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Coupling coordinated development among digital economy, regional innovation, and talent employment: A case study in the Hangzhou Metropolitan Circle, China

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ABSTRACT

Coordinative development across various systems, particularly the economic, social, cultural, and human resources subsystems, is a key aspect of urban sustainability and has a direct impact on the quality of urbanization. The Hangzhou Metropolitan Circle, comprising Hangzhou City, Huzhou City, Jiaxing City, and Shaoxing City, was the first metropolitan circle approved by the National Development and Reform Commission (NDRC) as a demonstration of economic transformation in China. To evaluate the coupling coordination degree of the four cities and analyze the coordinative development in three systems (including digital economy, regional innovation, and talent employment), we collected panel data during 2015–2022 from these four cities. The development level of the three systems was evaluated by the standard deviation method and comprehensive development index. The results are as follows: (1) the level of coupling coordinated development of the three systems in the Hangzhou Metropolitan Circle was relatively low; (2) the coupling coordination degree of the four cities in the Hangzhou Metropolitan Circle showed significant regional differences, among which Hangzhou City was in the leading position, and Huzhou, Jiaxing, and Shaoxing cities made steady but slow progress in the coupling development of the three systems; and (3) the development of digital economy and talent employment needs to be strengthened. This study contributes to the coordinative development of Hangzhou Metropolitan Circle by innovatively focusing on the coupling coordination relationship among digital economy, regional innovation, and talent employment, which also meets the industrial layout of Hangzhou Metropolitan Circle. In this way, the optimal allocation and sustainable development of digital economy, regional innovation, and talent employment in the Hangzhou Metropolitan Circle can be achieved.

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1. Introduction

As a distinct form of regional spatial structure, a metropolitan circle emerges from urban development up to a particular point (Galster and Killen, 1995). It comprises one or more core cities, along with connected towns and areas with strong social and economic ties to the core, displaying integration tendencies (Fang and Yu, 2017). China's urbanization has steadily progressed since the reform and opening up, fostering accelerated economic, social, and cultural integration among cities in economically developed regions, such as the Yangtze River Delta, the Pearl River Delta, and the Beijing-Tianjin-Hebei Region, leading to the formation of numerous metropolitan circles (Liu and Zhang, 2021). Many cities have actively initiated the establishment of metropolitan circles, with major cities at their cores and surrounding small and medium-sized cities as members, aiming to enhance regional economic cooperation, facilitate organic resource integration, and improve overall urban competitiveness (Sahana and Hong, 2018).

The Hangzhou Metropolitan Circle constitutes a pivotal segment of the Yangtze River Delta urban agglomeration, situated in the southern region of the Yangtze River Delta economic zone. It exhibits a spatial configuration centered around Hangzhou City, with Huzhou, Jiaxing, and Shaoxing cities serving as sub-centers and encompassing 20 adjacent regions in the immediate vicinity, alongside numerous small towns in the surrounding areas (Shen, 2019). Characterized by a relatively clear structure, the Hangzhou Metropolitan Circle features a well-organized arrangement of major cities, medium-sized counties, and small towns, rendering it one of China's regions with the highest degree of industrial concentration and coordination (Shen, 2019). Since 2015, the Hangzhou Metropolitan Circle has propelled industrial space optimization, industrial transformation and upgrading, and regional economic innovation and development through the creation of distinctive towns with industrial and cultural characteristics, eco-tourism attractions, and community amenities. During the 14th Five-Year Plan period, the Hangzhou Metropolitan Circle is capitalized on digital economy to achieve integrated digital and urban economic development (Zhu and Chen, 2022).

Under the spatial model of "big city and small town", three-circle layer industrial layout in the Hangzhou Metropolitan Circle is adopted (Fig. 1). Firstly, the core circle focuses on emerging digital industries, such as information technology, big data, cloud computing software, e-commerce, etc., predominantly developed within the digital economy framework. Secondly, the inner circle prioritizes traditional manufacturing sectors, including the pharmaceutical and chemical industry, textiles and clothing, the rubber and plastic industry, etc., supported by skilled labor and high-level talents. Thirdly, the outer circle emphasizes innovative service industries, such as cultural tourism industry, exhibition industry, rural tourism, etc., concentrated within a series of featured small towns. Enhancing interactions and coordination among digital economy, talent employment, and regional innovation is of significant importance in promoting the three-circle layer industrial layout under the spatial model of "big city and small town" (Shen, 2019; Duarte et al., 2021).
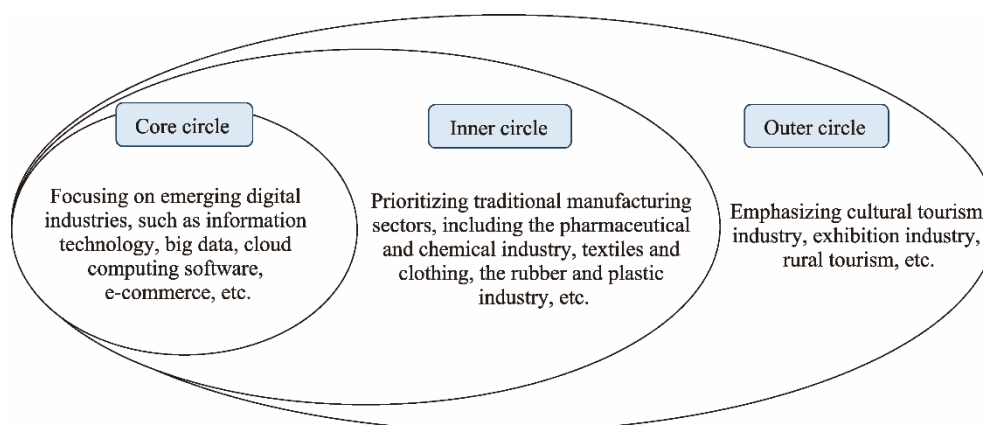

Fig. 1. Three-circle layer industrial layout in the Hangzhou Metropolitan Circle.

2. Literature review

Currently, the research of domestic and international scholars on metropolitan circles primarily focuses on concepts, scope, population size, urban relationships, innovative development, and other related areas. Limited

literature exists on the coordinative development of metropolitan circles, with most studies concentrating on the coordination between two systems. Hou et al. (2020) examined the changes of the coordinative development of urbanization in the Chengdu Metropolitan Circle, along with the coordination of urbanization with economic and environmental growth. Li et al. (2021a) conducted a study on the coupling coordination analysis and spatiotemporal heterogeneity between urbanization and ecosystem health in Chongqing Municipality. Ni et al. (2023) assessed the coupling coordination degree in the ecological-economic system of Hangzhou City and analyzed the evolution of coupling coordination characteristics and landscape ecological patterns during 2010–2020.

In recent years, scholars have increasingly focused on the impact of digital economy on urban development. These studies encompass the impact of digital economy on industrial development (Pauli et al., 2021; Liu et al., 2022), human capital (Zaborovskaia et al., 2020; Li et al., 2023), regional innovation (Banalieva and Dhanaraj, 2019; Pan et al., 2022; Tian et al., 2023), and regional coordinative development (Zhu, 2017; Chen and Sun, 2022; Liu et al., 2022). Regarding the Hangzhou Metropolitan Circle, Zhu (2017) highlighted the digital economy's core industry status, emphasizing the agglomeration of digital economic elements from a temporal and spatial perspective. Pan et al. (2022) classified digital economy elements into hardware and software, indicating that "soft elements", such as digital technology talents, digital industry policy, and digital technology services, are crucial, providing policy, innovation, and service support for the spatial agglomeration of digital economy. Banalieva and Dhanaraj (2019) and Li et al. (2021b) contended that the spatial agglomeration theory of urban economics underscores the influence of technology spillovers on regional innovation, suggesting that knowledge and technology spillovers facilitate industrial agglomeration and expanding that industrial agglomeration strengthens knowledge and technology spillovers. Kogan et al. (2017) argued that with the rapid advancement of network, communication, and digital technology, spatial spillovers of knowledge and technology become vital for regional innovation. Dong et al. (2021) observed that small towns are facing greater demands on their human capital due to the continuous emergence of new industries, business formats, and models brought about by technological innovation, effective networks, and convenient transportation. Kong and Chen (2019) and Zaborovskaia et al. (2020) suggested fully leveraging the distinct advantages of local service industries in the digital economy to broaden talent employment channels in the service industry, enhance employment absorption capacity, and narrow the gap with major cities.

From a quantitative analysis perspective, Billings and Johnson (2012) utilized the location quotient to compute the industrial agglomeration index across various spaces, aiming to gauge the degree of industrial concentration. For instance, the spatial agglomeration degree of an industry can be assessed by examining the relationship between the employment population of specific industries and the total population of the region. While this method offers valuable insights into industrial agglomeration, the location quotient primarily reflects the specialization degree of an industrial sector. However, the index lacks a comprehensive multidimensional, multi-level, and multi-form analysis.

In conclusion, prior studies have extensively analyzed the relationship between digital economy and regional innovation or the relationship between digital economy and talent employment from both theoretical and empirical perspectives. Nonetheless, there are avenues for further improvement in the following areas. Firstly, as the leading city in digital economy, Hangzhou City warrants special attention regarding the coupling coordinated development of digital economy, regional innovation, and talent employment, along with its spillover effect on neighboring cities within the Hangzhou Metropolitan Circle. Secondly, existing studies have predominantly focused on the coupling coordination of two systems, either digital economy and regional innovation or digital economy and talent employment. However, this study has identified a high degree of interrelation among digital economy, regional innovation, and talent employment, all of which align with the three-circle layer industrial layout within the spatial model of "big city and small town" in the Hangzhou Metropolitan Circle. Thirdly, most existing studies have relied on a single digital economy index, neglecting the regional development characteristics of the Hangzhou Metropolitan Circle. Therefore, drawing upon related studies and expert suggestions, in this study, we established a comprehensive evaluation system for digital economy, regional innovation, and talent employment, incorporating 24 indicators. By utilizing this comprehensive evaluation system, we assessed the comprehensive development level of digital economy, regional innovation, and talent employment across four cities within the Hangzhou Metropolitan Circle. We measured the coupling coordination degree among the three systems by evaluating the comprehensive development level, offering insights for policymaking aimed at integrating digital economy, regional innovation, and talent employment.

3. Methods

3.1. Theoretical model specification

Digital economy, regional innovation, and talent employment are all vital for fostering and propelling regional economic growth during the formation and development of industrial space in metropolitan circles (Dong et al., 2020). In executing the regional innovation and development strategy, Zhu et al. (2020) proposed that the Hangzhou Metropolitan Circle adopts a strategy of "promoting cities through industry and integrating industry with cities", fostering a pattern of coordinative development encompassing large, medium-sized, and small cities, as well as small towns, and establishing various digital economy hubs, such as high-tech industrial parks, maker spaces, pioneer parks, and feature towns. Guided by digital economy, numerous small towns have hastened their integration into the metropolitan network, engaging in division of labor and cooperation based on their competitive advantages, thereby gradually shaping the three-dimensional spatial pattern of the Hangzhou Metropolitan Circle (Fig. 2).
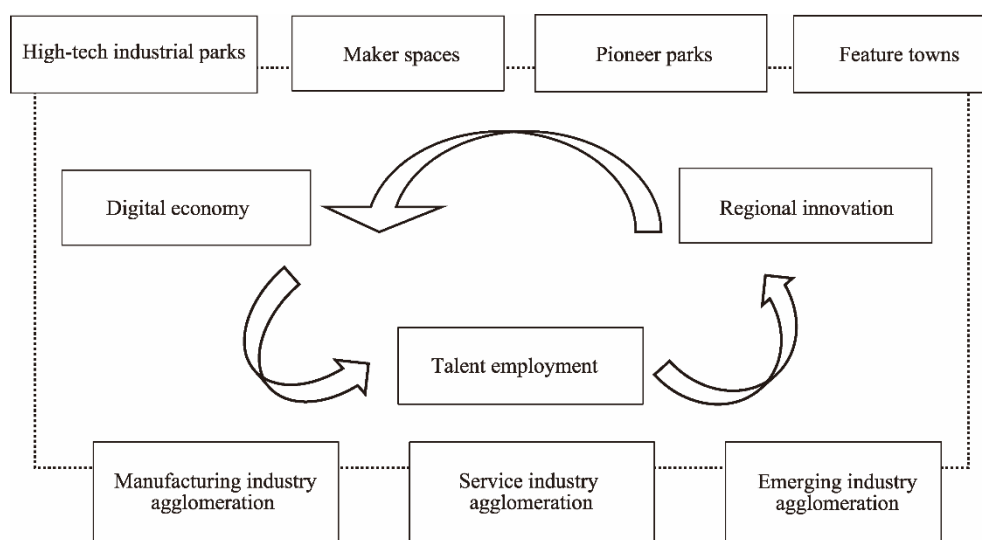

Fig. 2. Correlation among digital economy, regional innovation, and talent employment in the Hangzhou Metropolitan Circle.

Given the intricate coordination relationship among digital economy, regional innovation, and talent employment across multiple dimensions, levels, and forms, in this study, we selected four cities within the Hangzhou Metropolitan Circle, including Hangzhou City, Shaoxing City, Jiaxing City, and Huzhou City, as focal points to investigate the coupling coordinated development of digital economy, regional innovation, and talent employment. A comprehensive evaluation system comprising 6 subsystems and 24 indicators was established to evaluate the 3 systems: digital economy, regional innovation, and talent employment. The standard deviation method was employed to determine the weight of each indicator and each subsystem. We used the comprehensive development index to measure the development of the three systems based on weights determined by the standard deviation method. The coupling coordination degree model (CCDM) was employed to measure the coupling coordination degree among the three systems, providing policy implications for the coordinative development of the Hangzhou Metropolitan Circle.

3.2. Establishment of comprehensive evaluation system

Zhu (2017) proposed that digital industry agglomeration is influenced by various factors, with commonly selected indicators related to the development basis of digital economy, including the revenue of telecommunication industry, number of mobile phone users, number of broadband service users, etc. In this study, we also selected regional indicators related to the scale of digital industry agglomeration, such as the scale of cultural and creative industries, scale of information industry, along with freight transport volume and express delivery volume reflecting the scale of regional digital economy development at the logistics data level.

In recent years, the Hangzhou Metropolitan Circle has intensified the application of new knowledge and technology in the process of transforming and upgrading small and medium-sized enterprises, with significant increases in human, material, and financial resources invested in scientific research and experimental development activities (Chen, 2015; Zhu et al., 2020). Therefore, concerning regional innovation investment, in this study, we

selected four indicators related to research and development to gauge the scale and intensity of scientific and technological innovation activities in the Hangzhou Metropolitan Circle. Regarding innovation output, Pang et al. (2019) regarded the number of technology business incubators as a significant evaluation index. Additionally, considering time lags and other factors, this study included the number of patents granted and the productivity of new products as other indicators of innovation output.

To evaluate the relationship between talent employment and regional economic development effectively and scientifically, we considered the number of colleges graduates, and the number of graduates from vocational schools and technical schools as indicators of education scale and regional talent employment level (Fernandes and O'Sullivan, 2022).

The inclusion of graduates from vocational schools and technical schools in the evaluation system was warranted due to these institutions play a crucial role in supplying "blue-collar" employment groups, including junior and intermediate technical personnel and skilled workers, to society amidst the development of vocational education (Liu and Li, 2019). Additionally, data from LinkedIn, the largest professional social networking platform in the world, revealed that the most sought-after employment fields for college graduates in the Hangzhou Metropolitan Circle predominantly revolve around information technology, computer services, software development, business services, finance, and other tertiary industries. Consequently, in talent employment system, we prioritized the number of employees in these popular fields as main indicators. By integrating these indicators with the development basis and scale of digital economy, investment and output of regional innovation, and scale of education and talent employment in the Hangzhou Metropolitan Circle, we constructed a comprehensive evaluation system comprising 6 subsystems and 24 indicators encompassing digital economy, regional innovation, and talent employment (Table 1).

Research data sources must adhere to the principles of reliability, quantification, comparability, and stability. The data presented in this study were primarily originated from the statistical yearbooks of the four cities during 2015–2022 (Hangzhou Municipal Bureau of Statistics, 2017, 2023; Huzhou Municipal Bureau of Statistics, 2018, 2023; Jiaxing Municipal Bureau of Statistics, 2018, 2023; Shaoxing Municipal Bureau of Statistics, 2018, 2023; Zhejiang Provincial Bureau of Statistics, 2023). Before determining weights and analyzing data, standardization of data is necessary due to the variations in dimensions and units across different indicators. The formulas for standardization are as follows:

$$X'_{ij} = \frac{X_{ij} - X_{i\min}}{X_{i\max} - X_{i\min}} \text{ (positive effect)}, \tag{1}$$

$$X'_{ij} = \frac{X_{i\max} - X_{ij}}{X_{i\max} - X_{i\min}} \text{ (negative effect)}, \tag{2}$$

where X_{ij} refers to the original value of indicator j in the ith year; X'_{ij} represents the standardized value of X_{ij}; and $X_{i\max}$ and $X_{i\min}$ represent the maximum and minimum values of the original data in the ith year, respectively.

3.3. Calculation of weight

To avoid the subjectivity in the process of determining weights, we used the standard deviation method based on information entropy to determine weights. Entropy is a scientific measure of the degree of system disorder by the variability of indicators. The standard deviation and variability of indicators are consistent. The larger the standard deviation of the same indicator, the greater the variation of the indicator, the more information the indicator provided, and the greater the weight in the comprehensive evaluation, and vice versa (Wang, 1999). The calculation process of mean square deviation and weight is as follows:

$$\sigma_j = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (X'_{ij} - \overline{X'_{ij}})^2}, \tag{3}$$

$$W_j = \sigma_j / \sum_{i=1}^{m} \sigma_{ij}, \tag{4}$$

where σ_j denotes the mean squared deviation of indicator j; W_j denotes the weight of indicator j calculated by the mean squared deviation method; $\overline{X'_{ij}}$ is the average value of X'_{ij}; n is the number of observations; m is the number of indicators; and σ_{ij} is the mean squared deviation of indicator j in the ith year.

Table 1
Weight of digital economy, regional innovation, and talent employment indicators based on a comprehensive evaluation system.

System	Subsystem	Indicator	Effect	Weight
Digital economy	Development basis of digital economy	Revenue of telecommunication industry	+	0.159
		Number of mobile phone users	+	0.167
		Number of broadband service users	+	0.121
		Foreign direct investment projects in the tertiary industry	+	0.123
	Scale of digital economy	Scale of cultural and creative industries	+	0.109
		Scale of information industry	+	0.116
		Freight transport volume	+	0.125
		Express delivery volume	+	0.080
Regional innovation	Innovation investment	Research and development investment of the whole society	+	0.135
		Personnel research and experimental development activities	+	0.122
		Ratio of research and development expenditure to gross domestic product	+	0.182
		Number of scientific and technological institutions in enterprises	+	0.122
	Innovation output	Number of patents granted	+	0.142
		Number of research and experimental development projects of large-scale industrial enterprises	+	0.091
		Productivity of new products	+	0.114
		Number of technology business incubators	+	0.091
Talent employment	Scale of education	Number of students in colleges	+	0.120
		Number of college graduates	+	0.187
		Number of graduates from vocational schools and technical schools	+	0.082
	Scale of talent employment	Proportion of employment in the tertiary industry	+	0.092
		Employment in information transmission and computer services and software	+	0.093
		Employment in industry of leasing and business services	+	0.085
		Employment in financial industry	+	0.132
		Employment in scientific research and technical services	+	0.129

Note: + denotes positive effect.

3.4. Comprehensive development index (CDI)

The United Nations initially defined the comprehensive development index (CDI) as an approach for assessing the human development index. In this study, we assessed the development level of digital economy, regional innovation, and talent employment using the CDI, which is based on the afore-mentioned comprehensive evaluation system. Take digital economy as an example, the calculation of the CDI is as follows.

Firstly, the CDI of subsystems was computed. X'_{ij}, ranging from 0 to 1, was multiplied by W_j that obtained from Equation 4, and the respective score of the indicator can be computed. The scores of each indicator were added together to form the scores of subsystems. The computation can be performed using the following formula:

$$f(d)_s = \sum_{i=1}^{n} \left(W_j \times X'_{ij} \right),$$
(5)

where $f(d)_s$ is the CDI of subsystems of digital economy.

Secondly, the CDI of system was calculated. In order to compute the CDI of digital economy, it is necessary to determine the relative weight of each subsystem. The methods employed for determining the weight of subsystems are identical to those utilized for determining the weight of indicators. The equation provided below can be utilized for calculation:

$$f(d) = \sum_{s=1}^{n}\left(W_{is} \times f(d)_s\right), \tag{6}$$

where $f(d)$ is the CDI of digital economy; S represents the number of subsystems (S=1 or S=2, due to there are two subsystems in digital economy); and W_{is} is the weight of subsystem in the ith year.

3.5. Coupling coordination degree model (CCDM)

Because digital economy, regional innovation, and talent employment are complex system projects, and the relationship between each system is complex, it is difficult to analyze its operating mechanism based on experience. Therefore, we used the CCDM to analyze the correlation between these systems and how they affect each other. The coupling coordination model was firstly originated from physics, developed to study the interaction between two or more systems, and then gradually applied to many fields, such as geography, economy, science and technology, tourism, and so on. By referring to the model of capacity coupling coefficient in physics and coupling three different but interactive systems, i.e., digital economy, regional innovation, and talent employment that can reflect benign interaction and interdependence among systems, we developed the CCDM of the three systems. The equation can be expressed as follow:

$$C = \left\{ \frac{f(d) \times g(n) \times m(t)}{\dfrac{f(d) + g(n) + m(t)}{3}} \right\}^{1/3}, \tag{7}$$

where C denotes the coupling degree of digital economy, regional innovation, and talent employment; $g(n)$ is the CDI of regional innovation; and $m(t)$ is the CDI of talent employment. The C value ranges from 0.000 to 1.000, that is to say, when C value is equal to 0.000, the three systems are in the worst correlated and completely disordered state; when C value is equal to 1.000, the three systems are in the most correlated and orderly state. To more accurately judge the coupling coordination degree among digital economy, regional innovation, and talent employment, and reveal the dynamic equilibrium development state of the three systems, the CCDM can be further constructed as follows:

$$T = \beta_1 f(d) + \beta_2 g(n) + \beta_3 m(t), \tag{8}$$

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

where T represents the coupling coordination degree of the overall synergistic effect of digital economy, regional innovation, and talent employment; D represents the coupling coordination degree of digital economy, regional innovation, and talent employment; and β_1, β_2, and β_3 are coefficients of digital economy, regional innovation, and talent employment, respectively. Considering the equal importance of the three systems, i.e., equal importance of digital economy, regional innovation, and talent employment, in this study, we assumed that β_1, β_2, and β_3 are equal. The higher the D value, the better the coordination among the three systems, and vice versa.

4. Results

4.1. CDI of digital economy, regional innovation, and talent employment

Based on the calculation of coupling coordination degree described above, we derived the CDI of the three systems, including digital economy, regional innovation, and talent employment, in the Hangzhou Metropolitan Circle, as shown in Figure 3.

Figure 3 reveals that the CDI of regional innovation consistently outperformed that of digital economy and talent employment. From 2015 to 2022, the CDI of regional innovation consistently maintained a leading position, driving the comprehensive development of the Hangzhou Metropolitan Circle. Notably, the CDI of regional innovation experienced a rapid growth from 0.408 in 2019 to 0.516 in 2022. Concurrently, the CDI of digital economy also demonstrated a significant growth, underscoring the close relationship between regional innovation and digital economy. Conversely, the CDI of talent employment exhibited the slowest growth among the three systems. Since 2020, the CDI of talent employment has been surpassed by the CDI of digital economy, becoming the least advanced in the three systems. On an individual city basis, the CDI across the four cities varied within each system. As depicted in Figure 4, the CDI of digital economy in Hangzhou City significantly outperformed that in Shaoxing,

Huzhou, and Jiaxing cities.

The CDI of digital economy showed that, compared with the other cities, Hangzhou City had a significant advantage in digital economy. The development of Hangzhou City began in 2019, and by 2022, it had achieved near-perfect coordination, with a CDI value equaling 0.999, far surpassing the other cities. This demonstrates that digital economy has become a key comparative advantage industry in Hangzhou City. Alibaba and other leading internet companies have emerged as key players, shaping the commerce landscape in Hangzhou City. Industries, such as e-commerce, cultural and creative sectors, financial services, software development, and digital economy, are increasingly driving the innovation and development within the urban framework of Hangzhou City. While the digital economy of Jiaxing and Shaoxing cities has grown steadily, it was still lagging behind. Among the four cities, Huzhou City exhibited the lowest level of digital economy. The analysis reveals that the Hangzhou Metropolitan Circle's digital economy elements varied across the cities, leading to unequal levels of development within the region's digital economy sector.

The CDI of regional innovation exhibited the most significant overall growth and the least regional disparity among the three systems (Fig. 5). Hangzhou City maintained its leading position over the other three cities, particularly notable since 2020. During 2015–2022, Hangzhou City has accelerated operations in Hangzhou Independent Innovation Demonstration Zone. The synergistic effect of overlapping free trade and innovation policies has enhanced the regional innovation advantage of Hangzhou City. Moreover, various innovative digital economy spaces, such as Dream Town, Yunqi Town, and Hangzhou Science and Technology Park that amalgamate industrial, cultural, and community functions, have become vital platforms for project, talent, and capital aggregation, bolstering regional innovation in the Hangzhou Metropolitan Circle. By 2022, the CDI of regional innovation in Jiaxing City was only second to that in Hangzhou City, with a score of 0.630. The gap between Hangzhou City and Jiaxing City was gradually narrowing. Shaoxing City witnessed significant growth from 2018 to 2020, and then the CDI of innovation system began to fall.
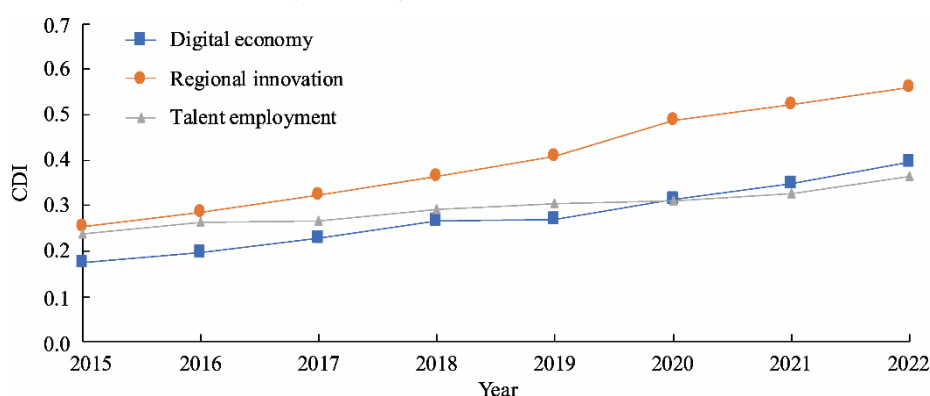

Fig. 3. Comprehensive development index (CDI) of digital economy, regional innovation, and talent employment systems in the Hangzhou Metropolitan Circle from 2015 to 2022.
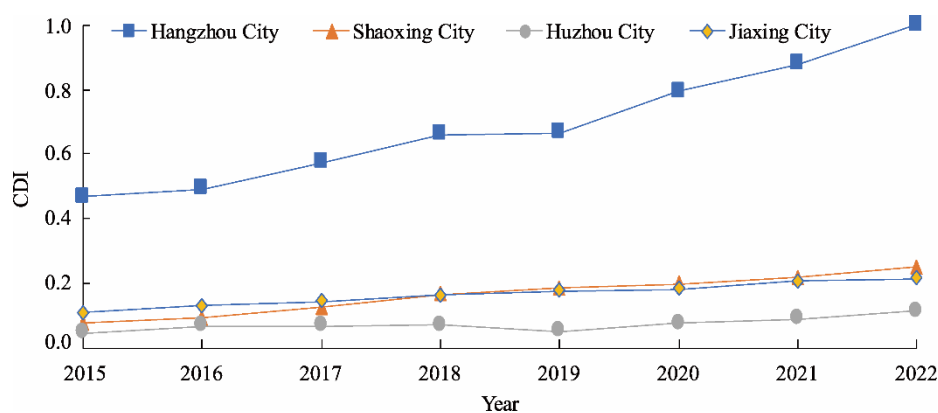

Fig. 4. CDI of digital economy in Hangzhou, Shaoxing, Huzhou, and Jiaxing cities from 2015 to 2022.
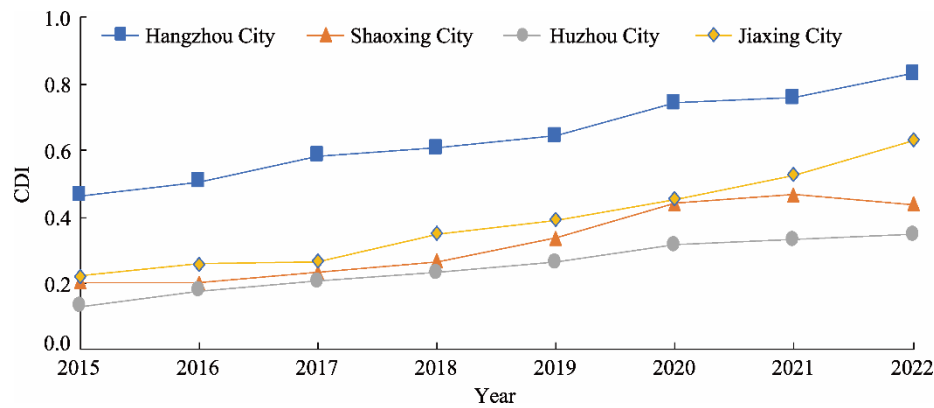
Fig. 5. CDI of regional innovation in Hangzhou, Shaoxing, Huzhou, and Jiaxing cities from 2015 to 2022.

The development of talent employment has been gradual, with the CDI remaining essentially stagnant from 2015 to 2019 (Fig. 6). Regional disparities within this system were particularly apparent among these cities. In 2022, the CDI of talent employment in Hangzhou City reached 0.944, significantly surpassing the others, while the CDI of Shaoxing, Jiaxing, and Huzhou cities lagged behind 0.200, markedly dragging down the overall system's development level. In 2022, there were 218,000 employees in the digital economy industry in Hangzhou City, accounting for 76.9% of the total number of employees in the Hangzhou Metropolitan Circle. Hangzhou National High-tech Zone and Future Science and Technology City serve as major bases for digital economy talents, attracting high-tech talents from both home and abroad. Although Shaoxing and Hangzhou cities are geographically proximity, Shaoxing City was relatively backward in the digital economy industry employment compared with the average level of the Hangzhou Metropolitan Circle, posing a challenge to the overall digital economy integration in the metropolitan circle.
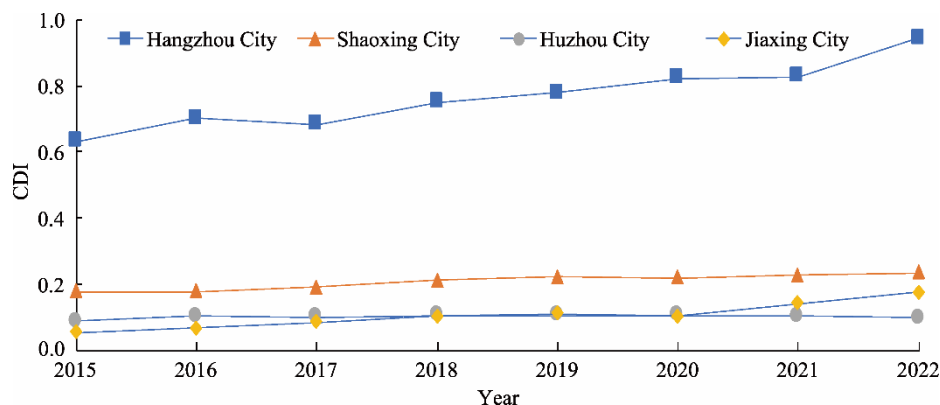

Fig. 6. CDI of talent employment in Hangzhou, Shaoxing, Huzhou, and Jiaxing cities from 2015 to 2022.

4.2. Coupling coordination degree of digital economy, regional innovation, and talent employment

Using the CCDM, we calculated the coupling degree and coupling coordination degree of digital economy, regional innovation, and talent employment in Hangzhou, Shaoxing, Jiaxing, and Huzhou cities as well as in the Hangzhou Metropolitan Circle from 2015 to 2022 (Table 2).

Through the construction of CCDM among the three systems, we observed a steady upward trend in the coupling coordination degree of digital economy, regional innovation, and talent employment in the Hangzhou Metropolitan Circle from 2015 to 2022. The level of coupled coordinative development remained relatively flat, and the coupling coordination degree reached a peak in 2022. However, among individual cities in the Hangzhou Metropolitan Circle, only Hangzhou City has achieved benign coordination coupling since 2020, with other cities remaining in low or moderate coupled coordinative development. According to the results shown in Table 2, we classified the coupling coordination degree into three types based on the varying development levels of digital economy, regional innovation, and talent employment: the "digital economy lag" type, when the CDI of digital economy lags behind

that of regional innovation and talent employment; the "regional innovation lag" type, when the CDI of regional innovation lags behind that of digital economy and talent employment; and the "talent employment lag" type, when the CDI of talent employment lags behind that of digital economy and regional innovation. Based on this, we analyzed the development trend of digital economy, regional innovation, and talent employment in the Hangzhou Metropolitan Circle from 2015 to 2022 (Table 3). Specifically, the coupling coordination type in the Hangzhou Metropolitan Circle belonged to the "digital economy lag" type during 2015–2019, and it was the "talent employment lag" type during 2020–2022.

Table 2
Coupling degree (C) and coupling coordination degree (D) in the Hangzhou Metropolitan Circle during 2015–2022.

	Index	2015	2016	2017	2018	2019	2020	2021	2022
Hangzhou Metropolitan Circle	C	0.329	0.329	0.330	0.331	0.328	0.326	0.326	0.327
	D	0.271	0.286	0.300	0.319	0.328	0.348	0.360	0.379
Hangzhou City	C	0.330	0.329	0.332	0.332	0.332	0.333	0.333	0.332
	D	0.414	0.432	0.452	0.473	0.481	0.512	0.523	0.554
Shaoxing City	C	0.306	0.317	0.324	0.328	0.323	0.312	0.312	0.312
	D	0.217	0.224	0.243	0.265	0.283	0.299	0.308	0.314
Jiaxing City	C	0.284	0.288	0.300	0.294	0.291	0.276	0.285	0.282
	D	0.191	0.209	0.223	0.245	0.257	0.260	0.288	0.309
Huzhou City	C	0.308	0.309	0.300	0.295	0.270	0.275	0.279	0.282
	D	0.166	0.190	0.194	0.201	0.195	0.214	0.221	0.230

Table 3
Coupling coordination types of digital economy, regional innovation, and talent employment in the Hangzhou Metropolitan Circle during 2015–2022.

Year	Coupling coordination type	Year	Coupling coordination type
2015	"Digital economy lag" type	2019	"Digital economy lag" type
2016	"Digital economy lag" type	2020	"Talent employment lag" type
2017	"Digital economy lag" type	2021	"Talent employment lag" type
2018	"Digital economy lag" type	2022	"Talent employment lag" type

5. Discussion

Although the Hangzhou Metropolitan Circle's innovation-oriented growth model has contributed to its digital economy, regional innovation, and talent employment, there remain disparities and inconsistencies among the three systems.

Firstly, urban development in the Hangzhou Metropolitan Circle exhibits imbalances. Results show that, among the three systems, regional innovation consistently maintained a leading position, driving the comprehensive development of the Hangzhou Metropolitan Circle, while digital economy and talent employment showed lagged development at various stages. The lagged development of talent employment can be explained by siphonic effect from the Shanghai Metropolitan Circle, which exerts a strong pull on talent, information, funds, and other elements. Inadequate power within the Hangzhou Metropolitan Circle may lead to an unstable industrial spatial pattern, weakening the gathering effect and facilitating the outflow of talents and capitals to the Shanghai Metropolitan Circle (Pang et al., 2019). Digital economy, talent, and innovation resources in the Hangzhou Metropolitan Circle are featured by unbalanced and incongruent development, supported by the study of Wu and Xu (2024), which reveals uneven industrial distribution in the Hangzhou Metropolitan Circle, with digital economy-related industries primarily concentrated in Hangzhou City. Furthermore, the Hangzhou Metropolitan Circle lacks planning and coordination mechanisms, hindering resources sharing and synergy among cities. This imbalance and incongruence may weaken the influence and correlation between cities in the Hangzhou Metropolitan Circle and necessitate

improvement and adjustment through various means. Tong and Cao (2019) also corroborated these findings that most cities in the Yangtze River Delta urban agglomeration experienced moderate coupling disorder and mild coupling disorder stages, with only Shanghai and Hangzhou cities achieving reluctant coupling and coordination.

Secondly, the radiation effect of high-quality resources remains subdued as resource sharing within the Hangzhou Metropolitan Circle is weak. From 2015 to 2021, the coupling coordination degree in Hangzhou City steadily increased, reaching the superior balanced stage in 2022. However, Shaoxing and Jiaxing cities remained at low coupling stage before 2020, only achieving moderate coordination coupling around 2021. From 2015 to 2022, Huzhou City has lingered in a stage of low coordination coupling, indicating that the three systems of Huzhou City are uncoordinated and unstable. Compared to the other three cities, Huzhou City has fewer colleges, universities, and graduates, exacerbating the instability of its talent system. This suggests that high-quality resources in the Hangzhou Metropolitan Circle are inadequately distributed to Huzhou City. Therefore, Huzhou City faces challenges in attracting high-end talent and other elements, and experiences slow development in high-tech industries. This is supported by Zhao and Han (2019) as well as Guo and Tao (2022). They found that the key factor in introducing high-quality education resources is the integration of universities with regional industry and economic development, forming a good innovation system, enabling enterprises to innovate more effectively, making regional economy more dynamic, and promoting coordinative development of education, technology, economy, and society. Additionally, the geographical constraint that e-commerce industry talents are primarily concentrated in Hangzhou City hinders the development of digital economy-related industries in Jiaxing, Huzhou, and Shaoxing cities. Tong and Cao (2019) pointed out that, as a core city, Hangzhou City should leverage its educational and talent resources to provide industrial support and technology transfer to the surrounding areas, which is an important strategy for the development of the Yangtze River Delta urban agglomeration. Therefore, it is necessary to address how to improve the distribution of high-quality resources from the core city to the surrounding areas.

Thirdly, relevant departments should accelerate the coupling coordinated development of digital economy, regional innovation, and talent employment, and promote the overall development of the Hangzhou Metropolitan Circle. The overall level of coupling coordinated development in the Hangzhou Metropolitan Circle is relatively flat, rising from 0.271 in 2015 to 0.379 in 2022. From the perspective of four cities, only Hangzhou City has achieved benign coordination coupling in 2020, while most cities remaining in low or moderate coordination coupling stages. In recent years, Hangzhou City has vigorously fostered innovative entities and attracted innovative elements by establishing an "Internet+" innovation and entrepreneurship center with global influence. According to the study of Zhu (2020), influential talent development spaces in the Hangzhou Metropolitan Circle include high-tech industrial parks, maker spaces, incubators, pioneer parks, feature towns, etc. Zhu and Chen (2022) as well as Chen and Sun (2022) found that the significance of leveraging these spaces in the coupling coordinated development of the metropolitan area for regional integration cannot be overstated. Geng et al. (2020) believed that feature towns are interconnected with the city's core circle through efficient digital and transportation networks, establishing an industrial collaborative innovation system around the city's core circle, creating ample opportunities for young people, and offering an ideal business environment for entrepreneurs. Feature towns play a crucial role in shaping the spatial model of "big city and small town" within the metropolitan network by fostering a conducive industrial ecosystem, attracting new formats, modes, and talents, and stimulating the development of characteristic industries and the regional innovation system through collaborative innovation (Wu and Xu, 2024).

6. Policy implications

First of all, the cooperation between Hangzhou City and surrounding cities in the Hangzhou Metropolitan Circle should be strengthened, forming a good situation of coupling coordinated development in shaping the spatial model of "big city and small town". An effective strategy would involve establishing an industrial collaboration network within the Hangzhou Metropolitan Circle. This initiative aims to strengthen the development of an industry collaboration platform within the Hangzhou Metropolitan Circle, resulting in the creation of industrial service platforms that promote regional cooperation and resources sharing. The network's major cities have implemented the principle of "mutual benefit, win-win, and common development", enhanced the exchange of scientific and technological resources, and achieved significant progress in centralizing regional collaboration. Secondly, the Hangzhou Metropolitan Circle should facilitate the exchange of talents within the region and establish a framework for talent development. Collaboration among governments, universities, and enterprises is crucial in fostering the

growth of advanced research institutions, such as the Westlake University and the Alibaba e-commerce high-tech research and development center. This collaboration will also expedite the progress of cutting-edge disciplines and sectors, such as digital economy and information technology. Further initiatives should prioritize the enhancement of local workforce development in information technology fields, such as computers, communications, software, and e-commerce. This can be achieved by implementing a system for the mutual selection and recognition of academic credits among college students in the metropolitan areas. Additionally, promoting the sharing of high-quality education resources across the Hangzhou Metropolitan Circle and reinforcing talent exchange programmes would also be beneficial. Finally, the development of a new regional innovation space and industrial growth platform, as well as the construction of a high-level, multi-level, three-dimensional invention gathering place should be prioritized. It is imperative to prioritize the role of a regional innovation platform in the Hangzhou Metropolitan Circle, such as maker spaces, incubators, pioneer parks, feature towns, etc. In particular, the potential of feature towns should be better explored to establish a diverse and inclusive innovation platform (Dong et al., 2021). This will enable the development of feature towns into optimal hubs for employment, social interaction, and entrepreneurial activities for young individuals and promote the sustainable development of the Hangzhou Metropolitan Circle.

7. Conclusions

The Hangzhou Metropolitan Circle, characterized by high economic development, warrants a study of the interactive relationship among digital economy, regional innovation, and talent development. We constructed a CCDM and employed multidimensional indicators to conduct an empirical study on digital economy, regional innovation, and talent employment in the Hangzhou Metropolitan Circle from 2015 to 2022. The results indicate that the development of the Hangzhou Metropolitan Circle has progressed from unbalanced to balanced stage, with relatively smooth development. This study evaluated the level of coordinative development among digital economy, regional innovation, and talent employment in the Hangzhou Metropolitan Circle, with the objective of establishing a coordination mechanism for the comprehensive development of the metropolitan area, thereby achieving optimal allocation and sustainable development of the Hangzhou Metropolitan Circle. There are three main highlights of this study. First, a comprehensive evaluating index system was established with 6 subsystems and 24 indicators for evaluating digital economy, regional innovation, and talent employment. Second, we employed the CCDM to measure the coupling coordination degree among the three systems in the Hangzhou Metropolitan Circle. Third, these findings will be useful to establish a coordination guarantee mechanism and to promote the sustainable development of the metropolitan area.

From the perspective of policy implication, the Hangzhou Metropolitan Circle needs to establish the industrial advantages and characteristics of the closely related and linked regions (including counties, cities, and districts). We recommend strengthening the coordinative development of small and medium-sized cities on the edge of metropolitan circle. It should take digital economy as the leading project, encourage greater talent flows, and improve the competitiveness of neighboring cities through industrial layout and talent cultivation in digital economy. This will promote the coordinative development of industries in the Hangzhou Metropolitan Circle. This study covered four cities in the Hangzhou Metropolitan Circle during 2015–2022 and the data sample is limited. In the further research, this study would expand the samples by adding other neighboring metropolitan circles for a comparison purpose.

Authorship contribution statement

QIU Luyi: data curation, formal analysis, methodology, and writing - original draft; Sharina OSMAN: resources, supervision, and writing- review & editing; and HUA Yidi: data curation and data analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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