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Research on the Development Path of Digital Economy in Guangdong Province—Based on Fuzzy Set Qualitative Comparative Analysis

Juan Zhang*

School of Information Management and Engineering, Neusoft Institute Guangdong, University Town, Shishan, Foshan, China
zhangjuan@nuit.edu.cn
**Corresponding author*

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Abstract: This study focuses on 21 cities in Guangdong Province and uses Fuzzy Set Qualitative Comparative Analysis (fsQCA) to explore the intricacies of the digital economy's development path in the region. Through configurational analysis, five distinct configurations emerge: economic foundation-driven, higher education level-marketization-led, poor economic foundation-development potential-constrained, lack of core elements of foundation and potential, and impediment of marketization level. The findings highlight the significant impact of economic development, higher education, and marketization levels on digital economy evolution, with nuanced effects contingent on specific city attributes. The study recommends customized policy support based on individual city strengths, advocating for enhanced collaboration to advance the digital economy comprehensively. These insights not only provide valuable policy guidance for formulating urban digital economy strategies but also present a new empirical approach for configurational analysis using the innovative fsQCA method. This contributes to improving both theoretical frameworks and methodological approaches in digital economy research. The implications extend beyond Guangdong Province, offering a benchmark for regions navigating the complex landscape of digital economic development.

1. Introduction

As a key driver of global economic progress, the digital economy assumes an increasingly pivotal role in the ascendancy and progress of Chinese provinces and regions. Guangdong Province has consistently led China's economic landscape, with its thriving digital economy setting a national precedent. Rapid advancements in information technology have steered Guangdong Province away from traditional manufacturing toward a digital and intelligent economic paradigm. Exemplary cities like Shenzhen and Guangzhou showcase robust innovation capabilities, exerting substantial market influence in the global digital economy. The extensive integration of digital technology has fundamentally reshaped the industrial framework, economic landscape, and societal habits in

Guangdong Province. Against this backdrop, what constitutes the core determinants influencing the digital economy's level in Guangdong Province? How do these determinants impact digital economy development? What trajectory does this influence follow? Does the digital economy's influence trajectory remain consistent across Guangdong Province? Investigating these questions holds significant theoretical and practical implications for determining the developmental path of the digital economy. Therefore, a comprehensive exploration of these aspects is warranted.

Since Don Tapscott[1] introduced the concept of the digital economy in his book "Digital Economy," scholars have extensively researched topics related to digital economy development, its influencing factors, and the interplay with high-level economic development, human capital, higher education, and resource endowment. Research primarily concentrates on the following areas:

One aspect is to explore the fundamental factors influencing digital economy development. Wang X[2] discovered a negative correlation between the old-age dependency ratio and the digital economy and a positive correlation with the urban-rural population ratio. Suggestions include accelerating the digitization transformation of the elderly care industry, fostering coordinated urban and rural digital economy development, and enhancing digital talent training. Zhang Y et al[3] identified the eastern region as having the highest digital economy development, primarily influenced by economic foundations. Recommendations include bolstering digital infrastructure, enhancing human capital, and driving the digital transformation of industries. Lv Y[4] exposed regional disparities in digital economic development, emphasizing the need for high-quality digital economy development policies to consider spatial and temporal variations.

Secondly, the digital economy's significant role is examined in tandem with higher education, human capital, and other factors. Song Y et al[5] contend that the digital economy and education levels jointly propel the health industry, with education as a mediating factor. The importance of health among individuals with higher education levels is proposed as a driver for health industry development. Luo X[6] suggests that the digital economy can enhance labor income, particularly benefiting different income groups, with a more pronounced impact on low-income segments. Emphasizing improved digital economic development involves reinforcing digital infrastructure, investing in human capital, and fostering industry and digital technology integration. Gao W[7] [7]asserts that digital economy practitioners exhibit characteristics of high education levels, youthfulness, and skill training. Recommendations include further elevating education levels and intensifying skills training to address the human capital gap in digital economy development.

Third, methodologically, the Qualitative Comparative Analysis (QCA) research method explores causal inferences based on cases and substantive explanations. QCA represents a significant innovation in case-based methodology, with limited applications in the digital economy field to date.

Xia M et al[8] uncovered the synergistic impact of human capital, financial capital, R&D capability, digital infrastructure, government size, and market size on the high-quality development of the digital economy in cities using the fs/QCA approach. Various driving paths and conditions for achieving a high-quality digital economy in cities are suggested to offer theoretical backing for urban digital economy advancement. Yang D[9] presented five pathways for achieving high-quality development driven by the digital economy, encompassing digital industry, digital talent, digital infrastructure, integrated type I, and integrated type II. Meanwhile, Lin Q[10] applied the fsQCA method to unveil the influencing mechanism of economic development level, human resources, R&D capital investment, data resources, innovation capacity, and digital infrastructure interaction on digital economy development.

Overall, the literature above indicates that the development of the digital economy is influenced by various factors, including demographic structure, regional disparities, and industrial integration. Variations exist among regions and industries, requiring tailored policies based on local conditions to foster high-quality development. While these studies contribute to the theoretical foundation of digital economy policies, they have limitations, such as sample selection and methodological constraints. In contrast to existing research, this paper's marginal contribution primarily lies in:

Firstly, this paper employs the fsQCA (Fuzzy-set Qualitative Comparative Analysis) qualitative research method, utilizing fuzzy-set theory to examine the relationship between conditions and outcomes. In contrast to traditional regression analysis methods, fsQCA excels in accommodating nonlinear relationships, incorporating multifactor analyses, and addressing path dependence and fuzziness in specific research topics.

Secondly, this paper examines the influence of various urban characteristics in Guangdong Province on the digital economy and explores the synergistic effects of influencing factors. It also investigates potential hindrances in the synergy path through group state analysis. Currently, there is limited literature on the development of the digital economy in Guangdong Province using group state analysis.

2. Research Design

2.1. Research Methodology

The fsQCA is a qualitative comparative analysis method based on fuzzy set theory. It is primarily employed to investigate how condition variables collaboratively contribute to a specific state of an outcome variable. The principle of the fsQCA method is as follows: Consider a research problem with n conditional variables $X_1, X_2, \dots, X_n$, and an outcome variable Y. Each conditional variable can assume two values, i.e., present (1) or absent (0). Thus, every possible combination of conditions A can be represented as an n-tuple, with each element being either 0 or 1. [11]

$$A \subseteq \{0.1\}^n \tag{1}$$

We observe the frequency of each conditional combination A in our sample, denoted as $N(A)$. A truth table is then constructed, listing the value of the outcome variable Y for each conditional combination A along with the corresponding frequency. This facilitates an understanding of each combination's contribution to the outcome. Additionally, in fsQCA, a threshold is set, typically used to differentiate between "presence" and "absence".

Subsequently, by analyzing the truth table, logical operations in fuzzy set theory are employed to identify condition combinations influencing the outcome variable Y. This involves establishing the relationship between $A \Rightarrow Y$ and $A \Leftarrow Y$, indicating that specific condition combinations are either sufficient or necessary conditions for Y. Simultaneously, formulas like consistency and coverage are calculated to further evaluate the model's quality and applicability. The consistency formula is:

$$inclN_{X \Leftarrow Y} = \sum \min(X,Y) \Big/ \sum Y \tag{2}$$

The coverage formula is:

$$\operatorname{cov} N_{X \Leftarrow Y} = \sum \min(X,Y) \Big/ \sum X \tag{3}$$

If $A \Rightarrow Y$, it implies that A is a sufficient condition for Y.

The consistency is calculated using the following formula:

$$inclS_{X \Rightarrow Y} = \sum \min(X,Y) \Big/ \sum X \tag{4}$$

The fsQCA method integrates logical analysis and fuzzy set theory, providing researchers with a qualitative approach to address the intricate effects of multiple conditions on outcomes. In this study, fsQCA is employed to examine how the combined impacts of five dimensions—higher education level, scientific and technological innovation level, economic development level, market index, and financial support—comprehensively influence the digital economy's development in Guangdong Province. The aim is to identify the conditions that facilitate high-level digital economy development and those that hinder it.

2.2. Description of research cases and variables

2.2.1. Study Cases

This paper chooses 21 cities in Guangdong Province as study cases because the province, a crucial driver of China's economy, consistently exhibits top-tier economic volume and innovation capacity nationwide. Cities like Shenzhen and Guangzhou, notable for their advanced digital economies, serve as representative examples. Analyzing these cities provides a more precise understanding of the primary trends and features of China's digital economy.

Guangdong Province's cities exhibit significant variations in economic development, geographic location, and industrial structure. This diversity enables researchers to gain a comprehensive understanding of how different factors influence digital economy development. It also captures the diverse paths cities take toward digital economy development, offering a comprehensive reference for practical policy formulation.

The selection of 21 cities encompasses those with both high and relatively low levels of digital economy development. This inclusivity allows researchers to comprehensively explore potential differences in the impact of each influencing factor on the digital economy across cities.

Hence, selecting 21 cities in Guangdong Province as the research sample contributes to a more comprehensive understanding of the paths influencing digital economy development, considering aspects of representativeness, comprehensiveness, exemplarism, and inclusiveness. It also facilitates offering more precise and practical policy suggestions for the future.

2.2.2. Variable Selection

Table 1: Measurement of Variables and Data Sources.

	Indicator Level	Specific Indicator Measurement Method	Description Source
Outcome Variable	Digital Economy Composite Index	Principal Component Method	Guangdong Statistical Yearbook, China Digital Financial Inclusion Index
Conditional variables	Level of scientific and technological innovation	Internal Expenditure on R&D/GDP	China Urban Statistical Yearbook
	Level of economic development	Real GDP per capita	China Urban Statistical Yearbook
	Level of marketisation	Calculated by Fan Gang Marketisation Index	Calculated
	Financial support	Total amount of credit from all types of financial institutions / GDP	China Urban Statistical Yearbook
	level of higher education	Number of general undergraduates (10,000)/resident population	China Urban Statistical Yearbook

This study employs the methodology introduced by Zhao T et al[12] to assess the comprehensive development of the digital economy, utilizing five indicators: Internet users per 100 people, the percentage of computer services and software employees, the total amount of telecommunication services per capita, the number of mobile phone subscribers per 100 people, and the digital financial inclusion index. Data is sourced from the China Urban Statistical Yearbook 2022. The digital financial inclusion index is derived from China's digital financial inclusion index, a collaborative effort by the Digital Finance Research Centre of Peking University and Ant Gold Service Group. Through principal component analysis, the indicators across these five dimensions are standardized and subjected to dimensionality reduction, resulting in a comprehensive digital economy measurement index.

Regarding the conditional variables, taking data availability into account, this study chooses variables related to the level of scientific and technological innovation, economic development, marketization, financial support, and higher education. These are displayed in Table 1:

2.2.3. Data calibration

To ensure consistent scales and metrics for the fuzzy set data used in the analysis, the direct calibration method by Ragin and Fiss [13] was employed. The 5%, 50%, and 95% quantiles were calculated for each variable. Values below the 5% quartile were set to 0 for complete non-affiliation, those between 5% and 95% were scaled between 0 and 1 for crossover, and values exceeding the 95% quartile were set to 1 for complete affiliation. Due to the small sample size, the 0.5 affiliation was adjusted to 0.501 to address issues in carrying over to truth table analysis. The same steps were applied for other variables, yielding a pooled affiliation ranging from 0 to 1 for subsequent fsQCA analyses.

3. Analysis of empirical results

Table 2: Configuration condition sufficiency analysis.

Conditional variables	Grouping that generates a high level of digital economy		Grouping that generates a non-high level of digital economy				
	H1	H2	NH1	NH2	NH3	NH4	NH5
Level of science, technology, and innovation	●	○	○				○
Level of economic development	★	○		☆	☆	●	☆
Level of marketisation	★	★	☆	☆	●	☆	
Financial support	●	○	○	○	●	○	●
Level of higher education		★		☆	☆	●	☆
Consistency	0.829	0.948	0.866	0.945	0.997	0.969	0.997
Original coverage	0.626	0.315	0.595	0.547	0.322	0.326	0.357
Unique coverage	0.390	0.079	0.038	0.009	0.018	0.034	0.015
Total consistency	0.843		0.883				
Total coverage	0.705		0.736				

Note: ●indicates that the edge condition exists, ○ indicates that the edge condition does not exist, ★ indicates that the core condition exists, ☆ indicates that the core condition does not exist, and blank indicates that the condition exists or not.

The fsQCA method categorizes solutions into three types—complex, simple, and intermediate—based on the handling of the "logical remainder." Intermediate solutions, aligning better with academic standards, demonstrate greater consistency with theoretical and practical knowledge[14]. Utilizing the group analysis framework proposed by Ragin and Fiss, we examined 21 cities in

Guangdong Province. By selecting conditions with frequency greater than 1 and consistency greater than 0.8, we identified two high-level digital economy development paths. These paths exhibit strong consistency, with a solution consistency of 0.843, indicating an 84.3% alignment of cities with high-level digital economy development. Furthermore, the solution's coverage is 0.705, reflecting substantial explanatory power. Notably, the level of higher education, economic development, and marketization emerge as core conditions in both parsimonious and intermediate solutions, underscoring their pivotal role in high-level digital economy development. Conversely, other conditions are deemed marginal, absent from the core solution.

Concurrently, we calculated five paths representing non-high-level digital economy development. These paths exhibit high consistency, reaching 0.883, implying that 88.3% of cities conforming to these paths display a non-high-level digital economy. The solution's coverage is 0.736, denoting robust explanatory power for these five paths. Group condition sufficiency analysis details are presented in Table 2:

3.1. Analysis of Paths Leading to High-Level Digital Economy

Grouping 1: Driven by the Economic Foundation

The consistency result for this group is 0.829, with an initial coverage of 0.626, explaining 62.6% of the sample data. Core factors in this group center around the level of economic development and marketization. Specifically, cities in this group demonstrate strong economic performance, and their marketization level is relatively high. These cities are characterized by a robust economic base, where the digital economy took root early and has a well-established foundation for development.

Representative cities, such as Guangzhou, Shenzhen, Dongguan, Foshan, and Jiangmen, stand out due to their robust economic foundation and efficient market mechanisms, positioning them as pioneers in the high-quality development of the digital economy. These cities showcase a rapid ascent in the digital economy, where the development and marketization levels mutually reinforce each other, creating a positive feedback loop.

Cohort 2: Led by Higher Education and Marketisation

This group exhibits a consistency result of 0.948, with an initial coverage of 0.315, explaining 31.5% of the sample data. Core factors in this group primarily revolve around higher education and marketization levels. Cities in this group excel in tertiary education, and their marketization level is comparatively high. However, in comparison to other pathways, this cohort exhibits relative weaknesses in the levels of science and technology innovation, economic development, and financial support. Representative cities in this group include Shaoguan and others. Despite a relatively late start in the digital economy and weaker foundational conditions, these cities exhibit significant development potential due to their high levels of higher education and marketization.

3.2. Analysis of Paths with Non-High-Level Digital Economy Development

Cohort 1: Limited by Marketisation Level type

This group exhibits a consistency result of 0.866 with an original coverage of 0.595, explaining 59.5% of the case sample data. It suggests that the combined impact of a core condition—low marketization level—and peripheral conditions—low levels of science and technology innovation and financial support—results in a non-high level of digital economy development.

Representative cities, such as Yangjiang, Shantou, Maoming, Yunfu, and others, typically face challenges like inadequate capital investment, limited innovation capacity, and small industry scale in digital industry development. The combined impact of these factors contributes to the relatively challenging development of the digital economy industry in these cities. In comparison to the eastern part of Guangdong, these cities experience lower R&D investments, weaker innovation capacity, and relatively lagging levels of marketization and financial support.

Grouping 2: Constrained by Weak Economic Foundation and Development Potential

This group exhibits a consistency result of 0.945 with an original coverage of 0.547, explaining 54.7% of the case sample data. Core factors primarily include low levels of higher education, marketization, and economic development. Simultaneously, low financial support acts as a peripheral condition, further worsening the relatively weak level of the digital economy in these cities.

Representative cities in this group, such as Shantou and Yunfu, face significant constraints on digital economy development due to relatively low levels of higher education, insufficient marketization, and relatively lagging economic development. Additionally, the low level of financial support further hinders these cities from rapid advancement in the digital economy.

Grouping 3: Deficient in Fundamental and Potential Core Elements

In Group 3, cities exhibit a deficiency in fundamental and potential core elements, with a consistency result of 0.997 and an original coverage of 0.322, explaining 32.2% of the case sample data. Core factors focus on low levels of higher education and economic development. Although this grouping displays a good level of marketization and financial support as marginal conditions, the lack of economic fundamentals and core elements of digital economy potential hinders the development of the digital economy in these cities. Representative cities include Heyuan and Qingyuan. Despite performing well in marketization and financial support, the failure to fully unlock the potential of the digital economy is attributed to low levels of higher education and relatively lagging economic development.

Grouping 4: Hindered by Marketisation Levels

Group state 4 illustrates that the hindered development of the digital economy is attributed to low marketization levels. The consistency result is 0.969, with an original coverage of 0.326. The core factors primarily focus on the low marketization level. Despite possessing a relatively good level of economic development and higher education as marginal conditions, along with the marginal condition of low financial support, these factors collectively impede the development of the digital economy in such cities. Representative cities, such as Maoming and Zhaoqing, exhibit reasonable performance in economic development and higher education, yet the low level of marketization constrains the digital economy's development.

Configuration 5: Resistant to Basic and Innovative Factors

Pattern 5 exhibits a consistency result of 0.997, with an original coverage of 0.357. The core factors primarily focus on the low level of higher education and economic development. Although this grouping has relatively good financial support as an edge condition, coupled with the edge condition of low levels of scientific and technological innovation, these factors collectively create resistance to the development of the digital economy in this type of city. Representative cities, such as Heyuan and Meizhou, encounter relatively weak capabilities in science and technology innovation within the context of low levels of higher education and economic development. This implies that providing financial support alone is insufficient to enhance the level of the digital economy.

3.3. Robustness test

Following Fiss's [15] approach, this study employs the consistency threshold increase method. It raises the consistency threshold of conditional histogram analysis from 0.8 to 0.85, keeping all other treatments unchanged. The purpose of this robustness test is to assess the reliability of the analysis results under different consistency thresholds—determining if the outcomes remain stable enough to uphold the study's primary conclusions.

Upon comparing the results with the original outcomes, we observe that the overall level of consistency has not changed significantly. The results also remain largely consistent regarding the grouping paths of the non-high-level digital economy. Notably, the grouping paths for high-level digital economies exhibit changes in individual edge conditions, but these alterations have not reversed the main trends. This indicates that the realization of a high-level digital economy is still influenced by similar core conditions, confirming the generalizability of these conditions across different settings. The relative stability of these results is confirmed in the context of increased consistency thresholds. The outcomes of the robustness tests strengthen the reliability and stability of the digital economy development pathways and related conditions identified in this study.

4. Economy Implications

The interplay of dimensions highlights the complexity and diversity in enhancing the digital economy. Cities must consider the interplay of various factors comprehensively when formulating their strategies for digital economy development. In this context, cities should explore diverse paths for digital economy development in the region. This exploration should be based on their unique development advantages, factor endowments, and the synergies between multiple factors. The following are policy implications based on this view:

1) Leverage Development Advantages: Cities should recognize and exploit their strengths in higher education, marketization, and economic base. They can establish a competitive path for digital economy development by delving into and leveraging these advantages.

2) Tailor Policy Support: The government should implement tailored policy support measures based on the development paths and characteristics of individual cities. For cities driven by economic foundation, support for key industries should be heightened. For cities leading in higher education and marketization, collaboration between universities and industries should be reinforced to boost scientific and technological innovation.

3) Enhance Cross-Dimensional Synergies: When formulating policies, emphasize synergies between different dimensions. The government can promote deep collaboration between higher education institutions, enterprises, and research institutes to facilitate synergistic improvement in marketization and scientific and technological innovation. This enables multi-dimensional complementary development.

4) Cultivate Digital Economy Potential: For cities facing constraints due to poor economic foundation and lack of development potential, the government can enhance the cultivation of digital economy potential. This can be achieved by guiding financial support and backing innovative enterprises, facilitating the development of the digital economy in these cities.

5) Tackle Marketisation Challenges: For cities facing impediments to marketization, the government should conduct a thorough analysis of marketization bottlenecks. It should then implement effective measures to address these challenges, unlocking the potential for digital economy development. Promoting marketization can involve reducing market access barriers and advancing digital inclusive finance.

During the implementation of these policy insights, cities should closely consider the interplay between different dimensions. They should develop an organically integrated digital economy development strategy to promote the synergistic advancement of various elements, achieving an overall enhancement of digital economy development.

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