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Research on the Relationship between Dynamic Evaluation of Digital Economy and Regional Income Based on Entropy Method

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Abstract: *To explore the dynamic composition in the development process of the digital economy and the correlation effect between the digital economy and regional income, this paper combs the connotation of the digital economy and defines its nature, builds an index system for developing digital economy dynamic, and measures the development of digital economy in Zhejiang Province, the innovation highland of China's digital economy from 2003 to 2017, by using entropy method, relative grey relation analysis, and bivariate correlation analysis. The research results show that there is a significant agglomeration effect in the digital economy dynamic in Zhejiang Province from 2003 to 2017, and a significant head effect in the number of mobile Internet users, weighted number of patents per 10,000 persons, the amount of online payment per capita and the number of subscribers accessing the fixed Internet broadband and other indexes. Moreover, there is a strong linkage effect between the dynamic index of digital economy development and regional income, and the amplification, superposition, and multiplication effects of the digital economy on economic development are gradually emerging, which has long played a role in guiding the sustainable growth of regional income. Also, the dynamic index of digital economy development presents the trend of collaborative development and differentiation among the sub-dimensions and between the sub-dimensions and the regional income.*

Keywords: *digital economy, growth dynamic, regional income, entropy, Zhejiang*

1. Introduction

As an increasingly important emerging phenomenon, the digital economy is multiplying (WEF, 2015) [1]. It has become a leading force driving global economic and social development and technological innovation, especially in developing countries. Although the average digital level of China's economy is still lower than that of developed economies, considerable achievements have been made in the digital development of some regions and sectors, especially e-commerce and financial technology (Miao, 2021)[2]. The digital economy refers to a broad range of economic activities that include using digitized information and knowledge as the key factor of production, modern information networks as a vital activity space, and the effective use of information and communication technology (ICT) as an essential driver of productivity growth and economic structural optimization (G20, 2016) [3]. Human society is entering a new historical stage with digital productivity as the primary mark. In China's coastal areas, the rapid growth of digitalization has boosted the growth of productivity, and has, in varying degrees, affected the industrial development and employment of various sectors. The integration of the digital economy and the traditional economy is not only the basic fact at the current stage, but also represents the future trend of economic development (Jing et al. 2019) [4]. Changes in the economic structure are resulting in a complex and diverse pattern of regional growth behavior. At the same time, digitalization will continue to drive the development of the industry by improving production efficiency, ease the declining trend of potential growth as the economy matures (which is irreversible), as well as give impetus to the reconstruction of the development dynamic of China's economy (Miao, 2021) [2].

2. Literature review

With the rapid development of the information and communication technology (ICT) division, the

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connotation of the digital economy has been constantly enriched and improved with the progress of basic technology (Chen & Miao, 2019)[5]. A group of new technologies continues to emerge, ranging from the computer in the 1960s, the Internet in the 1990s, and the recent industrial robot technology (OECD, 2017) [6], artificial intelligence, and blockchain technology. Moreover, due to the explosive growth of new technologies and the rapid application of new technologies at all levels, some new sectors have been derived, such as financial technology, driverless operation, and blockchain finance. At present, the concept of the digital economy can be defined from narrow and broad perspectives. In a narrow sense, it only refers to the ICT divisions, including telecommunications, Internet, IT services, hardware, and software. In a broad sense, it includes not only the ICT divisions but also the traditional sector, which is integrated with digital technology (Bukht et al. 2017) [7]. At the G20 Hangzhou Summit in 2016, this broad concept was applied, and the digital economy was defined as a broad range of economic activities that include using digitized information and knowledge as the key factor of production, modern information networks as an important activity space (G20, 2016)[3]. Bukht et al. (2017) believed that the core of the digital economy is the digital department, which refers to the IT / ICT division that manufactures basic digital products and services[7].

Erik and Kahin (2000) research pointed out that the essence of digital economy activities is "commodities and services are traded in digital form, which is a special economic form[8]. Carlsson (2004) called the digital economy a " new economy "and emphasized Higher productivity[9]; the digital economy pays more attention to new products and new activities. The Australian Government (2009) believes that the digital economy is a global network of economic and social activities formed by ICT technology[10]. Nathan et al. (2013) believe that the digital economy refers to one behalf of a group of departments, a group of outputs (products and services), and a group of inputs (production and distribution tools based on ICT technology)[11]. The key resource of the digital economy is information (Turcan et al. 2014)[12], Kotarba (2017) pointed out that the digital economy is an economic system that widely uses ICT technologies, including technical facilities, e-commerce, and electronic transactions[13]. Compared with the digitized economic activities carried out in the economic sector with the help of information and communication technology, it is believed in this paper that the digital economy is composed of data as the production index. Moreover, part or all of the output of the economic sector comes from a series of economic activities of digital technology, digital network, digital service, or digital business model.

The digital economy is changing the traditional concept of economic growth (Watanabe et al. 2018)[14]. The digital economy is a new economic form after various traditional forms of economy, such as the agricultural economy and industrial economy (Pei et al. 2018)[15]. To achieve sustained growth, the digital economy is driven by economic and political factors, which are also rooted in broader forces such as technological innovation (WEF, 2015)[1]. The rapidly growing technological innovations have endowed the individuals and organizations a range of digital capabilities so that they can take purposeful and potential actions on the digital system in their surroundings. Heeks (2017) pointed out that such actions were embodied in data-oriented development (the expansion of the phenomenon of holding data)[16], digitization (the conversion of all parts of the information value chain from analog to digital), virtualization (the physical embedding of the process) and generativity (the approach that the use and technology of data are not planned at the beginning of the plan through reprogramming and reorganization). The impact of technological innovation can be understood as the product of the scale of its diffusion and the depth of its impact (Handel, 2015)[17], and it has a positive impact on regional economic growth (Han, 2014)[18]. Such impact is not only the destruction of existing economic processes, systems and departments but also the reconstruction of existing consumer behavior, business interaction and business model (Dahlman et al. 2016)[19], which means the emergence of new economic forms, new economic processes, new economic systems, and sectors. As the digital economy develops rapidly, the relative difference of the information gap between regions is gradually decreasing (Sun et al. 2019)[20], while the regional income also shows the trend of the relative difference coefficient decreasing first and then increasing. The absolute difference has been gradually increasing. Moreover, as the spatial location changes, there will be an even larger disparity between the East, the middle, and the West.

At present, the research on digital economy mainly focuses on the spatial differentiation and influencing factors of the digital economy (Wang et al. 2018)[21], the research on ant effect and group behavior of digital economy (Xu & Liang, 2017)[22], the impact of the digital economy on social work and corporate production (Ahmad et al. 2018)[23], as well as the research on the digital economy, inclusive finance and inclusive growth, the analysis of the theoretical framework of the digital economy and high-quality economic growth (Jing et al. 2019)[4], and the evaluation system and application fields of the digital economy. However, there are few studies on the dynamic composition

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of digital economy growth and the spatial linkage effect between the dynamic development stage and regional income. The main purpose of this study is to find a proper way to build a set of evaluation index system for the dominant types of digital economy dynamic from the perspective of prefecture-level cities (Chen & Miao, 2019)[5], and analyze the combination types of its dominant force and the distribution of its spatial types, find out the dominant power and the power to be optimized in different regions, and reveal the linkage effect between the dynamic composition of the digital economy and regional income of the cities.

3. Research ideas

3.1 Construction of the evaluation index system

At present, there is a limited range of indexes on digital economy evaluation, but there are also some differences between them (Bukht et al. 2017)[7]. The existing digital economy evaluation system is mainly comprised of the Networked Readiness Index Transformations 2.0 proposed in the Global Information Technology Report 2010 -2011 of the World Economic Forum, the Digital Economy and Society Index proposed by the EU (DESI, 2018)[24], the suggestions of the Commerce Department of the United States on measuring the digital economy, the suggestions of the Organization for Economic Cooperation and Development on the indexes for measuring the digital economy (OECD,2017)[6] Based on the construction and comprehensive measurement of the evaluation index system of the digital economy, there are some differences in the selection of indexes in different research samples or the same samples at different periods. To scientifically and effectively reveal the development status of the research object and implement the long-term observation and evaluation of the growth of the digital economy, the principles of scientific and comparability, systematization and hierarchy, pertinence and operability should be followed in the construction of the evaluation index system in this study. The data that cannot be counted or has just been included in the statistical system should not be incorporated into the evaluation index system in this study. Instead, the continuous statistical data related to the digital economy that is mutually exclusive at multiple levels should be used as much as possible.

The driving force of economic growth can be analyzed from multiple perspectives. And it takes most economies a long time to develop their economic situation in a very tortuous process (Zhao et al. 2015)[25], and the composition and importance of its development momentum are also changing with the changes of the economic development stage. Solow(1956) pointed out that the driving force of economic growth lies in the accumulation of capital[26], the increase of labor force, and the improvement of production efficiency to drive the expansion of production capacity. Shumpeter(1983) proposed that innovation is the perpetual motive of capitalism[27], and he believed that its development motive force not only exists for a long time but also exists in a dynamically changing form in the development process. Han(2014) analyzed the regional economy in Korea and pointed out that innovation dynamics, industry-based dynamics[18], and social-economic power play an important role in promoting the growth of the regional economy. Dellink et al. (2017) believed that population, total factor productivity[28], physical capital, employment, and human capital, as well as energy and fossil fuel resources (especially oil and gas), were the main driving forces in the long cycle of economic growth. At the same time, as the new driving force of regional economic growth, the allocation efficiency and agglomeration pattern of indexes can not only promote regional economic growth but also give an impetus to the adjustment and optimization of economic structure.

As a new form of economy, the digital economy also abides by the corresponding law in the process of growth. It was pointed out by OECD (2017) that innovation is still the main driving force of ICT industry[6], that the growth of investment in information infrastructure can boost the development of the digital economy market, and that in many countries, digital economy growth is promoted by a regulatory framework that adapts to competition, innovation, and investment. Miao(2021)[2] pointed out that in the development evaluation system of the digital economy in China, the types of dynamic indexes cover a wide range of indexes, such as information and communication infrastructure, ICT application (primary and advanced), digital development of enterprises and the development of ICT industry.

Combined with the definition of the connotation of the digital economy in the previous text, and based on the data availability of provincial-level research units, this paper selects relevant indexes from five aspects to build the index system of dynamic evaluation of digital economy (Table 1). The index system of dynamic evaluation of the digital economy consists of five first-level dynamic indexes and fifteen second-level dynamic indexes. Among the indexes, the first-level indexes are digital consumer

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dynamic index, digital industry dynamic index, information-based dynamic index, digital application dynamic index, and digital innovation dynamic index. The fifteen second-level dynamic indexes are amount of online shopping per capita (replaced by per capita retail spending on consumer goods) (OECD 2017)[6], resident consumption level per capita(DESI 2018)[24], amount of online payment per capita(replace with per capita postal and telecommunication expenses) (DESI 2018[24]), proportion of output value of the tertiary industry to GDP(Kang, 2008)[29], degree of fiscal self-financing(Kang, 2008[29]; Han 2014[18]), length of long-distance optical cable per 10,000 persons(DESI, 2018)[24], capacity of local telephone switchboard(OECD 2017[6]), number of mobile telephone switchboard(Sun et al. 2019[20]; OECD 2017[6]), number of mobile phones(Sun et al. 2019[20]), number of mobile Internet users(Wang et al. 2018) [21], number of subscribers accessing the fixed Internet broadband, popularity rate of mobile phones, proportion of employment in the information software technology services(Sun et al. 2019[20]; OECD 2017[6]), proportion of college students per 10,000 persons(Han 2014[18]; OECD 2017[6]), R & D investment (Peng, 2019)[30] and number of patents per 10,000 persons(DESI 2018)[24].

Table 1: Evaluation index system of development digital economy dynamic and the sources of indexes

Index category	Index	Unit
Digital consumer dynamic index	X1 Amount of online shopping per capita	(Yuan)
	X2 Resident consumption level per capita	(Yuan)
	X3 Amount of online payment per capita	(Yuan)
Digital industry dynamic index	X4 Proportion of output value of the tertiary industry to GDP	(%)
	X5 Degree of fiscal self-financing	(%)
Information-based dynamic index	X6 Length of long-distance optical cable per 10,000 persons	(km)
	X7 Capacity of local telephone switchboard	(10,000)
	X8 Number of mobile telephone switchboard	(10,000 households)
Digital application dynamic index	X9 number of mobile phones	(10,000 households)
	X10 Number of mobile Internet users	(10,000 households)
	X11 Number of subscribers accessing the fixed Internet broadband	(10,000 households)
	X12 Popularity rate of mobile phones	(phone per 100 persons)
Digital innovation dynamic index	X13 Proportion of employment in the information software technology services	(%)
	X14 Proportion of college students per 10,000 persons	(%)
	X15 R & D investment per capita	(Yuan)
	X16 Weighted number of patents per 10,000 persons	(Item)

3.2 Date sources

In 2018, the total output value of the digital economy in Zhejiang Province was 2.33 trillion Yuan, ranking fourth in China, and the output value of the digital economy in broad sense accounted for 41.45% of China's GDP. In Zhejiang Province, the development highland of the digital economy in China, the digital economy is regarded as the No.1 Project. The four news, new technology, new business form, new product, and a new mode, are taken as the development ideas of the digital economy. The government is sparing no effort to advance the digital transformation of the government. Moreover, in Zhejiang Province, the relevant departments take the lead in promoting the local legislation of the digital economy shortly, which makes it conducive to developing a digital economy. The data needed in this paper are mainly from the Statistical Yearbook of Zhejiang and Zhejiang Information Almanac from 2003 to 2017. At the same time, supported by the hypsometric setting method in GIS, a geospatial database of dynamic indexes of the digital economy in Zhejiang Province was constructed, to complete the visualization of geospatial data. This paper analyzes the dynamic composition of the digital economy during its development in Zhejiang Province from 2003 to 2017 and its relationship with regional income. In this way, it can not only reveal the role of dynamic indexes in the development process of the digital economy in Zhejiang Province but also find out the composition of main dynamic indexes and the dynamic indexes to be optimized. But it can also provide some experience and guidance for accelerating the regional cooperation of the digital economy in the Yangtze River Delta

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and promoting the construction of the digital Yangtze River Delta and digital China.

3.3 Research methods

3.3.1 Data initialization

There are dimensional and quantitative differences among the dynamic indexes in the evaluation index system of development digital economy dynamic. At the same time, the indexes show a growing trend on the whole. Given this, we can eliminate the dimensional and order of magnitude differences between the data through the initial conversion of statistical data, and transform them into comparable series to meet the subsequent analysis. The method is as follows:

$$X_{ij}^{`} = \frac{X_{ij}}{X_{i1}} \quad \text{i=1, 2, …, 16; j=1, 2, …, 15} \tag{1}$$

In the formula, $X_{ij}^{`}$ represents the numerical value of the index i after its initialization in the year j; X_{ij} represents the original data of the index i in the year j, and X_{i1} represents the original data of the index i in the first year, i.e., the base year of 2003. When we figure out the numerical value of $X_{3,4}^{`}$, the third index in the fourth year (2006) after initialization $X_{3,4}$, the original value of $X_{3,4}$, $X_{3,4}^{`}$, the third index in the fourth year is 970. Its value at the base year $X_{3,1}$ is 729, and then the numerical value of the third index in the fourth year after initialization is represented as the equation: $X_{3,4}^{`} = \frac{X_{3,4}}{X_{3,1}} = \frac{970}{729} = 1.33$.

3.3.2 Entropy method and determination of weights

There is high human interference by using the subjective empowerment method. Then, when the weights of the indexes in the evaluation index system are determined, there is an error in the evaluation result. By objectively evaluating the relative importance of each index, entropy method can avoid the interference of subjective human factors, so that it has been extensively applied in economic and social domains and other domains. In this paper, with the help of the entropy method, the weight of each index is determined. The empowerment operations are as follows:

The first step is to calculate the information entropy of each index after initialization according to the formulas (2) and (3).

$$P_{ij} = \frac{X_{ij}^{`}}{\sum_{j=1}^{n} X_{ij}^{`}}, \quad \text{n=15 (} n \text{ is the year)} \tag{2}$$

$$e_i = -k\sum_{i=1}^{n} p_{ij} In(p_{ij}) \text{ , i=1, 2, …, 16} \tag{3}$$

$$k = \frac{1}{In(n)} = \frac{1}{In(15)} \approx 0.369$$

In the formula, P_{ij} represents the proportion of the value of the index i in the year j to the total value of the index, also known as the contribution degree; e_i represents the information entropy of the index i.

The second step is to calculate the corresponding weight of each index according to formula (4).

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$$w_i = \frac{d_i}{\sum_{i=1}^{m} d_i}, \text{ i=1, 2, …, 16; m=16, representing the number of indexes} \quad (4)$$

In the formula, w_i represents the entropy weight corresponding to the index i, and d_i represents the redundancy of information entropy (coefficient of variation), $d_i = 1 - e_i$.

3.3.3 Grey relation analysis method

Due to the short statistical life and weak continuity of evaluation indexes of the development of digital economy and regional income data, the difference in calculation methods may lead to more substantial errors. To solve this problem, we introduce the relative grey relation analysis method to verify the relevance between the dynamic index of regional development of the digital economy and regional income index. The calculation formulas are as the following formulas (5), (6), (7), and (8):

$$\gamma_{0i} = \frac{1 + \left|s_0^{'}\right| + \left|s_i^{'}\right|}{1 + \left|s_0^{'}\right| + \left|s_i^{'}\right| + \left|s_1^{'} - s_0^{'}\right|} \quad (5)$$

$$\left|s_0^{'}\right| = \left|\sum_{k=2}^{n-1} x_0^{0'}(k) + \frac{1}{2} x_0^{0'}(n)\right| \quad (6)$$

$$\left|s_i^{'}\right| = \left|\sum_{k=2}^{n-1} x_i^{0'}(k) + \frac{1}{2} x_i^{0'}(n)\right| \quad (7)$$

$$\left|s_i^{'} - s_0^{'}\right| = \left|\sum_{k=2}^{n-1} (x_i^{0'}(k) - x_0^{0'}(k)) + \frac{1}{2}(x_i^{0'}(n) - x_0^{0'}(n))\right| \quad (8)$$

In the formula, γ_{0i} represents the relative grey relation index, $s_0^{'}$ represents the initial value of the reference sequence, $s_i^{'}$ represents the initial value of the comparison sequence. $x_0^{0'}$ represents the zero-out of the starting point of the reference sequence, $x_i^{0'}$ represents the zero-out of the starting point of the comparison sequence, $x_i^{0'}(n)$ represents the zero-out of the starting point of the initial value $x_i(n)$. The value range γ_{0i} is greater than 0 but no more than 1. The larger the value is, the stronger the data association will be.

4. Analysis results

4.1 Measurement of digital economy dynamic in Zhejiang Province

As can be seen from Table 2, according to the initial value and entropy value of the dynamic index of digital economy development in Zhejiang Province from 2003 to 2017, the corresponding weights of three indexes, namely X10, X16, and X3, are in the top three, and the sum of their weights is 0.42. The higher entropy weight is, the more practical information the corresponding index contains. According to this law, the higher the entropy weight of an index is, the more significant impact the index will have on the development of the digital economy.

As a result, it can be inferred from Table 2 that, from 2003 to 2017, the three indexes, number of mobile Internet users, weighted number of patents per 10,000 persons and the amount of online payment per capita (i.e., per capita postal and telecommunication expenses) developed rapidly, playing an increasingly important role in the development of the digital economy. Secondly, the weights of the indexes, including number of subscribers accessing the fixed Internet broadband, R & D investment per

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capita, amount of online shopping per capita, popularity rate of mobile phones, the capacity of the local telephone switchboard, number of the mobile telephone switchboard, number of mobile phones and proportion of employment in the information software technology services, were between 0.03 and 0.1. The weights of the indexes, including the proportion of college students per 10,000 persons, the proportion of output value of the tertiary industry to GDP, length of long-distance optical cable line, and degree of fiscal self-financing, were all lower than 0.01. The sum of the four indexes was only 0.0154, and its contribution to the development of the digital economy is relatively small.

Table 2 : Initial values and entropy values of dynamic indexes of digital economy development in Zhejiang Province from 2003 to 2017

Index	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Entropy
X1	1	1.14	1.29	1.46	1.68	2.00	2.27	2.64	3.17	3.59	4.02	4.48	4.94	5.44	5.94	0.0677
X2	1	1.16	1.36	1.58	1.81	2.03	2.26	2.60	3.04	3.25	3.52	3.82	4.08	4.37	4.81	0.0454
X3	1	1.11	1.19	1.33	1.52	1.63	1.67	0.13	0.14	0.16	2.52	2.73	2.97	3.46	3.77	0.1213
X4	1	0.98	1.00	1.00	1.01	1.02	1.08	1.10	1.11	1.15	1.18	1.19	1.24	1.27	1.33	0.0032
X5	1	1.08	1.07	1.12	1.16	1.11	1.02	1.03	1.04	1.05	1.02	1.01	0.92	0.96	0.98	0.0017
X6	1	1.22	1.31	1.33	1.32	1.22	1.16	1.12	1.15	1.20	1.23	1.23	1.25	1.13	1.29	0.0021
X7	1	1.97	2.01	2.32	2.44	2.40	2.34	2.30	2.24	2.10	1.96	1.33	0.85	0.38	0.21	0.0562
X8	1	2.46	2.93	3.43	4.82	6.46	6.51	7.08	7.85	7.91	8.83	9.10	9.33	9.56	10.02	0.053
X9	1	3.44	3.98	4.46	5.23	5.89	6.57	7.48	8.53	9.55	10.48	10.92	11.06	10.70	11.24	0.0515
X10	1	1.22	1.63	2.03	2.41	2.84	3.15	14.03	17.47	20.80	16.67	17.90	19.19	22.49	26.35	0.1758
X11	1	1.82	2.68	3.60	4.46	5.49	6.52	6.89	8.10	9.15	9.87	10.13	10.44	17.14	19.56	0.1001
X12	1	1.16	1.30	1.43	1.65	1.84	2.02	0.87	0.84	0.81	3.04	3.18	3.21	3.08	3.21	0.0575
X13	1	0.73	0.94	1.03	2.45	2.12	2.13	1.65	1.52	1.37	1.41	1.56	2.01	2.51	3.06	0.0349
X14	1	1.17	1.31	1.42	1.57	1.67	1.73	1.72	1.76	1.81	1.85	1.89	1.91	1.91	1.91	0.0084
X15	1	1.47	2.04	2.76	3.47	4.15	4.73	5.67	7.01	8.25	9.29	10.30	11.41	12.64	13.99	0.0984
X16	1	1.13	1.76	2.28	2.95	3.77	4.79	5.63	7.55	10.70	12.21	10.99	13.08	15.18	14.42	0.1228

According to the initial value of each indicator in Table 2 and the corresponding entropy weight, we can calculate the comprehensive dynamic indexes and the second-level sub-dimension dynamic indexes corresponding to each indicator of digital economy development in Zhejiang Province from 2003 to 2017, based on the formula (9) below:

$$I_j = \frac{\sum X_{ij}^{`} w_i}{\sum w_i}, \text{ i=1, 2, …, 16; j=1, 2, …, 15} \quad (9)$$

In the formula, w_i represents the entropy weight of the index I, and I_j represents the dynamic index of the index i in the year j. The specific data is shown in Table 2. It can be seen from Table 2 that the comprehensive dynamic index for the development of the digital economy achieved an average annual growth rate of 19.6% from 2003 to 2017, while the regional income of Zhejiang Province showed an average annual growth rate of 11.5%. The fastest-growing index is a digital application dynamic index, which had been growing at an average annual rate of 23.45% from 2003 to 2017. Followed by the digital innovation dynamic index, it also maintained an annual average growth rate of 19.67%. It can be seen that the digital application dynamic index and digital innovation dynamic index play an important role in driving the rapid growth of a comprehensive dynamic index and promoting the rapid development of the digital economy. Moreover, it can also confirm the correlation analysis in Table 2. Accordingly, the three indexes of the information-based dynamic index, digital consumer dynamic index, and digital industry dynamic index showed the annual average growth rate of 12.02%, 11.52%, and 1.31%, respectively. The average growth rate of the three indexes was significantly lower than that of the comprehensive dynamic index for the development of the digital economy, playing a weaker role in boosting the development of the digital economy.

4.2 Grey relation analysis of digital economy dynamic and regional income

To verify the relevance between the dynamic indexes of digital economy development and regional income (GDP per capita) in Zhejiang Province, we conducted the relative grey relation analysis on the dynamic indexes of digital economy development and regional income in Zhejiang Province from 2003 to 2017, according to the formulas (5), (6), (7) and (8) and with the help of the modeling software GTMS3.0 of the grey system theory (Liu et al. 2013). As shown in Table 3, we can see from the

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analysis that the numerical value of the grey relational degree γ_{0i} for the regional income and comprehensive dynamic index was 0.672, and the numerical value of the grey relational degree γ_{0i} for the regional income and digital consumer dynamic index was 0.882. The numerical value of the grey relational degree γ_{0i} for the regional income and digital industry dynamic index was 0.536. At the same time, the numerical value of the grey relational degree γ_{0i} for the regional income and information-based dynamic index was 0.768, and that for regional income and digital application dynamic index was 0.612 and that for regional income and digital innovation dynamic index was 0.665.

The analysis results showed that the relational degree γ_{0i} for the regional income and the indexes of the digital economy dynamic satisfied the range of value, presenting more substantial relevance. Among the indexes, the regional income had the strongest relationship with the digital consumer dynamic index, indicating that the increase of income will enhance the digital consumer dynamic index of the people. For every 1 unit increase in people's income, 0.882 units of digital consumer dynamic index will be added. Next, the indexes, from high to low, are information-based dynamic index, comprehensive dynamic index, digital innovation dynamic index, digital application dynamic index, and digital industry dynamic index.

Table 3 : Relative grey relational degree of the dynamic indexes of the digital economy and regional income in Zhejiang Province from 2003 to 2017

Index category	$\left\|s_0^{'}\right\|$	$\left\|s_i^{'}\right\|$	$\left\|s_i^{'}-s_0^{'}\right\|$	γ_{0i}
Comprehensive dynamic index	22.655	66.795	44.140	0.672
Digital consumer dynamic index	22.655	17.210	5.445	0.882
Digital industry dynamic index	22.655	1.180	21.475	0.536
Information-based dynamic index	22.655	42.760	20.105	0.768
Digital application dynamic index	22.655	102.650	79.995	0.612
Digital innovation dynamic index	22.655	69.840	47.185	0.665

4.3 Correlation analysis of digital economy dynamic and regional income

Table 4 : Correlation analysis of the dynamic indexes of the digital economy and regional income in Zhejiang Province from 2003 to 2017

Index category	Mean	Standard deviation	1	2	3	4	5	6	7
Per capita GDP	2.631	1.150	1						
Comprehensive dynamic index	5.829	3.731	.994**	1					
Digital consumer dynamic index	2.267	1.212	.908**	.887**	1				
Digital industry dynamic index	1.086	0.058	.982**	.979**	.914**	1			
Information-based dynamic index	3.981	1.284	.850**	.820**	.650**	.816**	1		
Digital application dynamic index	8.448	6.035	.981**	.994**	.842**	.965**	.804**	1	
Digital innovation dynamic index	6.035	4.008	.993**	.992**	.922**	.975**	.813**	.974**	1

** represents that it has a significant correlation at 0.01 level (two-tailed).

It can be seen from the above that there are linkage effects between digital economic dynamic and regional income (GDP per capita) in varying degrees based on the relative grey relation analysis. To more accurately grasp the linkage effect of the dynamic index of digital economy development in Zhejiang Province and the degree of correlation with regional income, we carried out a correlation analysis with SPSS 23.0 based on the data after initialization. The results are shown in Table 4. According to the results of correlation analysis, there is a high correlation between regional income and its dynamic indexes of digital economy development in Zhejiang Province, as well as within the dynamic indexes of digital economy development. The pair with the highest correlation is the regional income and comprehensive dynamic index, and digital application dynamic index and comprehensive dynamic index, with a correlation of 0.994. However, the relationship between the information-based dynamic index and digital consumer dynamic index is the lowest, at 0.650, and the correlation degrees between other indexes are between 0.804 and 0.994.

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5. Conclusion and discussion

5.1 Conclusion

According to the development of digital economy in Zhejiang Province the data for fifteen consecutive years from 2003 to 2017, this paper constructed a set of the evaluation system and, and analyzed the overall characteristics of the digital economy in Zhejiang Province, as well as the development of sub-dimensions of the dynamic indexes, including comprehensive dynamic index for the development of digital economy, digital consumer dynamic index, digital industry dynamic index, information-based dynamic index, digital application dynamic index and digital innovation dynamic index. On this basis, the regional income variable was introduced, and the relationship between regional income and digital economy dynamic was explored. The differences of dynamic indexes affecting the development of the digital economy in Zhejiang Province were analyzed. In this way, it can provide a feasible plan for promoting the high-quality and rapid development of the digital economy in Zhejiang Province and provide some theoretical support for the development of the digital economy in the construction of the Digital Yangtze River Delta and a wider range. The main conclusions are as follows:

(1) There is a significant agglomeration effect in the dynamic of the digital economy. The results show that in the system of sixteen indexes, the sum of the weights of the four indexes, number of mobile Internet users, weighted number of patents per 10,000 persons, amount of online payment per capita and number of subscribers accessing the fixed Internet broadband was 0.5201, playing an important role in driving the development of the digital economy. However, the proportion of college students per 10,000 persons, the proportion of output value of the tertiary industry to GDP, length of long-distance optical cable line and the degree of fiscal self-financing, have made less than 1% contribution to the development of digital economy, so the role of these dynamic indexes in promoting the development of the digital economy can be almost neglected.

(2) The digital economy has been developing at a fast pace, while there are great differences between the dynamic indexes. The comprehensive dynamic index for the development of the digital economy achieved an average annual growth rate of 19.6%, which was higher than that of the regional income of Zhejiang Province of 11.5%. It indicates that the digital economy in Zhejiang Province has maintained an average annual growth rate of nearly 20% for 15 years from 2003 to 2017. And it also shows a trend of the digital economy guiding the growth of regional income for a long time. Among the indexes, the fastest growing index is a digital application dynamic index, followed by digital innovation dynamic index. It can be seen that the digital application dynamic index and digital innovation dynamic index play an important role in driving the rapid growth of a comprehensive dynamic index and promoting the rapid development of the digital economy. However, the annual growth rate of the three indexes, information-based dynamic index, digital consumer dynamic index, and digital industry dynamic index was significantly lower than that of the comprehensive dynamic index for the development of the digital economy, playing a less significant role in advancing the development of the digital economy.

(3) There is a strong linkage effect between the dynamic indexes of digital economy development and regional income. The results of the relative grey relation analysis show that there is a linkage effect at the level of 0.672 between the comprehensive dynamic index for the development of digital economy and regional income in Zhejiang Province, while the relational degree between the sub-dimensions of the dynamic index of digital economy development and regional income is between 0.536 and 0.882. Regional income has the strongest relevance with the digital consumer dynamic index. Still, the regional income has the poorest relevance with the digital industry dynamic index, indicating that the increase of income will enhance the digital consumer dynamic index of the people. For every 1 unit increase in people's income, 0.882 units of digital consumer dynamic index will be added.

(4) The sub-dimensions of the dynamic indexes of the digital economy develop in coordination and coexist in differentiation. Through the analysis of the linkage effects within the dynamic indexes of the digital economy in Zhejiang Province and the association between the dynamic indexes and regional income, we can find that there is a high correlation among the dynamic indexes of the digital economy in Zhejiang Province and between the regional income and the dynamic index of digital economy development. The pair with the highest correlation is the regional income and comprehensive dynamic index, and digital application dynamic index and comprehensive dynamic index. However, the correlation between the information-based dynamic index and the digital consumer dynamic index is the lowest. Therefore, we can improve the access rate of the people to the mobile Internet, accelerate

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the promotion of fixed Internet broadband access, improve digital application dynamic indexes such as popularity rate of mobile phones, and comprehensive dynamic indexes, which can significantly improve the development of the digital economy. In this way, these indexes and regional income will form a positive growth effect for mutual promotion.

5.2 Discussion

Informatization has brought China a once-in-a-lifetime opportunity for development, and the digital economy, which takes data and information as the main production factors, is proliferating, which promotes the continuous optimization of economic structure, the rapid improvement of industrial efficiency and the reconstruction of economic development momentum. Moreover, it has gradually become the dominant driving force for global economic, social, and technological innovations. Zhejiang Province is the frontier and innovation highland for the development of the digital economy in China. Under the continuous support of the policies of the central and local governments, the regional economy and population and other factors have been gathered in Zhejiang Province and the Yangtze River Delta core area. Then the development advantages of the digital economy in Zhejiang Province will be further strengthened. The results show that there is a significant agglomeration effect in the digital economy dynamic, and a considerable head effect in the indexes, such as the number of mobile Internet users, weighted number of patents per 10,000 persons, amount of online payment per capita and the number of subscribers accessing the fixed Internet broadband. Meanwhile, the comprehensive dynamic index for the development of the digital economy in Zhejiang Province has maintained an average annual growth rate of nearly 20% for 15 years. It means that the digital economy's amplification, superposition, and multiplication effects on economic development are gradually emerging and that the digital economy has long guided the sustained growth of regional income. Also, the dynamic index of digital economy development has a strong linkage effect with the regional income, and the dynamic index of digital economy development shows the trend of collaborative development and differentiation among its sub-dimensions and between the sub-dimensions and regional income.

Looking into the future, we can take the Outline of the Integrated Regional Development of the Yangtze River Delta as the guidance, and enhance the economies of scale and scope with the help of all-round digital economy, and drive the improvement of production efficiency and the rapid and healthy development of the industry. At the same time, we can take a series of measures to promote the overall development of the regional digital economy. Specifically, we can reduce the entry threshold of the mobile Internet and fixed Internet, enhance local scientific research and innovation ability, increase the investment in R&D, and take the initiative to cultivate the digital economy market and encourage consumption. Meanwhile, we can reduce the charge of mobile phones to promote its popularization in a broader range and expand the capacity of local and mobile telephone switchboards to optimize the experience of the use of digital networks. Meanwhile, it is s necessary to promote the deep integration of digital economy industry chain and innovation chain with the digitalized application capability as the orientation, make proper planning and layout of the digital economy industry, increase policy support and personnel training, accelerate the construction of the collaborative innovation platform of the digital economy, and boost the relative balance in the regional development, and advance the formation of digital Yangtze River Delta with complementary advantages and high-quality development. These measures play a vital role in enhancing the position of the Yangtze River Delta and even China in the global value chain of the digital economy.

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