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| RESEARCH ARTICLE

The Impact of the Quality of Digital Economy Development on Manufacturing in the Yangtze River Delta City Cluster

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| ABSTRACT

Yangtze River is the most dynamic, open and innovative region in China, as well as an important region for modernization and comprehensive opening. In this paper, under the strategic background of the integration of the Yangtze River Delta region, this paper systematically studies the transformation and upgrading of digitalization and manufacturing from the perspective of urban agglomeration, establishes a measurement model of the digital economy, constructs a comprehensive evaluation system for the quality of digital economy, and intuitively displays and studies the impact mechanism and realization path of digital economy and manufacturing transformation and upgrading. The objective of the study is to examine whether the development of the digital economy is a driver of regional development. The results of the study revealed that the quality of digital economy development in the Yangtze River Delta urban agglomeration has a positive impact on the transformation and upgrading of the local manufacturing industry.

| KEYWORDS

Yangtze River Delta; urban agglomeration; digital economy; manufacturing

| ARTICLE INFORMATION

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1. Introduction

The regional integration of the Yangtze River Delta region is an important strategic measure to promote national economic development and improve the quality of residents' livelihood and the level of governance in the Yangtze River Delta region. The Outline of the Yangtze River Delta Regional Integrated Development Plan issued by the Central Committee of the Communist Party of China and the State Council explicitly proposes to jointly build the "Digital Yangtze River Delta". To achieve the coordination of digital economy and industrial development, the Yangtze River Delta must accelerate the digital transformation of the manufacturing industry and realize the deep integration of informatization and advanced manufacturing technology. At present, the digital economy in the Yangtze River Delta region has been developing rapidly. According to Luan's (2018) study on the influence of the agglomeration of the productive service industry on the transformation and upgrading of the manufacturing industry in the Yangtze River Delta city cluster, the Yangtze River Delta city cluster mainly consists of 26 cities in Shanghai, Jiangsu, Zhejiang and Anhui provinces. The development of industrial clusters such as artificial intelligence, intelligent manufacturing, and the Internet in Shanghai, the development of intelligent manufacturing and Internet of Things industrial clusters in Jiangsu, the development of integrated circuit industry and intelligent terminal industrial clusters in Anhui, and e-commerce and Internet industrial clusters in Zhejiang, all of which may make a great contribution to the international competitiveness of Yangtze River Delta region. The core of the digital economy is digital information and expertise, which affects or even subverts the production methods of traditional industries, thus enhancing productivity as well as optimizing economic structures. Based on this, this paper conducts a systematic study on digitalization and transformation and upgrading of the manufacturing industry from the perspective of city clusters against the strategic background of the integration of the Yangtze River Delta region, and builds a theoretical framework to analyze the dynamic changes of digital economy and transformation and upgrading of manufacturing industry from the perspective of city clusters, establishes a measurement model and a comprehensive evaluation system of the digital economy, and visualizes the influence mechanism of digital economy and transformation and upgrading of the manufacturing industry. The objective of the study is to examine whether the development of the digital economy is a driver of regional development. It is concluded that the digital economy has a catalytic effect on the high-quality development of the manufacturing industry and the transformation and upgrading of the manufacturing industry in the Yangtze River Delta region. The digital economy needs to pay special attention to the related financial investment and the number of innovative projects in the development of the manufacturing industry, as well as to the new mode of energy conservation and environmental protection in the process of moving to high-quality development of the manufacturing industry.

2. Current Situation of the Digital Economy and Manufacturing Development in the Yangtze River Delta

The digital economy has become the new impetus for China's economic development in recent years, whose rapid development has made China enter a new era of the digital economy. The digital economy in the Yangtze River Delta region also follows this new trend, whose total scale continues to make breakthroughs. China Academy of Information and Communication Research and Zhejiang Tsinghua Yangtze River Delta Research Institute (2021) stated that The total digital economy in the Yangtze River Delta reached 10.83 trillion yuan in 2020, 2.23 trillion yuan higher than in 2019, accounting for 28% of the total scale of the national digital economy and about 44% of the GDP of the Yangtze River Delta region. With further development, the demand for digital consumption has been further expanded, 5G will be applied to more business and manufacturing sectors, and digital integration in the Yangtze River Delta region will develop deeply. The digital economy has become an important sector of high technology and high-tech innovation in today's world, which can promote the advancement and rationalization of industrial structure, and to a certain extent, optimize the structure of the manufacturing industry, playing a positive role in promoting the development of the economy.

From the analysis of "Effect Measurement and Realization Path of Digital Economy Empowering Manufacturing Transformation and Upgrading in Yangtze River Delta Region" by Liao and Yang (2021); At present, the manufacturing industry is in a critical period of replacing old driving forces with new ones, while the traditional manufacturing industry is facing the dilemma of overcapacity and insufficient effective demand. The two traditional advantages of mass production and low cost can no longer support the current development of the manufacturing industry. Therefore, manufacturing enterprises that have encountered bottlenecks in development need to seize the opportunities in the era of the digital economy. It is necessary to grasp the opportunities and make full use of the digital economy to provide technical support to the manufacturing industry, which is a major task for the development of the Chinese manufacturing industry at present.

Against the new development background, the competition among countries has shifted from the traditional manufacturing industry to the collaborative development of the digital economy-enabled manufacturing industry. The development of the manufacturing industry needs the collaborative development of digital technology and manufacturing industries to promote China's manufacturing industry from the low-end to the middle and high-end and realize the intelligence and digitalization of the manufacturing industry. Under the background of the new pattern of the "double cycle", the cooperative of the manufacturing industry in the Yangtze River Delta region will be based on digital technology, guiding the digital economy to embed in the traditional manufacturing industry, forming new impetus for economic growth and helping the local manufacturing industry to develop collaboratively and expanding the regional economic integration. From a global perspective, the petition of the manufacturing industry has shifted from "product manufacturing" to "industrial ecological construction", and the high permeability of the digital economy accelerates the transition from product manufacturing to industrial ecological construction. Countries in the world generally believe that the digital economy is the driving force and a new impetus for global economic development. To build a new platform for economic development and seize the commanding height of strategic competition, it is necessary to develop China's digital economy. China should effectively grasp the historic opportunities brought by the digital economy, accelerate the construction of the "Digital Design and Manufacturing" project, and provide a platform to promote collaborative innovation of digital design and manufacturing in the Yangtze River Delta region.

The report on the collaborative development of the manufacturing industry in the Yangtze River Delta region shows that the collaborative capacity of the manufacturing industry in Shanghai, Jiangsu, Zhejiang, and Anhui has been significantly improved, the division of labor in the industry has been deepened, and the industrial collaboration within the region has been innovated, forming a setup of collaborative innovation, accelerating the cooperation of capital and the coordination mechanism of investment. At present, the collaborative development of the manufacturing industry in the Yangtze River Delta region is in a leading position in China. In the future, the Yangtze River Delta region will promote collaborative development with a higher degree and higher levels and must adopt an integration path of "sharing information, resource, and capacity, embracing openness and cooperation for mutual benefit", making the manufacturing enterprises in Yangtze River Delta region become an internationally competitive industrial cluster.

3. Literature Review

3.1 Study of the Yangtze River Delta Economic Model

Based on the theory of urban linkages in regional economics, Hai-bin et al. (2008) construct a gravity model and an urban mobility model. Using census data by county, Zheng et al. (2009) illustrate the intensified population concentration and region-based urban transformation in China in the 1990s. Sun et al. (2018) find that the rate and composition of urban expansion forms (i.e., infilling, spreading edge, and leapfrogging) varied considerably across cities and administrative hierarchies over time due to differences in national and regional policies, physical characteristics, and cities. Considering the spatial relevance and dependence of green development, Yuan et al. (2019) propose a spatial analysis of area green efficiency (AGE) and total factor productivity change (TFPC) using a methodology that includes diversity and correlation. Zhang et al. (2019) conducted an empirical study on data from 71 cities in China.

3.2 Progress of Regional Governance Research in the Yangtze River Delta

Relevant studies on the coordinated regional economic governance in China have a long history, with studies focusing on 2010, 2020, and beyond. Zhang Juntao et al. (2010) discuss the basic theory of regional public administration. Drawing on the practice of China's economic and social development, they analyze the necessity and development trend of regional public administration. Li et al. (2012) demonstrate various types of "regionalization" initiatives and examine the development of regional governance in China. It is quite essential to find the best model under different conditions to change the current unfavorable institutional and policy environment. Based on data from 30 Chinese provinces from 1995-2017, Luo and Shen (2009) explore the impact mechanism of space on economic agglomeration and energy density and the impact of carbon emission intensity through exploratory analysis of spatial data, dynamic spatial Durbin, and mediated role models.

3.3 Yangtze River Delta Economic Development Study

The literature on economic development and related manufacturing in the Yangtze River Delta includes spatial scale, degree of development, and other aspects. Li et al. (2018) assess the sustainability of urban development in the Yangtze River Delta region from 2000-2014 at two spatial scales (corresponding to provincial and prefectural levels). According to the panel data of 26 cities along the Yangtze River, the overall entropy method is used to evaluate the delta of urban logistics industry development based on the mechanism analysis of the spillover effect of logistics industry development over economic growth. On this basis, Xu and Wang (2017) use the spatial Durbin model to study the direct impact and spatial spillover effect of logistics industry development over economic growth. With the rise of globalization, city brand promotion activities have become the focus of policymakers and planners aiming to build the reputation of cities and achieve the long-term prosperity of cities. Yang et al. (2019) aim to develop a sustainability-oriented city brand framework that assesses the empirical application of the potential of cities in global mega-regions to support their sustainable development. Li and Jonas (2019) depart from the contemporary post-Westphalian or hyper-globalized view, offering a new interpretation of Chinese urban regionalism and considering it as a case against geopolitical processes. Hou (2020) analyzes the strategic path of cruise tourism destination development and international marketing in the context of the integration of the Yangtze River Delta, aiming to enhance the international competitiveness of the Yangtze River Delta cruise economy. Based on data from automatic identification system (AIS), basic port data, hinterland city data, transportation network data, and relevant economic and policy data, Mou et al. (2020) construct a port development potential evaluation system using the FAHP-Fuzzy Analytical Hierarchy Process method to evaluate the development potential of eight representative ports of the Yangtze River Delta port cluster in China. The spatial and temporal characteristics of economic sustainability and eco-efficiency will provide theoretical guidance to alleviate ecological pressure and promote sustainable economic development (Li et al., 2022).

3.4 Literature Review

In addition to studies by Chinese scholars on the establishment and efficiency analysis of regional urban agglomerations in China, foreign scholars like Rungskunroch et al. (2020) also focus on economic growth, dynamic land use, and urban mobility of Chinese urban agglomerations. Although many studies have focused on urban heat islands from single sites to regional to global scales, few studies have addressed the multi-scale impacts of large urban agglomerations on the thermal environment.

4. Research Methods

4.1 Desktop Research Method

Desktop research can be used at various stages of a project, but it is more useful in the early stages of a project. This paper collects data to understand the entire current situation of digital economy development and manufacturing in the Yangtze River Delta region and draws certain analysis results that can pave the way for further research.

Desktop research is very important to the conduct of the project, but real research is not just desktop research. At the same time, after the basic desktop research, this paper also adopts a variety of research methods related to the basic research situation and related data analysis, mainly including statistical methods, including data processing, principal component analysis, factor analysis, AHP analytic hierarchy process, and so on.

4.2 Literature Analysis Method

The literature analysis method refers to the analysis method to find out the nature and status of the research object and to draw one's point of view through the research of the collected literature data. It can help investigators form a general impression about the research object, which is conducive to the dynamic grasp of the research object's history and can also study the research object that is impossible to approach. The main contents of the literature analysis method are as follows: (1) To analyze and research the relevant archive's data found. (2) To analyze and study the collected diaries, notes, and biographies of individuals. (3) Conduct analysis and research on the collected published books and publications and other materials.

4.3 Principal Component Analysis

Principal Component Analysis is a statistical method. A set of potentially correlated variables is transformed into a set of linearly uncorrelated variables through orthogonal transformation, and the transformed set of variables is called principal components. When using statistical analysis methods to study multivariate subjects, too many variables will increase the complexity of the subject. People naturally want to get more information with fewer variables. In many cases, there is a certain correlation between variables. When there is a certain correlation between two variables, it can be interpreted that the information of the two variables reflecting the subject overlaps to a certain extent. The principal component analysis is to delete the redundant variables (closely related variables) for all the variables originally proposed and establish as few new variables as possible so that these new variables are uncorrelated and these new variables are reflected. The information on the subject should be kept as original as possible.

4.4 AHP Analytic Hierarchy Process

Analytic Hierarchy Process, or AHP for short, refers to a decision-making method that decomposes elements that are always related to decision-making into levels such as goals, criteria, and plans and conducts qualitative and quantitative analysis on this basis. This method applies network system theory and multi-objective comprehensive evaluation method and proposes a hierarchical weight decision analysis method.

5. Construction of a Comprehensive Evaluation System of Digital Economy Quality

Based on the principles of validity and data availability, from the perspective of manufacturing enterprises in the Yangtze River Delta, the quality evaluation of the transformation and upgrading of the manufacturing industry mainly includes three dimensions - scientific research and innovation, manufacturing, energy conservation, and environmental protection which is based on the "Effect Measurement and Realization Path of Digital Economy Empowering the Transformation and Upgrading of Manufacturing Industries in the Yangtze River Delta Region" by Liao and Yang (2021). It prepares the ground for the following indicator measurement within the comprehensive evaluation system of digital economy development quality as well as the principal component analysis part.

In terms of scientific research and innovation, the development of the manufacturing industry requires technological innovation. The digital economy is an innovation that drives the innovation of manufacturing enterprises, both in terms of institutional innovation and management innovation, to improve the efficiency of product design, manufacturing, and marketing and promotion. When constructing new technologies, the use of a large number of digital technologies can effectively reduce the technical exchange between researchers and cooperation between research teams. From marketing, services, and other peripheral parts to product development, production, and processing equipment, the digital economy promotes the transformation and upgrading of the manufacturing industry by improving the core innovation capacity of enterprises.

In terms of manufacturing, the digital economy has a unique advantage of information transfer, which can effectively lower the cost of information exchange between upstream and downstream enterprises in the industrial chain and reduce the exchange of information in the supply chain, thus effectively simplifying the sales and transaction process of products, as well as reducing transaction costs (Zeng & Liu, 2019). The problem of information asymmetry in raw material procurement can be solved. Through optimal choice analysis, they can buy the required raw materials at the minimum price and then process them into products for sale to the downstream companies. The digital economy has gradually promoted the intelligent development of the manufacturing industry, and the mode of labor division and cooperation has transitioned from linear mode to network mode. At the same time, the integration of digital technology in the operation of manufacturing enterprises has greatly improved the previous problems of high cost and energy consumption.

In terms of energy conservation and environmental protection, the huge technological dividend led by the digital economy has brought about a comprehensive change in the way enterprises collaborate, making it more convenient and less costly for enterprises to work together. The collaborative development of manufacturing enterprises in the Yangtze River Delta has been promoted, which helps reduce the costs of energy consumption processing and environmental pollution treatment, promoting the improvement of capacity efficiency. It improves the ability of enterprise resource allocation, which in turn drives the upgrade of business performance, improves resource utilization, and reduces energy loss. The constraints of time and space for transactions in traditional manufacturing enterprises have been broken through - from the scattered, passive, and reactive one-way delivery mode of enterprises-consumers in the past to a two-way delivery with mutual connection and active participation between enterprises and consumers – which reduces marketing operating costs and facilitates the implementation of energy conservation and environmental protection in manufacturing enterprises.

6. Measurement of Indicators within the Comprehensive Evaluation System for the Quality of Digital Economy Development

6.1 Data sources

Under the first-level indicators of the comprehensive evaluation system of digital economy development quality, scientific research and innovation can be subdivided into R&D expenditure of industrial enterprises above the scale, the number of effective invention patents of industrial enterprises above the scale, and the number of new product projects of industrial enterprises above the scale; manufacturing can be subdivided into the three indicators of fixed asset investment in manufacturing, the number of industrial enterprises above the scale, and industrial added value; energy conservation and environmental protection can be subdivided into electricity consumption, total wastewater emission, and sulfur dioxide emission. From the perspective of manufacturing enterprises in the Yangtze River Delta, we can analyze the changes in indicators to roughly extract the impact of the quality of digital economy development in the Yangtze River Delta city cluster on the manufacturing industry and the degree of impact.

Table 1 Construction of the evaluation index system for the quality of digital economy development

Characteristic	Basic indicators	Positive and negative attributes of the indicator
Corporate Innovation	R&D expenditure of industrial enterprises above scale	+
	Number of valid invention patents for industrial enterprises above scale	+
	Number of new product projects in industrial enterprises above scale	+
Manufacturing	Investment in manufacturing fixed assets	+
	Number of industrial enterprise units above scale	+
	Industrial value added	+
Energy saving and environmental protection	Electricity consumption	-
	Total wastewater discharge	-
	Sulfur dioxide emissions	-

In this paper, the most important policy documents on China's economic policy adjustment and continuation are used as references in conjunction with the National 12th and 13th Five-Year Plans, the economic development reports of the Yangtze River Delta region, and the period from 2015 to 2020 is selected as the data source time point. The data sources are Yangtze River Delta Regional Urban Economic Growth Report (2016-2021), Yangtze River Delta Digital Economy Development Report (2016-2021), Yangtze River Delta Manufacturing Synergy Development Report, China City Statistical Yearbook (2016-2021), Shanghai Statistical Yearbook (2016-2021), Zhejiang Statistical Yearbook (2016 -2021), Jiangsu Provincial Statistical Yearbook (2016-2021), Anhui Provincial Statistical Yearbook (2016-2021), etc. This paper uses SPSS software to analyze the data and draws tables according to the software running results.

6.2 Data Processing and Measurement Results

The Yangtze River Delta Urban Agglomeration Development Plan stipulates that the Yangtze River Delta urban agglomeration of Shanghai, Jiangsu, Zhejiang, and Anhui is a key development area with Shanghai as the core and several cities nearby as the center, with an urbanization layout of "two horizontal and three vertical". Therefore, this paper selects the administrative data at the provincial level for data processing and corresponding measurement analysis.

This paper uses the above three attributes to analyze the level of quality of development of the digital economy-enabled manufacturing industry, with nine secondary indicators subdivided into the three attributes of enterprise innovation, manufacturing, energy conservation, and environmental protection. Therefore, there are nine indicators to be subjected to principal component analysis. The principal component analysis is a multidimensional statistical method of correlation between multiple variables, which uses a small number of principal components to reflect the intrinsic relationship between multiple variables; that is, a small number of principal components are deduced from the original variables, thus keeping as much information as possible about the original variables and not linked to each other. The following steps were followed to perform principal component analysis on the variables and obtain the principal component scores, as follows.

(1) Calculate the weight of each principal component.

Principal component analysis was used to analyze the contribution values of the changes in each major component of the Yangtze River Delta urban agglomeration from 2015 to 2020, and three major components were selected based on a cumulative contribution rate of 0.90.

Table 2 Explanation of variance

Explanation of variance						
No.	Characteristic roots			Principal Component Extraction		
	Characteristic roots	Explanation of variance %	Cumulative %	Characteristic roots	Explanation of variance %	Cumulative %
1	6.420	71.330	71.330	6.420	71.330	71.330
2	1.520	16.887	88.218	1.520	16.887	88.218
3	0.958	10.648	98.866	0.958	10.648	98.866

From the principal component analysis in Table 2 and the amount of information extracted from the principal components, it can be seen from the above table: that a total of three principal components were extracted from the principal component analysis, and the variance explained by these three principal components were 71.330%,16.887%, and 10.648% respectively, with a cumulative variance explained by 98.866%. In addition, their corresponding weighted variance explanation rates, i.e., weights, were 71.330/98.866=72.15%; 16.887/98.866=17.08%; 10.648/98.866=10.77% in order.

(2) Construction of composite indicators
The weights of each principal component are calculated from the variance contribution of each principal component. The score of each principal component can be calculated from the coefficient of each indicator in each principal component:

Table 3 Load factors

Load factor				
Name	Load factor			Commonality (common factor variance)
	Main component 1	Principal Component 2	Principal Component 3	
R&D expenditure of industrial enterprises above scale (RMB million)	0.966	0.226	-0.013	0.984
Number of valid invention patents for industrial enterprises above scale (pieces)	0.981	0.167	0.011	0.990
Number of new product projects for industrial enterprises above scale (items)	0.934	0.351	-0.003	0.997
Investment in fixed assets in manufacturing (excluding farmers)_ up (%) over the previous year	0.465	-0.219	0.854	0.993
Number of industrial enterprise units above scale (pcs)	-0.106	0.958	0.239	0.986
Industrial value added (billion yuan)	0.916	-0.031	-0.375	0.980
Electricity consumption (billion kWh)	0.968	-0.216	-0.111	0.996
Total wastewater discharge (million tons)	-0.985	-0.167	0.029	0.999
Nitrogen oxide emissions (million tons)	-0.823	0.527	-0.135	0.973
Blue indicates loading coefficients greater than 0.4 in absolute terms, and red indicates a commonality (common factor variance) of less than 0.4.				

As can be seen from Table 3, the commonality values of all the research items are higher than 0.4, which means that there is a strong correlation between the research items and the principal components and that the principal components can effectively extract the information. After ensuring that the principal component can extract most of the information from the research items, the correspondence between the principal component and the research items was then analyzed (a loading coefficient with an absolute value greater than 0.4 means that there is a correspondence between the item and the principal component).

(3) The composite index score was calculated from the individual principal component scores:

Table 4 *Component score coefficient matrix*

Component score coefficient matrix			
Name	Ingredients		
	Component 1	Component 2	Component 3
R&D expenditure of industrial enterprises above scale (RMB million)	1.000	-1.500	2.000
Number of valid invention patents for industrial enterprises above scale (pieces)	-0.875	-0.969	0.563
Number of new product projects for industrial enterprises above scale (items)	-3.000	2.000	-1.750
Investment in fixed assets in manufacturing (excluding farmers)_ up (%) over the previous year	0.500	0.500	0.438
Number of industrial enterprise units above scale (pcs)	0.000	-0.250	1.000
Industrial value added (billion yuan)	1.125	-0.625	-0.109
Electricity consumption (billion kWh)	-2.500	1.000	-0.750
Total wastewater discharge (million tons)	-4.000	-1.875	1.156
Nitrogen oxide emissions (million tons)	0.000	2.000	-1.750

The purpose of using principal component analysis is to concentrate the information, so the "matrix of component score coefficients" table is ignored. As shown in Table 4 above, the following conclusions can be drawn: "R&D expenditure of industrial enterprises above the scale", "number of new product projects of industrial enterprises above the scale", "industrial value added", "total wastewater discharge", and "industrial value added". "Total wastewater discharge" is located on the first factor with high loadings, and the first factor mainly explains these indicators, which are interpreted as the digital economy-enabled manufacturing technology innovation dimension of above-scale industrial enterprises; "Number of new product projects of above-scale industrial enterprises" "The second factor mainly explains these indicators and is interpreted as the manufacturing dimension, including manufacturing projects and their emission impact, thus indicating that the meaning of the factors is clearer.

Since this paper uses principal component analysis for weighting, it is necessary to use the "component score coefficient matrix" to establish the equation of the relationship between the principal components and the study items, and the three equations obtained are as follows.

Component Score1 = 1.000*R&D expenditure of industrial enterprises above scale - 0.875*Number of effective invention patents of industrial enterprises above scale - 3.000*Number of new product projects of industrial enterprises above scale + 0.500*Fixed asset investment in manufacturing industry + 1.125*Industrial value added - 2.500*Electricity consumption - 4.000*Total wastewater discharge

Component score2 = -1.500*R&D expenditure of industrial enterprises above scale - 0.969*Number of effective invention patents of industrial enterprises above scale + 2.000*Number of new product projects of industrial enterprises above scale + 0.500*Fixed asset investment in the manufacturing industry - 0.250*Number of units of industrial enterprises above scale - 0.625*Industrial value added + 1.000*Electricity Consumption - 1.875*Total wastewater emissions + 2.000*Nitrogen oxide emissions

Component score 3 = 2.000*R&D expenditure of industrial enterprises above scale + 0.562*Number of effective invention patents of industrial enterprises above scale - 1.750*Number of new product projects of industrial enterprises above scale + 0.438*Fixed asset investment in manufacturing industry + 1.000*Number of units of industrial enterprises above scale - 0.109*Value added of the industry - 0.750*Electricity consumption +1.156*Total wastewater emissions - 1.750*Nitrogen oxide emissions

By extracting the principal components of science and technology innovation, manufacturing and energy conservation, and environmental protection and calculating the variance explanation as well as the variance contribution rate, it can be found that the development quality level of the digital economy-enabled manufacturing industry plays an important role in all the above three dimensions, but there are different influencing factors for each indicator. The cumulative variance explained by the three principal components extracted by the principal component analysis reached 98.866%, and the corresponding common degree values of the research items and the principal components were all greater than 0.4, which means that these three principal components can be used as key influencing factors to reflect the original variables. As the composite score is calculated by accumulating the product of the variance explained rate and the component scores. The formula for the current data is: (71.330*Component Score 1 + 16.887*Component Score 2 + 10.648*Component Score 3)/98.866. The final equation is: 0.721*Component Score 1 + 0.171*Component Score 2 + 0.108*Component Score 3. The final equation for the relationship between the principal components and the study items is established as follows.

7. Empirical Analysis

In recent years, the R&D investment intensity in the Yangtze River Delta has been maintaining high and steady growth, ahead of the national average. One of the more representative secondary indicators is the R&D expenditure of industrial enterprises. To more accurately determine the impact path of the digital economy on industrial enterprises, a judgment matrix is constructed as follows.

(1) Construction of judgment matrix

Combined with the principal component score matrix, to select the important variables under the STI indicators that are most representative of the development quality of the digital economy, AHP hierarchical analysis was carried out to process and analyze the data under the STI attributes of the three provinces and one city in the Yangtze River Delta to obtain the weight share of each variable in the attributes, taking three variables under the STI attributes as examples. When using AHP hierarchical analysis to calculate the weights, it is first necessary to construct a judgment matrix, as shown in Table 5.

Table 5 AHP Hierarchical Analysis Judgement Matrix

AHP Hierarchical Analysis Judgement Matrix				
Average	Item	R&D expenditure of industrial enterprises above scale (RMB million)	Number of valid invention patents for industrial enterprises above scale (pieces)	Number of new product projects for industrial enterprises above scale (items)
5474755.500	R&D expenditure of industrial enterprises above scale (RMB million)	1	119.280	305.867
45898.333	Number of valid invention patents for industrial enterprises above scale (pieces)	0.008	1	2.564
17899.167	Number of new product projects for industrial enterprises above scale (items)	0.003	0.390	1

(2) AHP hierarchical analysis results.

Table 6 Results of AHP hierarchical analysis

AHP Hierarchical Analysis Results				
Item	Eigenvectors	Weighting values	Maximum Eigenvalue	CI value
R&D expenditure of industrial enterprises above scale (RMB million)	2.965	98.848%	3.000	0.000
Number of valid invention patents for industrial enterprises above scale (pieces)	0.025	0.829%		
No. of new product projects for industrial enterprises above scale (items)	0.010	0.323%		

As can be seen from Table 6, the AHP hierarchical study was carried out by constructing a third-order judgment matrix (calculated by the sum and product method) for a total of three items, namely, the R&D expenditure of industrial enterprises above the scale (RMB 10,000 yuan), the number of valid invention patents of industrial enterprises above the scale (pieces) and the number of new product projects of industrial enterprises above the scale (pieces), and the feature vectors were (2.965,0.025,0.010). The total of 3 items with corresponding weights is 98.848%, 0.829%, and 0.323%, respectively. In addition, the maximum Eigen root (3.000) can be calculated by combining the eigenvectors, and then the CI value (0.000) can be calculated by using the maximum Eigen root value.

(3) Consistency test

Table 7 Summary of consistency test results

Summary of Consistency Test Results				
Maximum characteristic root	CI value	RI value	CR value	Consistency test results
3.000	0.000	0.520	0.000	By

According to the results of the consistency test in Table 7, it can be seen that this study constructs a 3rd-order judgment matrix with a random consistency RI value of 0.520 for use in the consistency test calculation. Usually, the smaller the CR value, the better the consistency of the judgment matrix; in general, if the CR value is less than 0.1, then the judgment matrix satisfies the consistency test; if the CR value is greater than 0.1, it means that there is no consistency, and the judgment matrix should be adjusted appropriately and then analyzed again. The CI value calculated for the 3rd order judgment matrix is 0.000, and the table check for the RI value is 0.520, so the calculated CR value is 0.000<0.1, which means that the judgment matrix of this study meets the consistency test and the calculated weights are consistent.

Therefore, the consistency test of AHP hierarchical analysis passed, and the corresponding weight values of R&D expenditure of industrial enterprises above the scale (RMB million), the number of effective invention patents of industrial enterprises above the scale (pieces) and the number of new product projects of industrial enterprises above the scale (pieces) were 0.98848, 0.00829% and 0.00323% respectively. D expenditure (RMB million) of industrial enterprises above the scale is therefore used to analyze the level of science and technology innovation of the three provinces and one city in the Yangtze River Delta region. According to the data published by the National Bureau of Statistics, the intensity of R&D expenditure in 2020 is 4.17% in Shanghai, 2.93% and 2.88% in Jiangsu and Zhejiang, respectively, and 2.28% in Anhui. The Yangtze River Delta region, led by Shanghai, is a region with a developed economy, strong manufacturing capacity, and balanced links in the innovation chain, with advantages in resources such as science and technology, capital, and markets, and is one of the regions with deep integration between science and technology and industry and more outstanding innovation capabilities (Cheng et al., 20201).

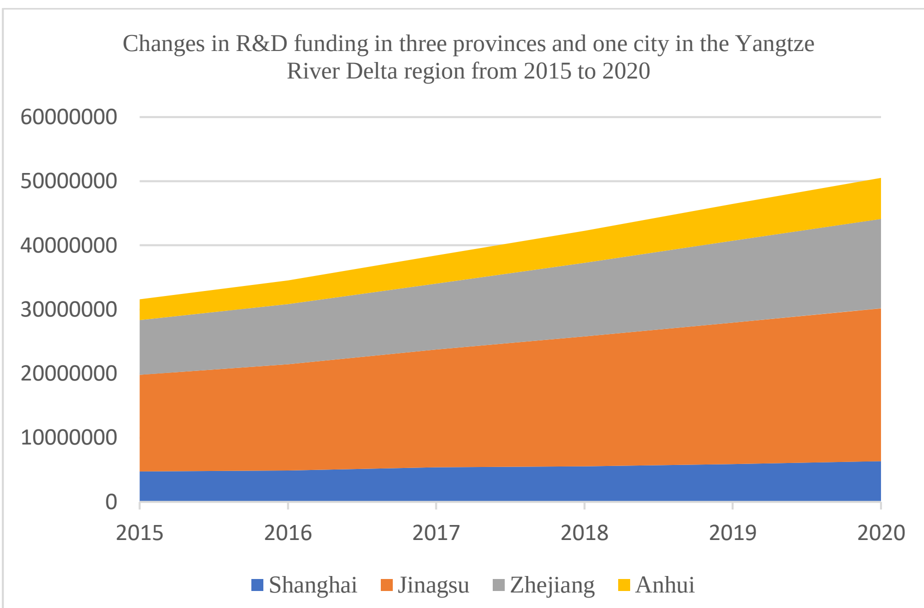

Figure 1 Changes in R&D funding in the three provinces and one city in the Yangtze River Delta region from 2015 to 2020

By analyzing the spatial aggregation characteristics of the level of development of the digital economy and the level of upgrading of the manufacturing industry in the Yangtze River Delta, a clearer understanding of its evolutionary characteristics is provided.

Three cities in the Yangtze River Delta rank among the top six cities in terms of R&D funding in 2020, namely Shanghai, Suzhou and Hangzhou. Shanghai has invested a whopping 161.57 billion yuan in R&D. It also has a strong headquarters economy and R&D innovation capability, gathering a large number of R&D talents, with a large part of Huawei's R&D team based in Shanghai. Suzhou remains the leader in the Yangtze River Delta region, second only to Hangzhou and Nanjing, both of which have the highest R&D investment.

As can be seen from Figure 1, the changes in R&D funding in the Yangtze River Delta region from 2015 to 2020 show that the Yangtze River Delta region is still characterized by significant regional differences in collaborative innovation. The resource elements in the Yangtze River Delta region have accelerated their concentration, and the foundation of collaborative innovation has been continuously consolidated. Taking the Yangtze River Delta region as an example, the overall R&D investment intensity in 2018 was 2.81%, but there were obvious regional differences, with 4.16% in Shanghai, 2.70% in Zhejiang, 2.57% in Jiangsu, and 2.16% in Anhui. The three provinces and one city play an important leading role in innovation-driven development, with the Yangtze River Delta region accounting for 4.57% of government funding in science and technology, which is higher than the national rate of 2.77%. The Yangtze River Delta region is increasingly playing a role in gathering scientific and technological innovation talents, forming several core cities such as Shanghai, Hangzhou, Suzhou, Nanjing, and Hefei.

The geographical differences and the disparity in development levels in the Yangtze River Delta region have led to a misaligned competitive situation in the regional manufacturing industry. Looking at the division of labour structure in the Yangtze River Delta region, the division of labor among the industries in the three provinces and one city is accelerating. For example, in Shanghai's auto parts industry, Ningbo and Taizhou's auto parts industries are developing rapidly, and there is frequent cooperation between industries. Hangzhou focuses on electronic information, cloud computing, and big data, Suzhou focuses on biomedicine and new generation information technology, and Nanjing relies on strong scientific research to develop new materials, intelligent equipment, and other industries, and the development gap between the Yangtze River Delta regions is becoming wider.

8. Conclusion

Today, China's economy has shifted from a stage of high-speed growth to a stage of high-quality development and is in the critical period of transforming the development mode, optimizing the economic structure, and changing the growth momentum. The Yangtze River Delta region, as one of the important urban economic circles in China, has a good economic foundation, a unique economic strength, and an important position in the national economy that determines that it must take the lead in developing a digital economy. Today's companies are constantly upgrading and transforming their business models towards digitalization to achieve high-quality development. Manufacturing is the basic industry of industry, and the improved quality of the development of the digital economy in the Yangtze River Delta will not only lead to the transformation and upgrading of the manufacturing industry but also lead to better economic development. The country is also strongly supporting the development of the digital economy industry: 5G will soon be commercially available, and smart technologies such as artificial intelligence and 3D printing are developing and gaining popularity. On a global scale, the digital transformation of the Yangtze River Delta city cluster is an inevitable choice in history and a necessary path to pursue development. The quality of the future development of the digital economy will directly affect the production capacity and scale of the manufacturing industry. Therefore, governments, enterprises, and individuals should seize the opportunity for the development of the digital economy.

This paper takes the growth trend of economic development in the Yangtze River Delta region in recent years as a study, integrates the in-depth interpretation of manufacturing development trends under the digital economy by recent economists, and constructs an analysis of the dynamic changes in the process of transformation and upgrading of the digital economy and manufacturing industry from the perspective of city clusters in the context of the integrated strategic layout of the Yangtze River Delta region. The resulting theoretical framework can visually and objectively represent the influence mechanism and realization path of the transformation and upgrading of the manufacturing industry, and the following three conclusions are finally drawn after empirical testing:

(1) This paper uses the entropy value method to analyze three first-level indicators for the comprehensive evaluation system of the quality of digital economy development: science and technology innovation, production and manufacturing, and energy conservation and environmental protection, to derive the impact of the quality of digital economy development in the Yangtze River Delta city cluster on the manufacturing industry and the degree of impact, in which the attributes of science and technology innovation and production and manufacturing indicators are positive, and the attributes of energy conservation and environmental protection indicators are negative, which indicates that science and technology innovation and production and manufacturing can promote This indicates that technological innovation and manufacturing can promote the development of the manufacturing industry in the YRD region, while energy conservation and environmental protection can hinder the development of manufacturing. In general, the digital economy has a facilitating effect on achieving high-quality development of the manufacturing industry in the Yangtze River Delta region and promoting the transformation and upgrading of manufacturing enterprises.

(2) This paper extracts the principal components of science and technology innovation, manufacturing, energy conservation, and environmental protection and calculates the variance explanation as well as the variance contribution rate to analyze the development quality level of the digitally economy empowered manufacturing industry. According to the results of the principal component analysis, R&D expenditure of industrial enterprises above the scale is the main positive influence factor, while the number of new product projects, electricity consumption, and total wastewater discharge of industrial enterprises above the scale is the main negative factors. New models of energy efficiency and environmental protection.

(3) Finally, the AHP hierarchical analysis was conducted on the important variables under the most representative science and technology innovation indicators for the development quality of the digital economy, and the AHP hierarchical analysis judgment matrix, the AHP hierarchical analysis result matrix calculated by the sum-product method, and the 3rd order judgment matrix of the consistency test were constructed in turn. The theoretical framework established in this way can clearly describe the spatial aggregation characteristics of the development level of the digital economy and the upgrading level of the manufacturing industry in the Yangtze River Delta and accurately identify their evolutionary characteristics.

The quality of digital economy development in the Yangtze River Delta city cluster has a positive impact on the transformation and upgrading of the local manufacturing industry, giving rise to four new business models personalized customization, networked collaboration, intelligent production, and service-oriented manufacturing providing a realistic vehicle for the transformation of China's manufacturing industry into "digital intelligence", upgrading the value chain and upgrading the industrial structure. The local manufacturing industry should seize development opportunities and explore new models for the development of digital manufacturing enterprises so that they can catch up with the world economic development trend and contribute to local development. As the history of mankind continues to move forward, technology is also advancing to a higher level. In today's digital development, the Yangtze River Delta city cluster should seize the opportunity of digital economic development and move to a new stage of high-quality development.

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