235	0.226	0.211
Liaoning	0.183	0.224	0.195	0.187	0.180	0.176	0.237	0.283	0.211	0.215	0.209
Jilin	0.166	0.178	0.155	0.164	0.172	0.156	0.215	0.195	0.211	0.213	0.182
Heilong jiang	0.197	0.224	0.264	0.223	0.180	0.162	0.167	0.181	0.206	0.240	0.204
Shanghai	0.234	0.255	0.270	0.261	0.279	0.285	0.296	0.274	0.210	0.189	0.255
Jiangsu	0.250	0.361	0.250	0.271	0.338	0.325	0.364	0.349	0.305	0.335	0.315
Zhejiang	0.287	0.300	0.372	0.269	0.338	0.292	0.446	0.405	0.356	0.315	0.338
Anhui	0.248	0.286	0.255	0.256	0.240	0.239	0.286	0.330	0.337	0.385	0.286
Fujian	0.221	0.230	0.216	0.209	0.218	0.224	0.299	0.297	0.271	0.260	0.245
Jiangxi	0.224	0.246	0.259	0.259	0.211	0.306	0.359	0.302	0.295	0.314	0.278
Shandong	0.247	0.281	0.297	0.306	0.306	0.288	0.345	0.330	0.392	0.308	0.310
Henan	0.215	0.261	0.259	0.288	0.291	0.313	0.332	0.359	0.392	0.488	0.320
Hubei	0.251	0.271	0.268	0.373	0.254	0.268	0.291	0.323	0.278	0.277	0.285
Hunan	0.248	0.293	0.252	0.271	0.275	0.278	0.290	0.339	0.351	0.340	0.294
Guang dong	0.278	0.304	0.275	0.309	0.328	0.341	0.353	0.483	0.441	0.438	0.355
Guangxi	0.180	0.203	0.210	0.233	0.230	0.262	0.305	0.297	0.304	0.338	0.256
Hainan	0.170	0.172	0.174	0.166	0.164	0.144	0.217	0.199	0.197	0.198	0.180
Chong qing	0.215	0.244	0.231	0.241	0.231	0.238	0.292	0.304	0.293	0.294	0.258
Sichuan	0.255	0.267	0.263	0.291	0.283	0.282	0.311	0.318	0.309	0.305	0.288
Guizhou	0.219	0.248	0.243	0.259	0.237	0.264	0.275	0.314	0.287	0.306	0.265

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	mean
Yunnan	0.189	0.271	0.248	0.231	0.249	0.259	0.325	0.335	0.277	0.226	0.261
Xizang	0.185	0.112	0.154	0.141	0.112	0.120	0.155	0.134	0.204	0.198	0.151
Shaanxi	0.255	0.263	0.255	0.237	0.248	0.236	0.299	0.318	0.261	0.228	0.260
Gansu	0.195	0.207	0.188	0.207	0.198	0.229	0.264	0.289	0.246	0.234	0.226
Qinghai	0.149	0.140	0.179	0.176	0.203	0.187	0.241	0.236	0.199	0.242	0.195
Ningxia	0.193	0.167	0.204	0.211	0.213	0.186	0.226	0.216	0.235	0.233	0.208
Xinjiang	0.188	0.205	0.207	0.222	0.233	0.228	0.256	0.236	0.255	0.284	0.231

For spatial changes, Fig. 2 shows the regional disparities from 2013 to 2022. Overall, there are significant differences in the comprehensive scores of higher vocational education in different regions, and this trend has been expanding in the past decade; Therefore, we can see that the development of higher vocational education in various provinces of China is relatively uneven. Among them, the career development level of eastern provinces such as Guangdong, Henan, Anhui, Shanxi, Zhejiang, and Hunan has improved, with a comprehensive score exceeding the threshold of 0.33 in 2022. Guangdong and Zhejiang provinces are typical representatives of higher vocational education in the eastern region, with abundant educational resources, superior educational infrastructure, and a strong faculty team synchronized with the region's economic prosperity. At the same time, provinces such as Anhui, Henan, and Hunan are vigorously promoting vocational education reform and development in the central region, each opening unique development paths. Hunan Vocational Education Science and Technology Park are a good example, which has received over 22 billion yuan in investment and developed more than 30 integrated industry education internship and training bases, including 6 national designated high skilled talent training bases. In contrast, the western and northeastern regions are significantly lagging, with slightly lower average comprehensive scores of 0.259 and 0.223 respectively in 2022, showing significant differences compared to the central and eastern regions. However, the accelerated growth of the economy in western China, such as the Chengdu Chongqing electronic industry cluster and the expansion of cross-border logistics industries in Guangxi, has intensified the demand for high skilled labor. This surge has stimulated investment and policy reforms in higher vocational education, resulting in measurable improvements in its development. For example, the vocational education system in Sichuan has expanded. By 2022, Sichuan will have 539 colleges and 1.644 million students, ranking seventh and fifth in the country respectively. The gap in the development of vocational education can be attributed to two main factors: firstly, the serious imbalance in inter provincial resource investment is evident, and among the 31 provinces in China, this imbalance gradually decreases from the eastern coastal provinces to the inland areas. Secondly, the relatively lagging development of vocational education in some provinces can be attributed to various factors, including geographical location, economic development level, industrial sector structure, and strategic deployment of educational resources.

Fig. 2. Spatial Variations of higher vocational education' comprehensive score.

1.2. Comprehensive score and evolution of digital economy

Table 4 describes the time course of the comprehensive score reflecting the digital economy from 2013 to 2022. Broadly speaking, the development of the digital economy continues to rise, with an average comprehensive score increasing from 0.160 in 2013 to 0.346 in 2022. More notably, the digital economy has significantly improved in all 31 provinces. For example, Beijing's comprehensive score has increased from 0.340 in 2012 to 0.525 in 2022, while Guizhou's has increased from 0.103 to 0.275. In fact, under the joint influence of government policies, strategic regional economic restructuring, and enterprise efforts to reduce costs and improve efficiency, the digitalization process of digital and traditional industries has significantly accelerated. This stimulated the development of digital economy in Chinese provinces and cities from 2013 to 2022. At present, China's digital economy has entered a stage of rapid expansion, with strong momentum in the digital transformation of traditional industries, exponential development of digital transformation infrastructure, and continuous emergence of new business forms and models. Data shows that from 2016 to 2022, the overall scale of China's digital economy continued to grow, reaching 50.2 trillion yuan in 2022, a year-on-year increase of 10.3%.

Table 4. Comprehensive score of digital economy.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	mean
Beijing	0.340	0.339	0.380	0.393	0.462	0.483	0.515	0.572	0.638	0.525	0.465
Tianjin	0.142	0.157	0.189	0.196	0.220	0.248	0.280	0.296	0.331	0.316	0.237
Hebei	0.149	0.176	0.208	0.237	0.277	0.305	0.329	0.344	0.371	0.354	0.275
Shanxi	0.119	0.140	0.163	0.177	0.201	0.227	0.234	0.246	0.272	0.277	0.206
Inner Mongolia	0.108	0.131	0.157	0.175	0.205	0.214	0.233	0.250	0.269	0.269	0.201
Liaoning	0.157	0.185	0.217	0.238	0.265	0.278	0.293	0.312	0.335	0.326	0.261

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	mean
Jilin	0.109	0.137	0.155	0.149	0.174	0.203	0.205	0.218	0.231	0.228	0.181
Heilong jiang	0.101	0.125	0.151	0.162	0.201	0.213	0.222	0.242	0.244	0.251	0.191
Shanghai	0.275	0.328	0.348	0.366	0.396	0.424	0.452	0.481	0.523	0.503	0.410
Jiangsu	0.325	0.323	0.386	0.419	0.473	0.492	0.525	0.570	0.610	0.505	0.463
Zhejiang	0.277	0.299	0.355	0.374	0.426	0.455	0.480	0.517	0.560	0.504	0.425
Anhui	0.163	0.181	0.224	0.257	0.293	0.324	0.344	0.363	0.394	0.384	0.293
Fujian	0.200	0.207	0.230	0.244	0.283	0.321	0.331	0.339	0.368	0.347	0.287
Jiangxi	0.136	0.160	0.190	0.192	0.241	0.277	0.292	0.312	0.339	0.326	0.247
Shandong	0.193	0.219	0.266	0.311	0.350	0.382	0.398	0.432	0.482	0.433	0.347
Henan	0.141	0.168	0.205	0.228	0.265	0.297	0.307	0.329	0.358	0.367	0.267
Hubei	0.171	0.183	0.216	0.243	0.283	0.308	0.337	0.363	0.391	0.376	0.287
Hunan	0.148	0.172	0.200	0.212	0.256	0.280	0.292	0.318	0.350	0.359	0.259
Guang dong	0.309	0.350	0.400	0.436	0.508	0.550	0.585	0.635	0.696	0.554	0.502
Guangxi	0.117	0.121	0.097	0.111	0.154	0.191	0.228	0.267	0.302	0.313	0.190
Hainan	0.145	0.169	0.195	0.206	0.232	0.241	0.247	0.243	0.279	0.281	0.224
Chong qing	0.142	0.165	0.187	0.214	0.247	0.281	0.296	0.315	0.347	0.366	0.256
Sichuan	0.173	0.214	0.261	0.295	0.337	0.371	0.411	0.417	0.447	0.434	0.336
Guizhou	0.103	0.119	0.132	0.159	0.180	0.206	0.217	0.237	0.265	0.275	0.189
Yunnan	0.127	0.148	0.179	0.173	0.201	0.227	0.246	0.263	0.284	0.291	0.214
Xizang	0.069	0.095	0.132	0.157	0.178	0.190	0.221	0.198	0.220	0.227	0.169
Shaanxi	0.152	0.184	0.207	0.221	0.249	0.274	0.300	0.322	0.354	0.345	0.261
Gansu	0.095	0.120	0.145	0.161	0.193	0.212	0.230	0.243	0.275	0.268	0.194
Qinghai	0.086	0.108	0.166	0.166	0.170	0.183	0.188	0.191	0.233	0.245	0.174
Ningxia	0.099	0.115	0.135	0.144	0.175	0.193	0.203	0.216	0.247	0.248	0.177
Xinjiang	0.094	0.106	0.129	0.132	0.156	0.187	0.190	0.205	0.246	0.232	0.168

From 2013 to 2022, there were significant differences in the spatial distribution of China's digital economy in different regions, showing a characteristic of “high in the east and low in the west” (see Fig. 3). Specifically, the pattern of China's digital economy presents a clear hierarchical pattern: the first tier is represented by Zhejiang, Guangdong, Beijing, Shanghai, and Jiangsu, most of which are located in the eastern region, with comprehensive scores above 0.5 for each region, thus forming significant differences from other provinces and cities. The second tier is mainly located in the central region, including Hebei, Shandong, Anhui, Henan, Hubei, Tianjin, Liaoning, Fujian, Jiangxi, Guangxi, Chongqing, and Sichuan, consisting of 13 provinces with scores ranging from 0.31 to 0.5, indicating enormous potential for future growth. The third level is mainly composed of provinces in the western and northeastern regions, such as Shanxi, Inner Mongolia, Jilin,

Heilongjiang, Hainan, Guizhou, and Yunnan Xizang、Gansu, Qinghai, Ningxia, and Xinjiang have relatively low comprehensive scores in digital economy development and need to improve their digital level in the future. In addition, the differences in the development of the digital economy are mainly due to the different stages of its evolution. Under the advanced application and innovation of digital technology, the huge market size, and the promotion of more mature digital industries, the eastern region has effectively concentrated resources, formed a strong digital economic infrastructure, and a solid growth foundation. At the same time, the central region has shown a strong upward trend in the application and innovation of digital technology, thanks to its good development in equipment manufacturing, electronic information, new materials, and abundant scientific and educational resources. The industrial foundation in the western region is relatively underdeveloped, and the pace of digital technology application and innovation is slow. For example, Alibaba, a global leader in the digital economy, was established in Zhejiang; However, there are almost no leading enterprises related to the digital economy in the western region.

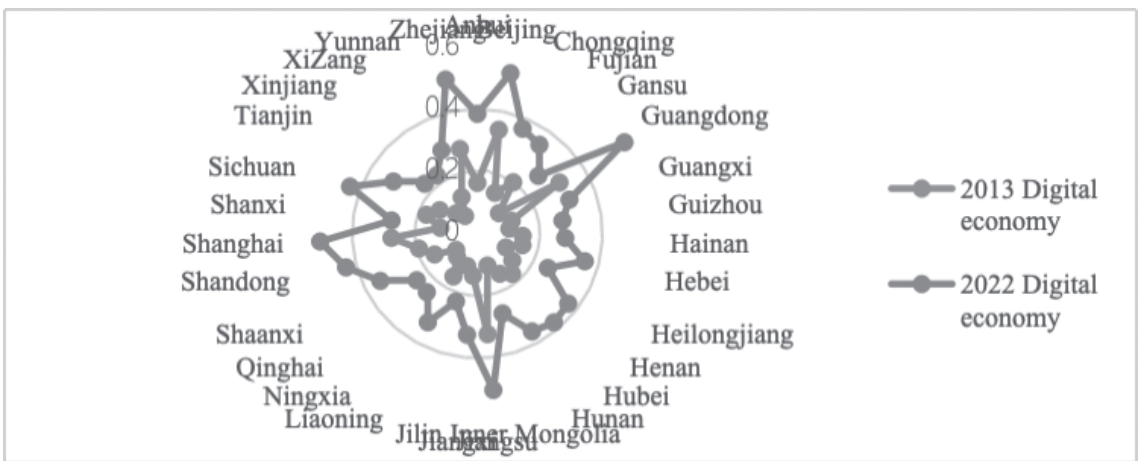

Fig. 3. Spatial variations of digital economy' comprehensive score.

2. Temporal changes and spatial variations of coupling coordination degree

2.1 Temporal changes of coupling coordination degree

Table 5 shows the coupling degree, coordination degree, and coupling coordination degree of each province over the years, and the results reveal that the coupling coordination between higher vocational education and the digital economy in Chinese provinces is on a continuous and stable upward trajectory, with the average index climbing from 0.4262 in 2013 to 0.555 by 2022. Furthermore, five grades were involved from 2013 to 2022: the lowest was the "slight imbalance grade" (0.30-0.39), and the highest was the "moderate coordination" (0.70-0.79). In general, the coupling coordination degree of regions escalated relatively steadily by one or two

grades, specifically, 58.1% (18 of 31) regions escalated by one grade, while 41.9% (13 of 31) escalated by two grades. Among them, the regions escalated into one grade are classified into three types: (1) Jilin, Ningxia, and Xizang have experienced an upward from the “slight imbalance” to “close to imbalance” category; (2) Fujian, Hebei, Hubei, Jiangxi, Liaoning, Shanxi, Shaanxi, Tianjin, Yunnan, and Chongqing have seen their status improve from “close to imbalance” to “primary coordination”; (3) Beijing, Jiangsu, and Zhejiang have demonstrated further enhancement from “barely coordination” to the “primary coordination” category. The regions in type (1) remained at the imbalance grades, indicating that these regions had not invested enough or made insufficient efforts to promote the coordinated development of higher vocational education and the digital economy in recent years. Type (2) and (3) showed that these regions had a relatively more stable and continuous investment in achieving the coordinated growth between higher vocational education and digital economy. Besides, regions escalated into two grades also can be divided into three types: (1) Gansu, Guangxi, Guizhou, Heilongjiang, Inner Mongolia, Qinghai, and Xinjiang have moved from “slight imbalance” to “primary coordination”; (2) Anhui, Henan, Hunan, Shandong, and Sichuan transitioned from “close to imbalance” to “primary coordination”. (3) Guangdong updated from “primary coordination” to “moderate coordination”. The increasing coordination coupling degree of these regions was they stimulated the output of the two subsystems (such as patents output and software business revenue) by increasing higher vocational education and digital economy investment (such as expenditure on research activities in both higher vocational education and digital economy).

Furthermore, upon careful examination of the degree of coupling and coordination between the two systems, it is evident that the characteristics of higher vocational education and the digital economy are characterized by a state of "high coupling and low coordination". Specifically, the coupling degree between the two systems is robust, and the overall coupling degree is significantly high, with an average of 0.971 in 2013 and 0.9881 in 2022, indicating that the system has been in the coupling stage. On the contrary, the coordination degree is relatively low, with an average value ranging from 0.1897 microliters in 2013 to 0.3155 microliters in 2022. Despite some growth, progress is slow and the level of coordinated development remains low. This means that although there is a close connection between higher vocational education and the digital economy, effective synergies have not been achieved in practical operations. The fundamental reason is mainly attributed to the insufficient adaptability of higher vocational education to the demands of the digital economy, characterized by a "low matching rate" between educational courses and talent needs. This mismatch has led to a significant gap between China's vocational education and its broader economic, social, and skilled workforce development goals, thereby hindering the harmonious development of these two subsystems.

Table 5. Temporal Changes of coupling degree, coupling degree, and coupling coordination degree

	Coupling degree		Coordination degree		Coupling coordination degree	
	2013	**2022**	**2013**	**2022**	**2013**	**2022**
Beijing	0.986	0.959	0.292	0.410	0.536	0.627
Tianjin	0.975	0.999	0.182	0.300	0.421	0.547
Hebei	0.956	0.993	0.211	0.317	0.449	0.561
Shanxi	0.957	0.994	0.168	0.311	0.401	0.556
Inner Mongolia	0.957	0.996	0.152	0.247	0.381	0.496
Liaoning	0.997	0.979	0.170	0.271	0.412	0.515
Jilin	0.978	0.999	0.138	0.221	0.367	0.470
Heilongjiang	0.947	0.999	0.149	0.246	0.376	0.496
Shanghai	0.997	0.891	0.254	0.346	0.503	0.555
Jiangsu	0.992	0.979	0.288	0.420	0.534	0.641
Zhejiang	1.000	0.973	0.282	0.410	0.531	0.632
Anhui	0.978	0.999	0.205	0.385	0.448	0.620
Fujian	0.999	0.990	0.211	0.303	0.459	0.548
Jiangxi	0.970	0.999	0.180	0.320	0.418	0.566
Shandong	0.992	0.986	0.220	0.371	0.467	0.604
Henan	0.978	0.990	0.178	0.428	0.418	0.651
Hubei	0.982	0.989	0.211	0.327	0.455	0.568
Hunan	0.967	0.999	0.198	0.350	0.437	0.591
Guangdong	0.999	0.993	0.294	0.496	0.541	0.702
Guangxi	0.977	0.999	0.149	0.326	0.381	0.570
Hainan	0.997	0.985	0.158	0.240	0.396	0.486
Chongqing	0.979	0.994	0.179	0.330	0.418	0.573
Sichuan	0.982	0.985	0.214	0.370	0.459	0.603
Guizhou	0.934	0.999	0.161	0.291	0.388	0.539
Yunnan	0.981	0.992	0.158	0.258	0.394	0.506
Xizang	0.889	0.998	0.127	0.213	0.336	0.460
Shaanxi	0.968	0.979	0.203	0.286	0.444	0.529
Gansu	0.939	0.998	0.145	0.251	0.369	0.501
Qinghai	0.963	0.999	0.117	0.244	0.336	0.494
Ningxia	0.947	0.999	0.146	0.240	0.372	0.490
Xinjiang	0.942	0.995	0.141	0.258	0.364	0.507

2.2. Spatial variations of coupling coordination degree

The coordination between the digital economy and higher vocational education across China are characterized by geographically "high in the eastern area and low in the western area". Specifically, the coupling and coordination degree in the eastern region ranks first, with five provinces featuring prominently in the top ten rankings for their coupling coordination levels. During the research period, Guangdong, Jiangsu, and Zhejiang have been at the forefront of the coordination between higher vocational education and digital economy in China, whose mean coupling coordination degrees of 0.645, 0.614, and 0.612 for the year 2022, respectively. The central region ranks second in terms of coupling coordination levels, with Henan, Hunan, and Hubei having coupling coordination degrees of 0.536, 0.521, and 0.531 for year 2022, respectively. Conversely, the northwestern region represented by Ningxia and Qinghai, and the northeastern region represented by Jilin and Heilongjiang, exhibit an almost uncoordinated state, with mean coupling coordination degrees of 0.435, 0.426, 0.424, and 0.44 in 2022, respectively. Moreover, the coupling and coordination degree between higher vocational education and digital economy in China is showing a clustering trend. Guangdong is part of the "Pearl River Delta" and leads in this indicator. Zhejiang and Jiangsu follow closely in the "Yangtze River Delta", while Beijing and Shandong in the "Bohai Rim region", as well as central and western provinces such as Henan and Sichuan, also rank high. In sharp contrast, regions with lower coordination indices are mainly located in the western and northeastern regions.

The fundamental reason is that there are differences in the level of digital economy development and vocational education investment among provinces, leading to varying degrees of coupling and coordination between higher vocational education and the digital economy. Firstly, the differences in the development of digital economy among provinces lead to inconsistencies between the specific needs of digital economy and the curriculum design and educational resources of higher vocational education system. The eastern coastal regions and some central provinces have made more significant progress in the development of the digital economy, with digital industries accounting for a large proportion in provinces such as Guangdong, Zhejiang, and Jiangsu, exceeding 50% of their respective gross domestic product. At the same time, the growth rate of the digital economy in the central region exceeded that of the eastern coastal areas, reaching 22.9%, and the proportion of digital economy in GDP in Henan, Hubei, Hunan and other regions reached as high as 30%. The strong growth of the digital economy in the central and eastern regions has not only stimulated industrial restructuring and progress, but also catalyzed the birth of new business models and industries. This in turn has prompted people to pay more attention to the digital transformation of higher vocational education and jointly promote the integration of higher vocational education and the digital economy. In sharp contrast, the digital economy in the western and northeastern regions lags behind, with their digital industries typically accounting for less than 20% of their gross domestic product. The underdeveloped state of the digital economy in these regions has led to a fragile industrial foundation and insufficient demand for skilled professionals, thereby limiting the scope of talent cultivation in higher vocational education and hindering its digital development. Essentially, this has led to a disharmony between the supply of higher vocational education and the demand of the digital economy.

Secondly, there are significant differences in policy support and resource investment for higher vocational education among provinces. The eastern and central regions, characterized by strong policy support and significant education funding, have achieved higher levels of higher vocational education, which in turn provides stronger support for digital economy initiatives. For example, Guangdong Province has shown a clear commitment to the development of higher vocational education, launching a series of policy measures aimed at cultivating reform and innovation in the industry. From 2012 to 2021, the total investment in higher vocational education in Guangdong Province soared to 448.663 billion yuan, significantly enhancing the province's comprehensive strength and educational quality in this field, placing it in a leading position in the country. There are 95 independently established higher vocational colleges in the province, and the dense concentration of higher vocational education resources provides a solid talent foundation for the expansion of the digital economy in Guangdong region. Therefore, Guangdong Province has become a pioneer in the coordinated development of higher vocational education and digital economy in China. In contrast, the northwest region represented by Ningxia and Qinghai, and the northeast region represented by Jilin and Heilongjiang, have seen a continuous increase in investment in higher vocational education in recent years, but still lag behind the national average level. Overall, there is an imbalance in the scale of higher vocational education between the western and northeastern regions, with lower levels of education and talent cultivation compared to the central and eastern regions. Their contribution to the digital economy is relatively small, which hinders the creation of a nurturing environment conducive to the integration and development of vocational education and the digital economy. This difference results in almost insufficient coordination between the two systems.

3. Influencing factors

The temporal and spatial changes of coordination and coupling degree are affected by many factors of both higher vocational education and digital economy subsystems. To explore the main influencing factors, we obtain the gray correlation degree matrix in the year 2013 and 2022 (See Table 6), respectively, which clearly explains the main influencing factors and constraints of higher vocational education and digital economy and demonstrates that there are close interactions and correlations among the two subsystems' elements. The detailed results are as follows.

3.1 Influencing of higher vocational education on digital economy

Our research first explores the role of higher vocational education in shaping the digital economy. In 2013, the GCDs for the dimensions of "talent cultivation (V1)", "innovative research (V2)", and "social vocational training (V3)" were 0.921, 0.928, and 0.920, respectively, indicating an exceptionally strong correlation between higher vocational education and the digital economy. It is worth noting that within the specific indicator range, "teaching and research investment" (V22, 0.935), "continuing education for employed labor force" (V33, 0.945), "education scale" (V11, 0.931), "vocational skills training" (V31, 0.921), and "research

and development investment" (V21, 0.920) stand out with the highest GCD values, indicating that they play a key role in influencing the digital economy. This result indicates that the expansion of research results and digital skills training scale can effectively help enterprises undergoing digital transformation significantly improve operational efficiency and competitiveness. Therefore, increasing investment in higher vocational education can increase its scale, help cultivate more qualified talents, and generate more research results related to the digital economy, thereby promoting the development of regional digital economy. In 2013, higher vocational education experienced a period of vigorous development, characterized by the increasing attractiveness of the higher vocational education sector and the continuous improvement of educational standards. The expansion of higher vocational education and the cultivation of a higher skilled talent pool have indeed further promoted the coordinated development of higher vocational education and the digital economy, aligning educational goals with the constantly changing needs of the digital economy.

The comparative analysis of influencing factors from 2013 to 2022 reveals several convincing new insights: (1) a decrease in system correlation. In 2013, the correlation between higher vocational education and the digital economy was high, but it has since declined. The GCD of all indicators has significantly decreased. For example, the GCD (V1) for talent cultivation decreased from 0.921 to 0.873; Innovation research (V2) decreased from 0.928 to 0.860; Social vocational training (V3) has decreased from 0.920 to 0.885. The decline in GCD value can be attributed to the rapid development of the digital economy, which has put forward new requirements for talent cultivation and practical teaching methods, and higher vocational education has not yet fully adapted to these requirements.

Table 6. Gray correlation matrix of higher vocational education (V1-3) and digital economy (D1-4); (a)2013; (b)2022

2013		**V1**			**V2**			**V3**		**mean**	**mean**
		V11	**V12**	**V13**	**V21**	**V22**	**V31**	**V32**	**V33**		
D1	D11	0.938	0.931	0.931	0.923	0.959	0.921	0.906	0.957	0.933	0.933
	D12	0.963	0.922	0.926	0.943	0.936	0.930	0.901	0.944	0.933	
	D13	0.954	0.917	0.938	0.942	0.940	0.930	0.897	0.944	0.933	
D2	D21	0.923	0.941	0.892	0.900	0.957	0.905	0.922	0.953	0.924	0.913
	D22	0.913	0.875	0.919	0.906	0.908	0.932	0.866	0.893	0.902	
D3	D31	0.922	0.924	0.887	0.914	0.934	0.920	0.912	0.931	0.918	0.922
	D32	0.927	0.972	0.850	0.899	0.930	0.896	0.970	0.948	0.924	
	D33	0.940	0.938	0.923	0.921	0.965	0.918	0.912	0.966	0.926	
D4	D41	0.907	0.881	0.952	0.914	0.912	0.926	0.863	0.911	0.908	0.910
	D42	0.923	0.885	0.925	0.937	0.912	0.933	0.871	0.909	0.912	
mean		0.931	0.919	0.914	0.920	0.935	0.921	0.902	0.935		
mean			0.921		0.928			0.920			

2022		V1			V2			V3		mean	mean
		V11	V12	V13	V21	V22	V31	V32	V33		
D1	D11	0.887	0.909	0.939	0.809	0.889	0.859	0.871	0.931	0.887	0.886
	D12	0.958	0.913	0.856	0.863	0.866	0.880	0.907	0.897	0.892	
	D13	0.940	0.884	0.875	0.845	0.835	0.862	0.876	0.901	0.878	
D2	D21	0.875	0.927	0.845	0.838	0.937	0.875	0.919	0.899	0.889	0.868
	D22	0.839	0.850	0.741	0.885	0.826	0.916	0.904	0.817	0.847	
D3	D31	0.861	0.896	0.843	0.819	0.903	0.869	0.892	0.897	0.872	0.893
	D32	0.893	0.956	0.830	0.872	0.924	0.907	0.964	0.900	0.906	
	D33	0.898	0.946	0.912	0.833	0.911	0.873	0.899	0.945	0.902	
D4	D41	0.828	0.786	0.749	0.802	0.785	0.810	0.809	0.799	0.796	0.833
	D42	0.881	0.876	0.785	0.897	0.856	0.906	0.923	0.842	0.871	
mean		0.886	0.894	0.838	0.846	0.873	0.876	0.896	0.883		
mean			0.873		0.860			0.885			

(2) The transformation of key influencing factors. The main influencing factors have shifted from “teaching and research investment” (V22) and “research and development investment” (V11) to “training services” (V32) and “education quality” (V12). The main influencing factors have shifted from “teaching and research investment” (V22) and “research and development investment” (V11) to “training services” (V32) and “education quality” (V12). In 2013, “teaching and research investment” (V22, 0.935) and “research and development investment” (V11, 0.920) were important factors, but by 2022, their impact has weakened, with GCD values of 0.873 and 0.846, respectively. In contrast, “training services” (V32, 0.896) and “education quality” (V12, 0.894) became the most influential factors in 2022. This shift indicates that with the improvement of digital infrastructure, the contribution of investment to the digital economy has weakened, and additional investment in research and teaching has not led to effective transformation or adaptation to constantly changing industrial upgrading needs. Therefore, the driving factor has shifted from investment to the quality of education and training services, which is more directly related to the demand of the digital economy.

To address these challenges, targeted measures must be implemented to strengthen the coupling and coordination between higher vocational education and the digital economy. For example, by adopting new digital tools and platforms to improve the quality of education and training services, the transformation of higher vocational education can be strengthened; Strengthen the integration of industry and education, develop specialized education and training plans to meet the specific needs of the regional digital economy.

3.2 Influencing of the digital economy on higher vocational education

In 2013, from the dimension's perspective, the GDC of digital infrastructure (D1) was 0.933, and digital industrialization (D2), industry digitization (D3), and digital technology support (D4) were 0.913, 0.926, and 0.910 respectively, indicating that digital economy-related professional contribution to improving sustainable higher vocational education has shown obvious importance. In addition, in terms of specific indicators, "Internet penetration rate" (D11, 0.933), "Mobile telephony services" (D12, 0.933), "Telecommunications infrastructure" (D13, 0.933) were the most influential factors, which proves that the modern infrastructure of digital economy contributes to the better growth of higher vocational education and the better coordination interactions between higher vocational education and digital economy. Furthermore, "ICT Workforce" (D21, 0.924), "E-commerce" (D32, 0.924), and "Digital financial inclusion index" (D33, 0.926) also strongly impacted higher vocational education, indicating that increasing digital economy-related employees, revenues and application of digital technology are conducive to supporting the development of higher vocational education from the human resource, financial perspective, and technical application. These findings are the insights for those who wish to use the digital economy to develop higher vocational education: they should know what they can do more effectively and efficiently.

Comparing the influencing factors between 2013 and 2022, there are several noteworthy developments: (1) there is a discernible downward trend in the degree of influence, with digital infrastructure (D1) experiencing a decline from 0.933 to 0.886, digital industrialization (D2) slipping from 0.912 to 0.868, industry digitization (D3) receding from 0.922 to 0.893, and digital technology support (D4) plummeting from 0.910 to 0.833. This trend indicates that there is a lingering important influence of the digital economy on higher vocational education, the explosive growth of the digital economy has introduced fresh demands for the cultivation of talent and the enhancement of practical teaching methodologies within the realm of higher vocational education. However, the adaptability of higher vocational education to these new demands of the digital economy exhibits a degree of latency, consequently leading to a waning impact of digital economy on higher vocational education. (2) In specific indicators, we can find that the most influential factor shifts with a transition from "Internet penetration rate" (D11, 0.887), "Mobile telephony services" (D12, 0.892), "Telecommunications Infrastructure" (D13, 0.878) to "E-commerce" (D32, 0.906) and "Digital financial inclusion index" (D33, 0.902). This shift illustrates that industry digitization has supplanted digital infrastructure as a critical influence on higher vocational education. As digital infrastructure matures, its influence on higher education has diminished, yet the swift growth of industry digitization has amplified the productivity of enterprises related to the digital economy, creating a spillover effect that allows higher education to reap "Digital dividends". Thus, the educational content, resources, and instructional approaches within higher vocational education should undergo continuous transformation in tandem with the digital metamorphosis of the industry.

In conclusion, higher vocational education and the digital economy are closely interacting and influencing each other; their dimensions and indicators have constantly interacted tightly with strong coupling coordination effects. The development of higher vocational education is conducive to promoting digital economy-related

innovation and technological progress, increasing the output of the digital industry; the improvement of the digital economy accelerates the digital transformation of higher vocational education, optimizes higher vocational education teaching modes, expands its teaching resources, improves students' performances, and enhances higher vocational education's overall competitiveness. In addition, we can find that "Talent cultivation", "Training Services" and "Industry digitization" dimensions are the more influential dimensions: higher vocational education provides sufficient technical and skilled talents to support digital economy growth, and industry digitization makes higher vocational education enjoy the "digital dividends" of digital economy growth.

V. Discussion and Policy recommendation

1. Discussion

This section compares the results with other studies and obtains several new discussion topics.

First, this study finds that the development of coupling coordinated degrees between China's higher vocational education and digital economy has shown a steady ascent, characterized by "high coupling with low coordination", which highlight the dynamic and evolving nature of their relationship that previous studies have not emphasized. Our finding aligns with the developmental history of the digital economy and higher vocational education in China. During the period from 2006 to 2011, issues related to training objectives, teaching methods, funding, and institutional mechanisms at higher vocational institutions led to a low degree of alignment between higher vocational education and regional economic and social development. However, with the intensification of demands for regional digital economic progression, coupled with clear national positioning and robust policy support for the development of vocational education, continuous reforms have been made in the approaches and philosophies of running educational institutions, as well as in talent cultivation strategies and goals. Efforts through industry-education integration, school-enterprise collaboration, and the nurturing of technically skilled talents have effectively served the regional digital economic development. This has fostered a "high coupling" relationship between higher vocational education and digital economy, with a consistently improving degree of fit with the digital economy. Yet, as the digital economy has accelerated, the systemic reforms in higher vocational education have struggled to fully accommodate the swift developmental demands. The proficiency in specialized development, educational paradigms, and resource allocation at higher vocational colleges have not been entirely in sync with the exigencies of regional digital transformation. Their potential to aid in regional economic reconfiguration and to catalyze digital transformation remains underutilized, culminating in a "low coordination" development scenario between higher vocational education and digital economy, as Geng et al. (2023) proved that Yangtze River economic belt had a low degree of coordination between higher vocational education and the digital economy.

Second, this study finds that the coupling development between higher vocational education and the digital

economy across China's 31 provinces has noticeable spatial differences, with a spatial hierarchy of "Eastern region > Central region > Western region". Compared with the findings of Bai et al. (2023), our finding provides a more nuanced understanding of the spatially varied nature of this relationship. Specifically, regional heterogeneity of notable spatial clustering and regional consolidation, with the Pearl River Delta, Yangtze River Delta, and Jing-Jin-Ji (Beijing-Tianjin-Hebei) region standing out as vanguard areas for coordinated development. As Geng et al. (2023) highlight that Eastern coastal and central regions are endowed with abundant superior flatlands for social development, convenient transportation, a giant population (sufficient laborers and consumers), a long history in education and innovation, and sufficient fiscal revenue, which are conducive to the coordinated growth of higher vocational education and digital economy in China. Our study further confirms that regional development differences in higher vocational education and digital economy lead to distinct spatial patterns. The variations between provinces are largely attributed to the uneven development across the "economy-society-environment-population-education" spectrum. Yet, with the continuous growth of the coupling and coordinated development trend across provinces over the span of ten years, regional spatial disparities are exhibiting a slow reduction. This is a positive sign, indicating that policy interventions and regional development strategies are having some effect.

Thirdly, the key influencing factors of the coordinated development of higher vocational education and digital economy have evolved with the coupling and coordinated development of the two systems and regional disparities, shifting from "teaching and research investment", "research and development investment", and "digital infrastructure" to "training services", "education quality", and "industrial digitization". This is a finding that has not been widely explored in previous research. This transformation highlights the evolving nature of the relationship between higher vocational education and the digital economy. With the continuous improvement and popularization of digital infrastructure, the focus of the digital economy has shifted to utilizing this infrastructure to promote the digital transformation of industries and enterprises. This has put forward new requirements for talent cultivation in higher vocational education, requiring the cultivation of versatile individuals with digital skills, the ability to engage in industrial practice, and the ability to continuously learn and improve skills. It requires higher vocational education to improve the quality of education for first-time employees, increase opportunities for continuing education and skill enhancement for professionals, and further promote the coordinated development of coupling with the digital economy.

2. Policy recommendation

Due to the relatively stable coupling coordination degree in time and significant spatial differences, targeted and diversified strategies must be carefully considered to improve the coupling coordination between the two systems and alleviate regional differences. The specific measures are as follows.

For the regions where coupling coordination degrees have been in relatively less satisfactory coordination stages (such as Xizang, whose coupling coordination degree is the lowest), they should discover their specific advantages and capitalize on external opportunities and favorable policies to attain differentiated coordinated

development. (1) Efficiently utilize national policies for digital economy development, align with the region's resource endowments and cultural uniqueness and synergize with other advanced digital economy regions to attract technological and capital inflows, robustly develop distinctive digital industries, advance digital infrastructure construction, and elevate the region's digital economic development level. (2) Based on the regional features of digital economy growth, motivate local higher vocational institutions to hasten the digital transformation of higher vocational education, create specialized educational programs for local digital economy enterprises, and establish exchange and internship schemes with regions that excel in higher vocational education and the digital economy to stimulate intentional growth in both sectors.

For regions exhibiting stable averages in coupling coordination degree (such as Hubei, and Hunan), it is necessary to overcome substantial hurdles and further improve the coupling coordination degree of higher vocational education and digital economy. (1) By encouraging the combination of traditional industries with digital technology to advance industrial upgrading; further perfecting the construction of digital infrastructure including networks and digital hubs; elevating the government's capacity for digital governance and optimizing the business environment for the digital economy, thereby accelerating the swift development of the regional digital economy. (2) Aligning with the digital transformation and upgrading requirements of the region's manufacturing sector, it is crucial to optimize the digital economy-related majors and disciplines within local higher vocational institutions, while also leveraging the region's digital infrastructure to create an educational resource-sharing platform that enhances the efficiency of educational resource utilization and promotes the growth and quality of digital economy-related students.

For regions with high average coupling coordination like Guangdong, Zhejiang, and Jiangsu, a comprehensive strategy must be implemented to strengthen the synergistic advantages between higher vocational education and the digital economy. (1) Utilizing big data and artificial intelligence technology to support data-driven decision-making for governments and enterprises, improving the digital economy innovation ecosystem, continuously promoting the healthy development of the digital economy, while strengthening collaborative development with other regions, highlighting the exemplary role of the eastern region in the field of digital economy. (2) Utilizing the abundant presence of well-known vocational colleges and digital economy enterprises, promoting the integration of industry and education, motivating enterprises to participate in vocational education curriculum development and talent cultivation, providing professional training for employees in the digital economy industry to improve their work performance and market competitiveness.

VI. Conclusion

This study first explores the current development status and spatiotemporal coupling coordination relationship between higher vocational education and digital economy in 31 provinces of China from 2013 to 2022, and analyzes the factors that affect the degree of coupling coordination through a grey relational model.

Based on the research results, we can make some suggestions.

First, the characteristic of coupling coordination degree between higher vocational education and digital economy in China is "high coupling with low coordination". Specifically, from 2013 to 2022, the average coupling degree increased from 0.971 to 0.988, but the coordination degree is relatively low (from 0.1897 to 0.3155), indicating that there is a strong connection but low match between higher vocational education and the digital economy.

Second, there is significant spatial differences, charactered by "eastern > central > western" in the coupling coordination degree between higher vocational education and digital economy. The reason for this spatial hierarchy is uneven development of higher vocational education and the digital economy across different regions. Provinces like Guangdong, Jiangsu, and Zhejiang in the eastern region has the rapid development of digital economy and the large scale of investment in vocational education, while provinces in the western and northeastern regions, such as Ningxia, Qinghai, Jilin, and Heilongjiang, experiencing uneven economic development and low investment in vocational education.

Third, the driver factors of the coupling coordination degree have changed from "instructional research investment", "R&D investment", and "digital infrastructure" to "training Services", "education quality", and "industry digitization", reflecting that the talent cultivation of higher vocational education should adapt to the development and changes demand of the digital economy.

VII. Limitations and future research

In the context of rapid development of digital economy, coupling and coordination between higher vocational education and digital economy becomes increasingly important for all countries or regions. This research used provincial level data in China to explore the coupling and coordination dynamics, and the policy recommendations are suitable for China's current development in digital economy and higher vocational education. And the findings can serve as a theoretical reference for other countries or regions. Nonetheless, due to the different policy environment and development of digital economy and higher vocational education in different countries and regions, the finding of this paper can't be direct applicated. Thus, it is necessary to tailor strategic planning based on the specific development stage and policy background of local higher vocational education and digital economy. In the future studies, we may introduce data from other countries or regions to explore more target policy recommendations.

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