Study On the Driving Mode of Production Factor Allocation on Regional Digital Transformation Under the Configuration Perspective

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Abstract. To explore the different paths of regional digital transformation in China and understand its development mechanism, this paper employs the Fuzzy-set Qualitative Comparative Analysis (fsQCA) method. It examines 21 prefectural-level cities (or municipalities) with national high-tech zones in China's Yangtze River Delta (YRD) region using relevant data from 2022. The study investigates regional digital transformation from two aspects: the labour factor and the data element, based on six measures. The study finds that, firstly, none of the six single antecedents is necessary for a high level of regional digital transformation, but multi-factorial synergies can help achieve a high level of regional digital transformation. Secondly, after the group analysis, there are five configurations to achieve high-level regional digital transformation, which are divided into four paths according to the characteristics of the core variables, namely, the 'talent development' path, the 'digitalisation of a diversified economic base' path, the 'public factor orientation' path, and the 'education and life integration' path, The 'public factor-oriented' path and the 'education and life integration' path. Thirdly, the robustness of the grouping is tested by changing the consistency threshold, after which the grouping is still stable, indicating that the grouping results are reliable. Unlike existing econometric studies that focus on the impact of a single factor, this study reveals the multi-factor driving mechanism of regional digital transformation from a multi-path perspective. This paper provides new perspectives and methods for the theoretical study of regional digital transformation, as well as a more targeted theoretical basis for regional policymaking.

Keywords: Labour Factor Levels, Data Factor Allocation, Digital Transformation of the Region, FsQCA.

1. Introduction

Against the backdrop of accelerated innovation in technologies such as the Internet and big data, and the continuous advancement of globalisation and informatisation, digital transformation of the region (DTR) has become an important factor in enhancing competitiveness. Digital transformation has a significant role in advancing enterprises to break the limitations of traditional business models and improve profitability and market competitiveness. In addition, studies have shown that enterprise digital transformation can improve productivity, streamline management efficiency, and enhance industrial development [1]. Therefore, revealing the key driving factors and path selection of regional digital transformation becomes a topic of great interest, which is an important reference for regional economic development.

With regard to digital transformation, scholars have conducted rich discussions and studies from multiple dimensions, such as information systems, technological innovation, and strategy, and from diverse perspectives, such as regions and enterprises. Zhu and Lin [2] pointed out through literature combing that although the definition of digital transformation has not been unified, certain research results have been achieved in the field. Fang et al. [3] found that the digital transformation capabilities of enterprises enable sustainable innovation in products and processes through extensive integration of digital assets and business resources. Oberländer et al. [4] further found that exploiting digital opportunities is critical for manufacturing companies to achieve digital transformation. Ling et al. [5]

explored the role of digital inclusion in facilitating digital transformation from a digital inclusion perspective. Shi and Guo [6] examined the influences on digital transformation at the policy level. Yao et al. [7] used regression analysis and bootstrap analysis to explore the impact of digital leadership on digital transformation and the mediating role of digital strategy consensus. Past studies have provided some perspectives, methods and conclusions for studying digital transformation. However, the existing studies have mainly used methods such as regression analysis to focus on the impact of a single factor on digital transformation, making it difficult to capture the non-linear relationship and causal asymmetry of factors in the digital transformation process. Therefore, this paper will adopt the fsQCA approach in order to adequately deal with the group effects of multiple antecedent elements on the outcome elements and provide a theoretical reference for studying regional digital transformation.

This paper starts from the ‘multi-path perspective’ to break through the limitations of research. Using the fsQCA method, this paper takes 21 prefecture-level cities (or municipalities) with national high-tech zones in the Yangtze River Delta region of China as the research objects. Then systematically examines the impact of the synergistic effect of multiple factors on regional digital transformation in terms of two dimensions, which are the labour factor and the data factor. Through configurational analysis, this paper identifies multiple paths to achieve high-level digital transformation and reveals the core drivers of each path. This study not only provides new theoretical perspectives for understanding the complex mechanisms of regional digital transformation, but also provides more targeted policy recommendations for policymakers, and makes up for the shortcomings of existing studies in terms of multifactor interactions and the diversity of paths.

2. Research background

2.1. Impact of labour factor levels on regional digital transformation

Studies from managers' perspectives have shown that employee competence and digital knowledge are both important enablers of digital transformation, as well as bringing challenges such as skill gaps and resistance to change to digital transformation [8]. From the perspective of managerial competence, studies such as the DEA- Tobit two-stage model have found that the stronger the managerial competence, the more significantly it can promote the digital transformation of resource-based enterprises. Li et al. [9] explored the relationship between workforce upgrading and digital transformation. Lv et al. [10] found that a high-skilled workforce is better able to adapt to digital technology application and innovation, thus promoting the digital transformation of enterprises and society. Qin et al. [11] found that with digital transformation, enterprises' demand for high-quality labour force also rises, thus changing the labour force structure and further promoting the level of digital transformation.

2.2. Impact of data element levels on regional digital transformation

With the development of science and technology and the establishment of intellectual property rights system, data is gradually put into production as a relatively independent factor. China published a government document in 2020, officially listing data as one of the five major factors of production. Li et al. [12] suggested that, benefiting from the maturity and popularity of digital technology, the emerging digital economy has begun to deeply integrate with the traditional production and lifestyle, promoting the further digitalisation of traditional industries. Gu et al. [13] take data as the production factor, conceptual innovation as the top-level design, and technology and system together to promote transformation in multiple fields. In recent years, the rapid construction of information infrastructure, such as 5G and artificial intelligence, has become an important in promoting digital transformation in the Yangtze River Delta region. However, a study released by Accenture shows that only 15% of Chinese companies have a dedicated strategy and budget for AI. Therefore, China's digital economy is still immature and there is still room for development.

All in all, existing research on the development of labour factors proves that employee competencies, digital knowledge [8] and educational level [9] are strongly correlated with digital transformation. And studies on the configuration of the data factor show that the development of digital technology [13], industrial digitisation and digital infrastructure [12] can facilitate digital transformation. However, most existing studies focus only on the impact of single variables, with few exploring multi-factor driving paths. In this context, investigating the factors and influence mechanisms of labour and data on the digital economy transformation in Chinese prefectural cities and municipalities has become a topic of great interest. It is also important to consider how to formulate a reasonable regional digital transformation strategy.

3. Method

3.1. Entropy Weight Method

Entropy weight method is an objective assignment method based on information entropy, which determines the weight of each indicator by calculating its degree of dispersion. This method can effectively avoid the bias of subjective assignment and ensure the objectivity and scientificity of weight allocation. In the study of regional digital transformation, the entropy value method can more accurately reflect the degree of contribution of each factor to the transformation, and has been widely used in related research. Wang et al. [14] analysed the regional differences in the level of digital economy development of Chinese provinces through the entropy method. Hu et al. [15] used the entropy weight method to synthesize the evaluation index system of antecedent variables constituting the level of provincial digital economy.

Referring to existing studies, using entropy weight method, data from 21 cities and five indicators, which are technical input,innovation output,level of industrial upgrading,internet retailing and level of digital infrastructure development, to calculate the level of regional digital transformation level.

For the 21 objects to be evaluated, 5 evaluation indicators, bringing n = 21 and m = 5 into the following normalization matrix.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{1}$$

Let the normalisation matrix be Z, and the elements in Z be denoted as z_{ij}, where i represents the city and j the indicator.

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{21} x_{ij}^2}} \tag{2}$$

This formula is used to standardise the raw data, converting the raw data into standardised, dimensionless data and eliminating the effect of differences in the scale of different indicators on the results.

Thus, the normalised non-negative matrix is obtained:

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nm} \end{bmatrix} \tag{3}$$

Next, the probability matrix P is computed such that the probability sum corresponding to each indicator is 1, where the formula for each element p_{ij} in P is as follows:

$$p_{ij} = \frac{z_{ij}}{\sqrt{\sum_{i=1}^{21} z_{ij}}} \tag{4}$$

For the jth indicator, its information entropy is:

$$e_j = -\frac{1}{\ln 21}\sum_{i=1}^{21} p_{ij}\ln(p_{ij}), \qquad (j = 1,2,\dots,5) \tag{5}$$

For the jth indicator, the information utility value is as follows, the larger the information utility value, the more information it corresponds to.

$$d_j = 1 - e_j \tag{6}$$

Finally, the weights of each of the five indicators can be calculated using the following formula, which facilitates the final calculation of the regional digitisation level.

$$\omega_j = \frac{d_j}{\sum_{j=1}^{m} d_j}, \ (j = 1,2,3,\dots,5) \tag{7}$$

This formula normalises the information utility values to obtain the entropy weight of each indicator.

3.2. Fuzzy-set Qualitative Comparative Analysis (fsQCA)

The fsQCA approach is based on configuration theory and uses Boolean algebra and set theory to explain multiple concurrent causality. Currently, it is applied to study the relationship between event outcomes and conditional configurations in the social domain [16]. The method is an important method for identifying the multiple paths of a system and is applicable to the study of complex systems in which multiple elements interact to influence the digital transformation of a region.

Using DTR as the explanatory variable, this paper explores the causal relationship between the synergistic effect of multiple explanatory variables and the level of regional digital transformation based on the group state perspective. The reasons for adopting the fsQCA method are as follows: Firstly, the six sub-conditions affecting the allocation of factors of production explored in this paper work together in digital transformation through interaction and synergy, which is applicable to the study of the configuration perspective. Secondly, fsQCA is particularly suitable for small and medium sized samples, and its sensitivity in analysing the complexity of causality gives it an advantage over regression analysis, structural equation modelling and other methods in analysing small and medium sized samples [15]. Thirdly, unlike the csQCA method, which assigns variables to 0 or 1, fsQCA assigns variables between 0 and 1 with reference to the ideal value, which can characterise the variables relatively more accurately.

Based on this, this paper adopts the fsQCA method and selects six antecedent conditions, which are enterprise talent import, educational input, talent cultivation, foundation of digital economy, digital environment, and the construction of open government platforms, with the aim of exploring how the combinations of different conditions synergistically affect the regional digital transformation, and constructing the research framework as shown in the Figure 1.

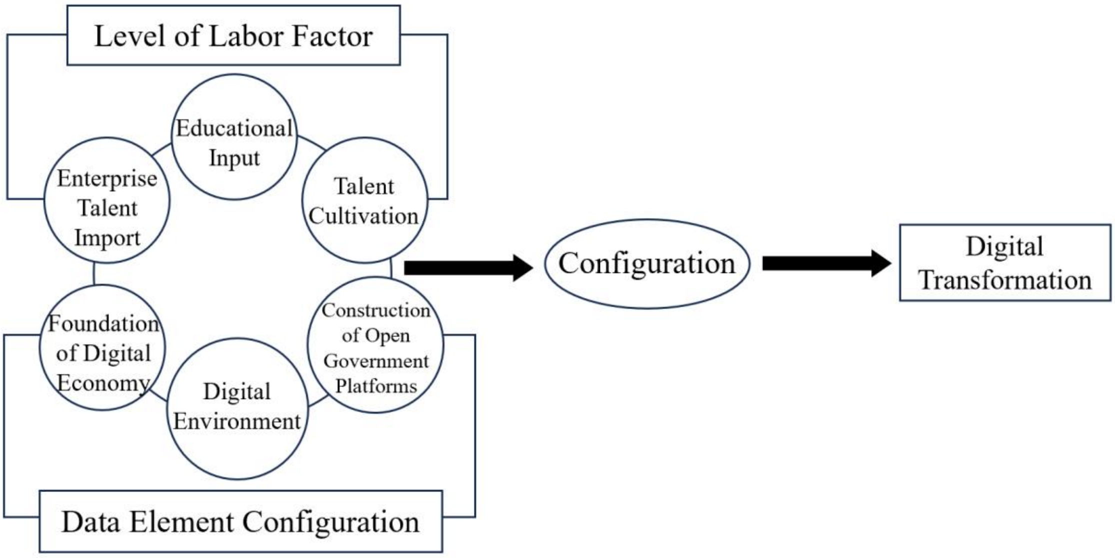

Figure 1. Impact factor research framework

4. Data processing

4.1. Explained and explanatory variables Variable Calibration

4.1.1 Explained variable

Drawing on Yin et al. [17] and others, this paper measures the level of digital transformation from three perspectives: digital technology, digital products and the infrastructure of digital platforms. With the help of existing studies, this paper divides the above indicators into five influencing factors for measurement, which are technical input,innovation output,level of industrial upgrading,internet retailing and level of digital infrastructure development, and calculates the regional digital transformation index through the entropy weight method.

4.1.2 Explanatory variable

Combining the existing literature research and the theory of production factor allocation, this paper carries out a fuzzy qualitative comparative analysis of the factors affecting the digital transformation of the Yangtze River Delta urban agglomeration in terms of two measures: labour factor cultivation and data factor allocation, with the indicator system as shown in the Table.1.

Table.1. Indicator system for evaluating the level of allocation of production factors

Conditional variable: Allocation of production factors		Variable abbreviation	Variable Definition	Source of variables	References
Labour factor development	Enterprise talent import	TI	Percentage of research and development staff	China torch statistical yearbook	Gu et al., 2023 [18]
	Educational input	EDU	Level of investment in urban education	China City Yearbook	Yang et al., 2024 [19]
	Talent cultivation	CULTI	Number of general higher education institutions	CNKI China city statistics database (annual data version)	Ren and Chi, 2024 [20]
Data element configuration	Foundation of digital economy	FOU	Number of Internet access ports	Municipal statistical bulletins on national economic and social development and provincial and municipal statistical yearbooks	Hu et al., 2024 [15]
	Digital environment	ENV	Digital Economy Policy Word Frequency	Macrodatas.cn	Yang et al., 2024 [19]
	Construction of open government platforms	PLAT	Open data index of city	China local government data openness report (Cities)	Hu and Xu, 2024 [21]

4.2. Variable calibration

In this paper, with reference to Pappas's study [22], the six condition variables and one outcome variable were directly calibrated by setting the boundaries that are fully in, crossover, and fully out to the quantile values of 90%, 50%, and 10%, respectively, so as to facilitate the subsequent analyses of intra-group, inter-group, and overall consistency and coverage. The specific calibration results are shown in Table.2.

Table.2. Variable calibration

Condition and result elements	Calibration anchors		
	Fully in	Crossover	Fully out
TI	0.071	0.031	0.013
EDU	0.195	0.163	0.133
CULTI	51.000	10.000	5.000
FOU	1810.720	297.140	168.800
ENV	69.000	49.000	23.000
PLAT	56.020	21.000	2.364
CDT	0.353	0.137	0.065

5. Results

5.1. Necessary condition analysis

According to the fsQCA method, variables should be tested for necessity after calibration for all individual antecedent elements. According to the conventional practice in QCA studies, when the consistency level of an antecedent condition is greater than 0.9, the condition is judged to be necessary. The results of the univariate necessity test are shown in Table.3, which shows that the consistency level of all individual conditions is not higher than 0.9, which means that none of the conditions is a necessary condition for the digital transformation of the Yangtze River Delta city cluster.

Table.3. Necessary condition analysis

Sets of conditions	DTR		~ DTR	
	Consistency	Coverage	Consistency	Coverage
TI	0.709	0.703	0.396	0.484
~TI	0.479	0.391	0.757	0.763
EDU	0.699	0.680	0.462	0.554
~EDU	0.541	0.449	0.733	0.750
CULTI	0.804	0.839	0.350	0.451
~CULTI	0.473	0.371	0.875	0.847
FOU	0.831	0.865	0.347	0.445
~FOU	0.467	0.367	0.895	0.867
ENV	0.755	0.732	0.451	0.539
~ENV	0.524	0.436	0.776	0.797
PLAT	0.782	0.732	0.367	0.424
~PLAT	0.385	0.330	0.768	0.813

Note: ~ indicates logical not.

5.2. Sufficient conditions and configurations of high digital transformation

Through the fsQCA method, high level and non-high level regional digital transformation configurations can be identified. Referring to the study of Navarro et al. [23], in the process of truth table construction, this paper selects the consistency threshold as 0.8, the PRI threshold as 0.75, and the number of cases threshold as 1, and finally obtains the adapted grouping that forms the high-level regional digital transformation. The results of the grouping are shown in Table.4, and the overall consistency of the grouping is 0.84, and the overall coverage is 0.889, which has strong explanatory power and credibility.

From the perspective of each group path, there are the following findings:

In the grouping H1 (‘talent development’ path), education investment, talent cultivation and the foundation of the digital economy play a central role. The antecedent elements that play a supporting role are the existence of enterprise talent input existence, and the digital environment and the construction of the government's open platform are irrelevant conditions. This grouping indicates that regional digital transformation can be facilitated by increasing the proportion of education expenditure in total fiscal expenditure and improving the number and quality of colleges and universities. It also involves vigorously promoting the strategy of strengthening the country with talent and formulating relevant policies, regardless of the level of the digital environment and the construction of the government's open platform.

Represented cases for Configuration H1 are Nanjing, Hangzhou, Wenzhou, Hefei, Nantong, Changzhou, Shanghai, Suzhou, Ningbo and Wuxi. Taking Shanghai as a typical case, as the economic centre of China, it is in the leading position in China in terms of the number and quality of R&D personnel, the level of education, and the formulation of policies related to digital development. In recent years, Shanghai has promoted the synergistic development of education and science and technology innovation by deepening the reform of talent cultivation in universities. At the same time, Shanghai has issued a series of policies related to the development of the digital economy, including the '14th Five-Year Plan for the Development of Shanghai's Digital Economy', which provides strong talent and policy support for digital transformation.

In Configuration H2a and H2b ('digitalisation of diversified economic base' path), both emphasize the degree of digitization in talent building and infrastructure. The common core conditions include talent cultivation, the foundation of the digital economy, and the government's open platform construction, which are further divided into two configurations based on different auxiliary conditions. In H2a, enterprise talent input is an auxiliary condition, while education input and digital environment are irrelevant conditions. This grouping has a consistency of 0.978, second only to H2b. In H2b, the digital environment is included as a core condition, and education input is missing as an auxiliary condition, with or without enterprise talent input. Although this grouping has a coverage of 0.046, tied for the lowest with grouping H4, it has a consistency of 1, the highest of all configurations. Together, these two configurations suggest that when the government values labour force education, it invests more resources in education and training to provide high-quality human resources for the development of digital innovation in the region. When digital technology covers the daily lives of residents in the region, it can promote the initiative of residents to participate in digital public services, and the level of regional digitalisation is further enhanced.

Represented cases for Configuration H2a and H2b are Shanghai, Nanjing, Suzhou, Hangzhou, Hefei, Ningbo, Wuxi, Wenzhou, Changzhou, Shaoxing and Jiaxing. Taking Hangzhou as a typical case, with high-level universities such as Zhejiang University, Hangzhou has established a talent flow channel that integrates cultivation and recruitment through the innovative approach of university-enterprise cooperation. In recent years, Hangzhou has introduced a number of digitalisation policies, with a detailed layout for building an integrated development model for education, science and technology talents, and promoting the high-quality development of regional digitalisation. Meanwhile, Hangzhou has been actively building a national-level data openness platform and published a document on the implementation rules for public data openness in July 2024, further deploying for the city's digital transformation.

In configuration H3 ('public factor-oriented' path), the digital environment and the government open platform construction play a central role. Education investment exists as an auxiliary condition, while enterprise talent input and the digital economy foundation are missing as auxiliary conditions, and talent training is considered an irrelevant condition. This group state indicates that under the premise of low level of enterprise talent input and digital economic foundation, the formulation of digitisation-related policies and the construction of open digital platforms can promote regional digital transformation.

Represented cases for Configuration H3 are Wuxi, Jiaxing, Shanghai, Hangzhou, Suzhou, Shaoxing and Wenzhou. Taking Wuxi as a typical case, its government has issued a series of innovative policies. Among them, the first local regulation on digital transformation in China was enacted in 2023, providing a solid institutional guarantee for the development of the local digital economy. At the same time, Wuxi's policy established a special fund for the development of digital economy and digital transformation to support local enterprises in their digital transformation. In terms of data openness, Wuxi aims to build "Digital Wuxi" and continuously improves the "1+8+X" data element market construction model. The city has ranked first in the province and among the top ten in the country in data openness for five consecutive years, which has significantly promoted the process of digital transformation.

In H4(education and life integration' path), education input and digital economy foundation together constitute the core conditions of the path. Meanwhile, enterprise talent input, talent cultivation, digital environment and government open platform construction are the auxiliary conditions missing. This histogram illustrates that when the level of digital talent cultivation and input, digital policy making and public data openness is low, the improvement of government investment in digital education and digital infrastructure will promote regional digital transformation. This configuration not only considers the role of higher education, but also integrates education and people's living standards.

Represented cases for Configuration H4 are Nanjing, Hangzhou, Wenzhou, Hefei, Nantong and Changzhou. Taking Wenzhou as a typical case, in education, Wenzhou actively promotes the deep integration of education and industry. It also advances the digital and intelligent transformation of traditional manufacturing industries through a new cooperation model involving government, industry, academia, and research. In terms of infrastructure construction, Wenzhou is comprehensively promoting the construction of six national pilot projects, such as digital field, trusted data space and privacy protection computing. At the same time, Wenzhou has more than 80% of enterprises above scale have completed the basic construction of information technology infrastructure. These measures provide strong talent and infrastructure support for the development of digital economy in Wenzhou.

Table.4. Digital Transformation Conditional Configuration for Yangtze River Delta Cities

Configuration	Solution				
	H1	H2a	H3	H2b	H4
TI	●	●	⊗		⊗
EDU	●		●	⊗	●
CULTI	●	●		●	⊗
FOU	●	●	⊗	●	●
ENV			●	●	⊗
PLAT		●	●	●	⊗
Consistency	0.960	0.978	0.950	1.000	0.838
Raw Coverage	0.416	0.512	0.262	0.339	0.160
Unique Coverage	0.072	0.056	0.100	0.046	0.046
Overall solution consistency	0.840				
Overall solution coverage	0.888				

Note:● indicates that the corresponding variable is present in the corresponding grouping in the form of a core condition, ⊗ indicates that the corresponding variable is missing from the grouping in the form of a core condition, ● indicates that the corresponding variable is present in the corresponding grouping in the form of an edge condition, and ⊗ indicates that the corresponding variable is missing from the grouping in the form of an edge condition.

5.3. Robustness test

In order to further enhance the accuracy and credibility of the research results, the robustness test was conducted for the previous studies. With reference to the existing studies, the consistency threshold was adjusted from 0.8 to 0.85 and the PRI consistency is changed from 0.75 to 0.7 [24]. After analysing the results, it was found that all the other configurations were completely consistent, except that the number of configurations in the high-level group was increased by one, H5. The two configurations were slightly different from the original configurations of H2a and H2b. Overall, this difference did not substantially affect the core conclusions of the study, and therefore, the conclusions of this study can be considered robust.

6. Conclusions

Starting from the perspective of production factor allocation, this paper employs the fsQCA methodology to analyze data from 21 prefecture-level cities (or municipalities) with state-level high-tech zones in the Yangtze River Delta region. It examines the common impacts of six measurements on the digital transformation of China's YRD region, including talent input from enterprises, education investment, talent cultivation, digital economy foundation, digital environment, and open government platform construction. The study ultimately identifies five paths and conducts in-depth analyses of typical cases, providing a theoretical basis for the study of regional digital transformation and achieving the following contributions.

6.1. Contribution

First, there is no single necessary condition for both manufacturing process digitalisation and business model digitalisation. The necessary condition test reveals that none of the six antecedent conditions is essential for digital transformation in the YRD region. This indicates that regional digital transformation in today's era is driven by a complex causal mechanism, rather than being fully determined by a single condition. This finding aligns with global digital transformation research, which also emphasizes the complexity and multifactorial nature of the process.

Second, the study finds that also for the outcome variable regional digital transformation, the composition of antecedent elements has different paths. These configurations illustrate the multiple paths and solutions that can be taken in the face of the transformative trend of digital transformation in the YRD region. Only the deep integration and synergistic interaction of the factors in the paths of the configurations can vigorously promote the digital transformation of the region. The YRD region is representative, and the findings can serve as a guide for other similar regions globally. This highlights the importance of context-specific solutions and the need for regions to identify their unique pathways to digital transformation based on local conditions and resource.

Third, further study of the grouping pattern reveals that there are five paths to promote high-level regional digital transformation, and each path is composed of multiple elements. Based on the results of each conditional configuration, the results are categorised into four types of paths, namely, the ‘talent development’ path, the ‘digitalisation of a diversified economic base’ path, the ‘public factor-oriented’ path and the ‘public factor-orientated’ path. Taking the ‘talent development’ as an example, increasing investment in education, the promotion of general higher education, and the development of infrastructure such as urban networks can synergistically contribute to the promotion of high-level digital transformation. This conclusion has significant research value for other developing countries. It underscores the importance of a holistic approach that integrates talent development, infrastructure, and economic diversification to achieve sustainable digital transformation.

6.2. Limitations of the research

This paper analyses the factors affecting digital transformation in the Yangtze River Delta region as a group, but there are some limitations. Firstly, only six influencing factors affecting digital transformation in the region are selected under the research framework of this paper, which may not be able to comprehensively and systematically characterise the influencing factors of digital transformation of enterprises in the YRD region, and it is necessary to expand the antecedent variables of the study. Second, in terms of sample selection, considering the availability of data, this paper only focuses on the cities with national high-tech zones in the YRD region in 2022, and needs to further expand the sample size to verify the validity of the results of this study. What’s more, the fsQCA research method itself has some limitations, which does not take into account the fact that the influencing factors and driving mechanisms of different development stages of the region may change over time, and the time dimension should be added into the model for a more comprehensive dynamic qualitative comparative analysis in the future.

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