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The Synergistic Evolution of Resilience and Efficiency in the Digital Economy and Its Path Identification: Evidence from China

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Abstract: An effective combination of resilience and efficiency will help to promote the high-quality development of the digital economy. In this paper, we use the entropy method, the Super-SBM model, and the Haken model to measure the digital economy resilience, digital economy efficiency, and their synergistic evolution mechanisms in 31 Chinese provinces and autonomous regions from 2013 to 2020, respectively. The results show that: (1) The resilience of the digital economy is the order parameter leading synergistic development, playing a prominent role in promoting the development of the digital economy from disorder to order. (2) Synergistic evolution has evolved from low-level to high-level, but it is in the primary stage as a whole, and the fluctuation of its development is not obvious, showing a unipolar development pattern. (3) There are significant regional differences in synergistic evolution, showing a polarization pattern, with the "Matthew effect" that the stronger the start the stronger the development. (4) Overall, the resilience and efficiency of the digital economy show a positive synergistic effect, but some provinces show a negative feedback mechanism that inhibits the orderly development of the system, there is a bias effect, and the development levels of the resilience and efficiency of the digital economy are mismatched. (5) The four paths that drive the synergistic evolution of resilience and efficiency in a high digital economy are the "Resilience Dominates Driven Path", the "Basic Driven Path", the "Innovation Driven Path", and the "Balanced Driven Path", respectively. In short, the synergistic evolution of the resilience and efficiency of the digital economy shows that the future development of the digital economy needs to cultivate endogenous momentum, pay attention to strengthening resilience in the process of continuing to build a diversified industrial system, and continuously improve the operational efficiency of the digital economy, in order to promote its high-quality development.

Keywords: digital economy; resilience; efficiency; synergy

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1. Introduction

According to the China Digital Economy Development Research Report (2023), the average annual growth rate of China's digital economy from 2012 to 2022 was 16.39%, much higher than the average growth rate of its GDP during the same period. As a new economic pattern, the development mode, structure, and efficiency of the digital economy reflect, to a certain extent, the stage characteristics of China's high-quality economic development. At present, China's economy is in the "three-phase superposition" (growth-rate-shifting period, structural adjustment pain period, and economic stimulus digestion period), and the development of the digital economy will pay more and more attention to efficiency improvement. It can be seen that the efficiency of resource allocation has become an urgent requirement for the sustainable development of the digital economy. However, by simply emphasizing the goal of achieving high efficiency, the system tends to generate high-correlation properties within the system, leading to insufficient space for internal resilience. When faced with unexpected shocks, especially in the "VUCA" era, the unilateral pursuit of efficiency is likely to produce catastrophic dilemmas. However, over-emphasis on resilience can lead to resource redundance [1,2]. Therefore, in the face of the uncertainty of the external environment and the requirements of sustainable development, resilience and efficiency have become two core essentials for the healthy development of the digital economy. Clarifying the synergistic evolutionary development between the two and how to enhance the efficiency of digital economic development while maintaining the resilience of the digital economic system will become important parts of the study to promote the high-quality development of the digital economy in the new period.

Resilience, as a concept in physics, refers to the process of the recovery and growth of an object in the face of the impact of external forces [3]. With the in-depth study of resilience, it has developed from engineering resilience to ecological resilience, and then to evolutionary resilience, and its research field has gradually expanded from physics to social science disciplines such as ecology, sociology, and economics [4]. Fujita and Thisse (2002) first put forward "economic resilience", which has become an important indicator for the study of the synergistic, dynamic evolution of the internal system of the economy and the external environment, as well as effective governance [5]. At present, the economic resilience research results are relatively rich. For example, Crescenzi et al. found that, for EU countries, fiscal surplus is an important guarantee of national economic resilience, while human capital and core industries have a more significant impact on regional economic resilience [6]. Lu and Teng took 281 Chinese cities as their research object to test the impact of innovation-driven policies on the economic resilience of these cities [7]. Modica and Reggiani analysed the characteristics of spatial economic resilience, considering the concept of resilience using the relevant theories of spatial economics [8]. Liu et al. used 151 macroeconomic indicators to measure macroeconomic resilience, arguing that it is affected by economic conditions, monetary cycles, and total factor productivity [3]. Tóth et al. used data from 269 metropolitan areas in Europe and found that regional patent co-operation network resilience can significantly affect regional economic resilience [9]. Li et al. took the Yangtze River Delta urban agglomeration as their research object to analyse the impact of urban industrial evolution path dependence on economic resilience [10]. It can be seen that the existing research on economic resilience mainly explores the concept, evolution, and influencing factors of economic resilience considering the aspects of region, industry, and policy, the research object involves the national level and the city level, and the research perspective involves the time, space, and network dimensions. However, there are fewer studies on the measurement and evolution path of digital economic resilience, and there is the lack of systematic analysis of digital economic resilience.

Scholars have made certain achievements in the research of digital economic efficiency, mainly focusing on the measurement and evaluation of digital economic efficiency. The measurement methods for digital economic efficiency mainly include the industry efficiency measurement model, Spatial Markov Chain, Data Envelopment Approach (DEA), DEA-Malmquist dynamic index model, and Super-SBM model [11–13]. Among them, the data envelopment method has been adopted by some scholars for its non-parametric estimation nature of not having to give a specific production function. For example, Cai et al., Zhao, and Qi measured the efficiency of the digital economy by using the data envelopment method [13–15]. However, the traditional DEA model has the shortcoming of finding it difficult to distinguish between multiple effective frontier surfaces, and it is easy to ignore the relaxation of inputs and outputs. The Super-SBM model, on the other hand, is a non-radial and non-angle model proposed based on relaxation, which has been adopted by many scholars. For example, Liu et al., Wang et al., and Liu et al. used the Super-Efficiency SBM model to explore regional digital economy efficiency differences [16–18].

The synergistic development between resilience and efficiency has been explored in the context of transport networks, the sustainable development of water resources, the marine economy, and urban systems [2,19–22]. In the context of high-quality and sustainable development, the coexistence of the specialisation and diversification of the economic structure requires that the digital economic system should not only maintain operational efficiency, but also have the resilience to withstand external shocks, and serve as the main driving force of national development to improve the quality and speed of national economic growth. However, most existing studies have studied economic resilience and digital economic efficiency as independent factors [8,11,18], and have not analysed the systematic evolution of digital economic resilience and digital economic efficiency as two interrelated systems. Based on this, this paper takes 31 provinces, cities, and autonomous regions in China as the research object (in view of the availability of data, the research object does not include the Taiwan Province, Hong Kong Special Administrative Region, and Macao Special Administrative Region), constructs a digital economy resilience evaluation index system based on the evolutionary resilience theory and TOE theory, and measures the level of the development of the digital economy efficiency using the Super-SBM model. On this basis, the Haken model is used to explore the synergistic evolution mechanism of digital economic resilience and efficiency, aiming to clarify the direction of the high-quality development of China's digital economy in the new period.

2. Digital Economy Resilience and Efficiency Measures and Data Sources

2.1. Evaluation of the Resilience of the Digital Economy

There are three main approaches to measuring economic resilience: the core variable method, the economic model, and the indicator system. Among them, the core variable method mainly measures economic resilience with a variable that is sensitive to external shocks and can reflect the economic operation, but it is difficult for this method to comprehensively include multiple dimensions of resilience [23]. The economic model, on the other hand, combines the core variables with the economic model to measure resilience, but it is easy to ignore the necessary theoretical foundations in empirical research [24]. The method of the indicator system is able to consider the development of economic resilience comprehensively, considering multiple dimensions. Although scholars focus differently on the evaluation of economic resilience, they all include the system's ability to resist, recover, adjust, and innovate in the face of shocks, which is used more frequently in existing research.

On the basis of economic resilience research, this paper defines digital economic resilience from an evolutionary perspective, taking into account the characteristics of digital economic development. Digital economic development from an evolutionary perspective has distinctive dynamic evolutionary features, including not only the ability to resist and recover from the impact of external uncertainties, but also the ability to adjust and adapt in the post-impact era, as well as the ability to innovate and transform to a more advanced stage of evolution. However, this evolutionary process coincides with the TOE theory of the diffusion of emerging digital technology applications, which analyses the impact of the technology application context on the application effect from technology, organization, and environment (Figure 1). Specifically, the technology dimension mainly includes the scale of existing digital technologies and technological leapfrogging. The organization dimension mainly involves the development level of enterprises or the regional digital economy. The environmental dimension involves the construction of digital economy infrastructure and the degree of support and attention given to the digital economy by local governments. Therefore, this paper divides the resilience of the digital economy into three primary evaluation indicators (Table 1): organisational resistance and recovery ability (OR), environmental adjustment and adaptive capacity (EA), and technological innovation and transformation capacity (TI). OR is mainly measured by two secondary indicators: the digital industry scale and industrial digital empowerment. EA is mainly measured by two secondary indicators: the hardware development environment and software governance and regulation. TI is measured by two secondary indicators: technology R&D support and digital product results. Drawing on the research of the scholars Pan Weihua et al. (2021), Jiao Yong (2021), and Wang Shengpeng et al. (2022), a total of 23 tertiary indicators are used to evaluate the digital economy resilience index [25–27].

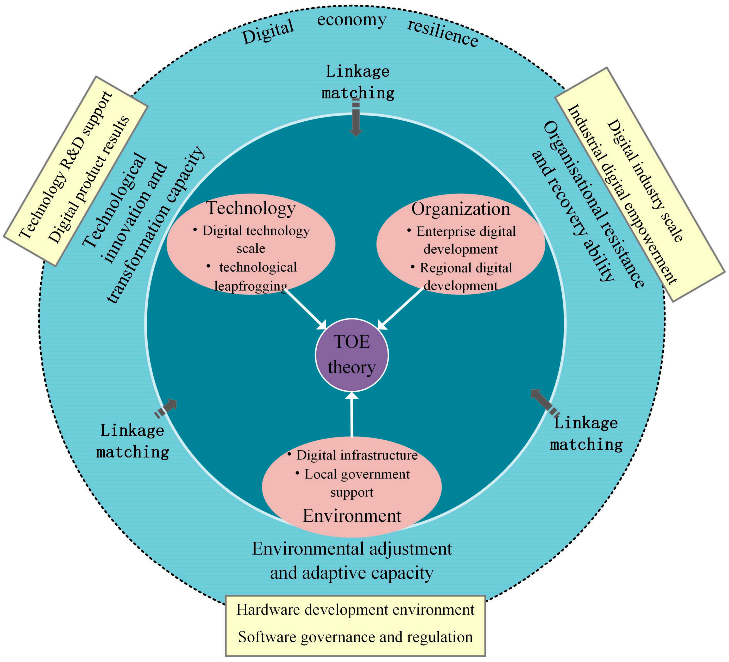


Figure 1. Theoretical framework for digital economic resilience. Source: Authors, 2023.

Table 1. Digital economy resilience evaluation index system.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Unit	Weight
Organisational resistance and recovery ability (OR)	Digital industry scale	The gross industrial output value of the digital industry	10^8 yuan	0.168
		The number of employees in the digital industry	10^4 persons	0.118
		Revenue from software operations	10^8 yuan	0.190
		Revenue from telecommunication services	10^8 yuan	0.058
	Industrial digital empowerment	E-commerce sales	10^8 yuan	0.131
		The coverage rate of enterprise websites	%	0.056
		Enterprise website coverage	%	0.023
		The digital inclusive finance index	/	0.067
		The number of express business	10^4 pieces	0.188
Environmental adjustment and adaptive capacity (EA)	Hardware development environment	Value added of tertiary industry as a proportion of GDP	%	0.152
		The number of internet domain names	Ten thousand	0.129
		Mobile phone penetration rate	1 mobile phone/100 persons	0.124
		Length of long-distance fibre-optic cable routes	Kilometres	0.096
		Internet broadband penetration	%	0.082
	Software governance and regulation	Total government investment in science and technology	10^4 yuan	0.192
		The level of digital government affairs	Sites	0.188
		The government political microblogging competitiveness index	/	0.037

Table 1. *Cont.*

Primary Indicators	Secondary Indicators	Tertiary Indicators	Unit	Weight
Technological innovation and transformation capacity (TI)	Technology R&D support	R&D full-time equivalent of full staff input	Person-year	0.229
		R&D investment intensity	%	0.099
		Students enrolled in higher education per 100,000 population	Person	0.055
		Expenditure on education and science and technology as a share of total fiscal expenditure	%	0.066
	Digital product results	The number of patent applications received	Patent	0.261
		Technology market turnover	10^8 yuan	0.290

Source: Authors, 2023.

2.2. Sample Selection and Data Processing

The Global Digital Economy White Paper (2023) released by the China Academy of Information and Communications Technology (CAICT) shows that the development of the digital economies in five major countries across the world, including the United States, China, Germany, Japan, and South Korea, continues to accelerate, with a total volume of $31 trillion, accounting for 58 per cent of GDP. From a country-specific perspective, China's digital economy will grow at a compound annual growth rate of 14.2% from 2016 to 2022, which is 1.6 times higher than the overall average annual growth rate in line with the digital economies of the five countries of the U.S., China, Germany, Japan, and South Korea during the same period. Although the scale of China's digital economy is the second-largest in the world, its growth rate is the fastest. It can be seen that, in China, in the face of the "three phases" of economic downward pressure, the digital economy is a new driving force for economic growth and has become an important pillar of the national economy. Although the development of China's digital economy has been on the rise year by year, there are significant regional differences, showing a spatial pattern, in which the eastern provinces are developed, the central and western provinces lag behind, and the northeastern provinces develop slowly. Therefore, China has put forward higher requirements for the development of its digital economy after it has become the main driving force of its economic development. There is an urgent need to address the high-quality development of China's digital economy through multi-factor synergistic optimisation to enhance the efficiency of the digital economy while maintaining its sustainable development.

In the above indicators, the gross industrial output value of the digital industry is measured by the gross industrial output value of the manufacturing industry of communications equipment, computers, and other electronic equipment. The number of employees in the digital industry is measured by the number of urban employees in the information transmission, software, and information technology services industries. The informatisation level is measured by the proportion of enterprises managed by informatisation. The coverage rate of enterprise websites is measured by the proportion of enterprises with websites. The Digital Inclusive Finance Index is from the "Peking University Digital Inclusive Finance Index (Third Issue, 2011–2020)" published by the Research Group of Digital Finance Centre of Peking University. The level of digital government affairs is measured by the number of websites owned by the government. The government political microblogging competitiveness index is published by the People's Daily Online Public Opinion Centre. This paper adopts the entropy value method to determine the weights of each index of digital economic resilience, measuring the resilience comprehensive evaluation score on this basis. The relevant data in this paper come from the China Science and Technology Statistical Yearbook, China Population and Employment Statistical Yearbook, China Statistical Yearbook, and the statistical yearbooks of the provinces. In order to eliminate the influence of the time factor, the price-type indicators in the above indicators are treated as constant prices, with 2013 as the base period and the missing data being supplemented by the linear interpolation method.

2.3. Evaluation of the Efficiency of the Digital Economy

Efficiency emphasises performance at maximum capacity with the minimum use of scarce resources. For the measurement of efficiency, this study draws on the slack-based Super-efficient SBM (Super-SBM) model proposed by Tone (2001) to measure the efficiency of the digital economy's inputs and outputs [28]. Assuming that there are n decision-making units (DMUs), with each DMU containing m inputs and g outputs, the Super-SBM formula is:

$$\rho* = \min \frac{1 + \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{ik}}}{1 - \frac{1}{g}\sum_{r=1}^{g} \frac{s_r^+}{y_{rk}}}$$
$$s.t. \begin{cases} x_k \geq X\lambda - s^- \\ y_k \leq Y\lambda + s^+ \\ 1 - \frac{1}{g}\sum_{r=1}^{g} \frac{s_r^+}{y_{rk}} > 0 \\ \lambda \geq 0,\ s^- \geq 0,\ s^+ \geq 0 \\ i = 1,\ 2, \ldots,\ m \\ r = 1,\ 2, \ldots,\ g \end{cases} \tag{1}$$

where s^- is the slack variable of the digital economy input. s^+ is the slack variable of the digital economy output. X and Y are the digital economy input and output matrices, respectively. λ is the weight of the matrix. $\rho*$ is the final efficiency value, generally with a larger value representing a higher efficiency of the digital economy.

Drawing on the research of the scholars Qi, Zhao, and Liu et al. [13,15,18], the digital economy input–output efficiency indicator system is shown in Table 2. Among them, for the input indicators, capital, labour, and infrastructure are selected as input factors, and the intensity of R&D funding, number of employees in the digital industry, and number of internet broadband access ports are used as proxy variables, respectively. As for the output indicators, technical output and economic output are selected as output elements, and the number of invention patent applications received and total industrial output value of the digital industry are used as proxy variables, respectively.

Table 2. Digital economy input–output efficiency indicator system.

Category	Primary Indicators	Secondary Indicators
Input	Capital input	R&D investment intensity
	Labour input	The number of employees in the digital industry
	Infrastructure investment	The number of internet broadband access ports
Output	Technical output	The number of patent applications received
	Economic output	The gross industrial output value of the digital industry

Note: Secondary indicator proxy variables are consistent with those in the resilience indicator system. Source: Authors, 2023.

2.4. Evaluation of Synergistic Evolution

Due to the complexity of the digital economy system itself, changes in any of the subsystems within it will cause changes in the whole system. There is a complex, non-linear relationship between the elements of the two subsystems of the digital economy, resilience and efficiency, and the evolutionary state of the system changes to some extent as the variables of the subsystems change. When the period exceeds the critical value of its evolution, the system will undergo a qualitative change, thus forming a new evolutionary structure. The Haken model is a model proposed by Haken (1977) to analyse the degree of orderliness in complex systems [29]. He argued that, during the evolution of a system, the parameter damping values of each subsystem are different, and the rate of change of the parameter state is not the same. The larger the damping value, the faster the parameter decays and is a fast variable. The smaller the damping value, the slower the parameter changes, which makes it a slow variable and also an order parameter. The order parameter can dominate the evolutionary direction of the system. When the order parameter exceeds the stability point of the system, a new ordered structure of the system will occur. Therefore, this paper chooses the Haken model to study the synergistic evolution of digital economic toughness and efficiency, analyse the dominant parameters in the evolution process of the two, and provide a basis for the synergistic development of digital economic resilience and efficiency from an empirical point of view.

The specific calculation steps of the Haken model assume that q_1 is the order parameter of the system and q_2 is the fast variable of the system, and the equations of the motion of the system are as follows:

$$\dot{q}_1 = -\gamma_1 q_1 - a q_1 q_2 \tag{2}$$

$$\dot{q}_2 = -\gamma_2 q_2 + b q_1^2 \tag{3}$$

where $\dot{q}_1$ and $\dot{q}_2$ are the derivations of the state variables to time; q_1 and q_2 are the state variables; and γ_1, γ_2, a, and b are parameters of the equation of motion, and their magnitude can reflect the evolution behaviour of the total system. γ_1 and γ_2 are damping coefficients, $\gamma \neq 0$. When $\gamma_1 < 0$, it indicates that the q_1 subsystem presents a positive feedback mechanism, and the larger the absolute value, the higher the degree of order; when $\gamma_1 > 0$, it indicates that the q_1 subsystem establishes a negative feedback mechanism, and the larger the absolute value, the higher the degree of disorder; when $\gamma_2 < 0$, it indicates that the q_2 subsystem establishes a positive feedback mechanism, and the larger the absolute value, the higher the degree of order; and when $\gamma_2 > 0$, it indicates that the q_2 subsystem presents a negative feedback mechanism, and the larger the absolute value, the higher the degree of disorder. a and b are constants, reflecting the interaction strength of q_1 and q_2, respectively. When $a < 0$, q_2 has a promoting effect on q_1, and the larger the absolute value is, the more significant the promoting effect is. When $a > 0$, q_2 has an inhibitory effect on q_1, and the larger the absolute value is, the more significant the inhibitory effect is. When $b < 0$, q_1 has an inhibitory effect on q_2, and the larger the absolute value is, the more significant the inhibitory effect is. When $b > 0$, q_1 has a promoting effect on q_2, and the greater the absolute value, the more significant the promoting effect. When $q_1 = q_2 = 0$, $|\gamma_2| \gg |\gamma_1|$, and $\gamma_2 > 0$, the system satisfies the "adiabatic approximation assumption", and $q_2 = 0$, then

$$q_2 = \frac{b}{\gamma_2} q_1^2 \tag{4}$$

Substituting Equation (4) into Equation (2) shows that:

$$\dot{q}_1 = -\gamma_1 q_1 - \frac{ab}{\gamma_2} q_1^3 \tag{5}$$

Then, the potential function for the system is obtained by integrating the inverse of $\dot{q}_1$. The state of the system can be evaluated by solving the potential function.

$$v = \frac{1}{2}\gamma_1 q_1^2 + \frac{ab}{4\gamma_2} q_1^4 \tag{6}$$

Determine the parameters γ_1, γ_2, a, and b of the equations of motion and determine the evolutionary state of the system. If the system is in a steady state, determining the solution q^* from Equation (5) equals 0. When $\gamma_1 \times \gamma_2 \times a \times b > 0$, there exists a unique solution to the equation, $q^* = 0$. When $\gamma_1 \times \gamma_2 \times a \times b < 0$, there exists three solutions to the equation, which are 0, $-\sqrt{\left|\frac{\gamma_1\gamma_2}{ab}\right|}$, and $\sqrt{\left|\frac{\gamma_1\gamma_2}{ab}\right|}$. If the order parameter is a positive indicator, the stable solution is uniquely determined to be $q^* = \sqrt{\left|\frac{\gamma_1\gamma_2}{ab}\right|}$, namely, the stable point in the potential function is $(q^*, v(q^*))$.

Unlike the above formulas, the indicators studied in this paper are discrete variables, so Equations (4) and (5) are discretized as:

$$q_1(t) = (1-\gamma_1)q_1(t-1) - aq_1(t-1)q_2(t-1) \tag{7}$$

$$q_2(t) = (1-\gamma_2)q_2(t-1) + bq_1(t-1)q_1(t-1) \tag{8}$$

2.5. Analysis of Path Identification

(1) The DEMATEL method

DEMATEL is a method that uses matrix and graph theory to determine the interactions between the factors within a system, and is able to analyse the interdependence between indicators and clarify the causal mechanism between factors. The formula is as follows:

First, the direct influence mechanism relationship matrix R among the indicators is constructed according to the variables:

$$R = (r_{jm})_{s\times s} = \begin{bmatrix} r_{11} & \cdots & r_{1s} \\ \vdots & \ddots & \vdots \\ r_{11} & \cdots & r_{ss} \end{bmatrix} \tag{9}$$

where $r_{jj} = 0$, $r_{jm} = \frac{\omega_j}{\omega_m}$, and r_{jm} is the importance of the jth indicator relative to the mth indicator.

Second, the relationship matrix R is normalized and the matrix L is obtained:

$$L = \frac{R}{\max\limits_{1\le j\le s}\left(\sum\limits_{m=1}^{s} r_{jm}\right)} \tag{10}$$

Third, the comprehensive influence full correlation matrix T is obtained:

$$T = (t_{jm})_{s\times s} = L(I-L)^{-1} \tag{11}$$

Finally, calculate the degree of influence F_j, the degree of being influenced D_j, and the degree of cause G_j between each variable:

$$F_j = \sum_{m=1}^{s} t_{jm} \tag{12}$$

$$D_j = \sum_{m=1}^{s} t_{mj} \tag{13}$$

$$G_j = F_j - D_j \tag{14}$$

where the degree of cause G_j indicates the causal relationship between the jth indicator and other indicators; if it is positive, it indicates that the influence of the indicator on the other indicators is greater than the influence of the other indicators on it, which is the cause factor. Otherwise, it is the result factor.

(2) Qualitative comparative analysis methods

The configuration theory analyses the relationship between the factor configurations and outcome variables from a holistic perspective, emphasising the complexity of the causality and arguing that there are multiple paths that can produce the same outcome (Ragin, 2014). The synergistic evolution of digital economic resilience and efficiency has more influencing factors, and it has become more difficult to analyse the combination effect between multiple factors using traditional econometric models. Therefore, this paper takes the configuration theory as its theoretical basis and adopts a qualitative comparative analysis (QCA) to conduct the analysis of the synergistic evolution path identification. QCA is based on the idea of set theory and Boolean algebra operations, combining the advantages of qualitative analyses and quantitative analyses, and the research explores the ideal set of paths, in which multiple combinations of antecedent variables lead to the final outcome, which is a case-oriented research method (Ragin, 2014).

The QCA method is divided into a crisp set, a multi-value set, and a fuzzy set. Among them, the crisp set and multi-value set use categorical variables, while the fuzzy set is applicable to continuous data variables. Therefore, based on the variable data in this paper, we choose a fuzzy set qualitative comparative analysis (fsQCA) as the method for analysing the identification of the synergistic evolutionary paths of digital economic resilience and efficiency. This method performs a path identification analysis based on consistency and coverage, and the calculation formula is as follows:

$$Consistency(X_i \leqslant Y_i) = \sum \min(X_i, Y_i) / \sum (X_i) \tag{15}$$

$$Coverage(X_i \leqslant Y_i) = \sum \min(X_i, Y_i) / \sum (Y_i) \tag{16}$$

where X is the set of antecedent variable affiliations and Y is the set of outcome variable affiliations. Consistency is a sufficient condition for determining whether X is a sufficient condition for Y. A sufficient condition is considered to hold if it is higher than 0.75. The conditional coverage of a configuration in an outcome analysis is divided into raw coverage and unique coverage. Raw coverage indicates the proportion of total cases in which the configuration led to the outcome. Unique coverage indicates the proportion of cases in which the condition led to the occurrence of the outcome, but at the same time, other conditions did not lead to the occurrence of the outcome. The larger the value of the coverage, the greater the explanatory power of the configuration for the outcome variable.

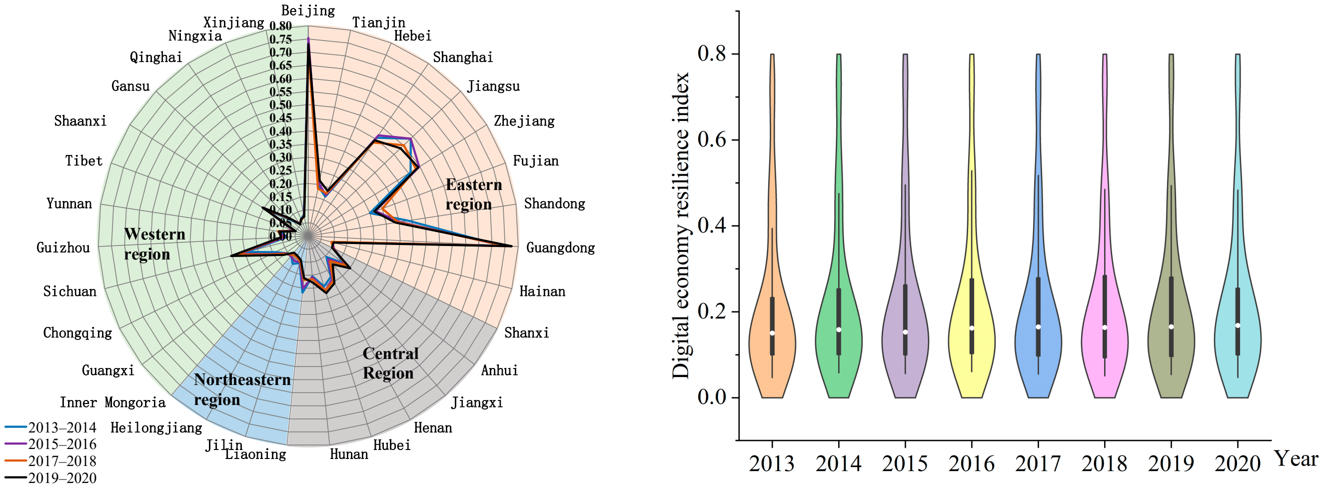
3. Results

3.1. Analysis of the Results of the Digital Economy Resilience and Efficiency Measures

3.1.1. Analysis of the Results of the Digital Economy Resilience Measure

In this paper, the entropy method and Super-SBM model are used to measure the resilience and efficiency of the digital economy in 31 provinces (autonomous regions and municipalities directly under the Central Government) of China, and a comparative analysis is made on the eastern, central, northeast, and western regions (Figure 2). Drawing on Chen Jinghua's (2020) study, the digital economic resilience index R is classified into "leading" ($R >> E + 0.5$ SD), "progressing" ($E < R \leq E + 0.5$ SD), "catching up" ($E - 0.5$ SD $< R \leq E$), and "lagging behind" ($R \leq E - 0.5$ SD) provinces based on the relationship between the corresponding mean E and standard deviation SD for each year from 2013 to 2020 [30]. From Figure 2a, it can be seen that the resilience of the national digital economy fluctuates and rises, but the regional differences are significant, as shown by the resilience index of the eastern region being much higher than that of the other three regions, the resilience indexes of the central region and the western region rising steadily, but the western region being in the low range, and the resilience index of the northeastern region showing a downward trend.

Specifically: (1) The "leading" provinces in terms of the resilience level of the digital economy include Beijing, Shanghai, Jiangsu, Zhejiang, Shandong, and Guangdong, all of which are located in the eastern region, indicating that the digital economy, as a new type of economic form, has higher requirements for industrial support and economic development conditions. As a pioneer region in the development of China's digital economy, the eastern part of the country has a high dynamic adaptive adjustment capacity in the face of uncertain risk shocks, and is able to break the path of dependence and carry out innovation and transformation according to external shocks, by taking advantage of its superior technology, resources, market, and environmental advantages.



(**a**) Regional analysis of digital economic resilience (**b**) Kernel density analysis of digital economic resilience

Figure 2. Spatial and temporal analysis of digital economic resilience. Source: Authors, 2023.

(2) There are fewer "progressive" provinces, including Fujian, Hubei, and Sichuan. These provinces have relatively complete digital development infrastructure through the construction of innovative development pilot zones, high-tech development zones, the "East Counts, West Counts" project, and other "strong foundations". Their good infrastructure and policy environment can mitigate the impact of external uncertainties on the development of the digital economy. However, there are problems such as insufficient support for the R&D of digital technology and a low conversion rate of innovation results. Relying on the existing development path, although it can temporarily resist the negative impact of external shocks, it is difficult to carry out targeted upgrading and transformation in the face of long-term disturbances. In the future, these provinces should continue to strengthen their investments into digital economy research and development, and at the same time, enhance their ability to transform and promote digital products, so as to continuously optimise the industrial structure of the digital economy.

(3) The "catching-up" provinces include Hebei, Liaoning, Anhui, Henan, Hunan, Chongqing, and Shaanxi, with the central region accounting for the majority of these. Although these provinces have a certain scale of digital economy development foundation, most of them are in the manufacturing cluster area. Facing problems such as an unsound organisational system for digital industry, an insufficient transformation of innovation results, insufficient support for technology R&D, and imperfect development of the digital economy market, their resilience to external uncertainties is generally low. In the future, it will be possible to strengthen their cooperation with developed provinces in the east, take advantage of their geographical location, actively undertake industrial transfers from "leading" provinces, and focus on improving their ability to attract factors for the development of the digital industry.

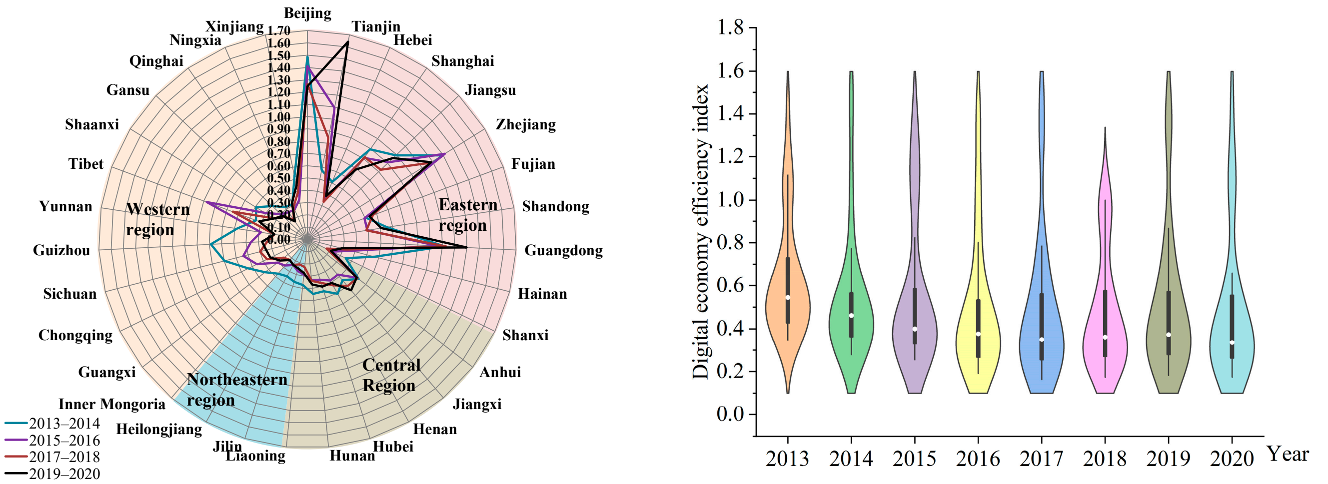
(4) The "lagging" provinces include Hainan, Shanxi, Jilin, Heilongjiang, the Inner Mongolia Autonomous Region, the Guangxi Zhuang Autonomous Region, Guizhou, Yunnan, the Tibet Autonomous Region, Gansu, Qinghai, the Ningxia Hui Autonomous Region, and the Xinjiang Uygur Autonomous Region, and are mainly concentrated in the northeastern and western regions. The lack of infrastructure, industrial support, talent reserves, and technological innovation required for the development of the digital economy in these provinces has led to their relatively weak ability to cope with external uncertainty and risks, and highlights the problem of the weak competitiveness of the digital economy. Therefore, these provinces should focus on improving the hardware and software environment for the

development of the digital industry in the future, and fulfil their latecomer advantage to achieve leapfrog development by laying out "new infrastructure" for the digital economy.

(5) On the time trend (Figure 2b), the kernel density curve is characterised by a bimodal distribution, and the resilience index is polarised. More low values are mainly concentrated between 0.05 and 0.2, indicating that the overall level of national digital economic toughness is not high and there is an obvious regional variability. The shape and degree of the flattening of the kernel density curves change less from 2013 to 2020, suggesting that this variability has not improved significantly over the study period. However, the violin plots for each year have a longer trailing tail, indicating a generally positive trend in digital economic resilience.

3.1.2. Analysis of the Results of the Digital Economy Efficiency Measure

The efficiency of the national digital economy, as a whole, is in a moderately high state of development (Figure 3a), but there are significant differences in the "digital divide" between regions. The digital economy efficiency in the eastern region shows a fluctuating upward trend and is much higher than that in other regions. The central, northeastern, and western regions all have a lower digital economic efficiency, with the northeastern region's efficiency value remaining at a low level during the study period and the western region experiencing the greatest fluctuations.



(**a**) Regional analysis of digital economic efficiency (**b**) Kernel density analysis of digital economic efficiency

Figure 3. Spatial and temporal analysis of digital economic efficiency. Source: Authors, 2023.

Specifically, (1) "leading" provinces generally have a higher digital economy efficiency, including Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, and Guangdong, all of which are located in the eastern region. These provinces have the necessary inputs for the digital economy, and have taken the lead in building a number of digital economy projects such as industrial internet, big data centres, and 5G, which have contributed to the incremental increase in the scale of the digital economy industry.

(2) "Progressive" provinces include Fujian and Shandong in the eastern region, Anhui in the central region, and Sichuan and the Tibet Autonomous Region in the western region. These provinces have invested relatively more in the development of the digital economy, but their digital economic output is still not high compared to the "leading" provinces, and their relatively low-scale efficiency constrains the continuous improvement of the levels of inputs and outputs.

(3) The "catching-up" provinces include Hebei and Hainan in the eastern region, Jiangxi, Henan, Hubei, and Hunan in the central region, and Chongqing, Guizhou, Yunnan, Shaanxi, and the Xinjiang Uygur Autonomous Region in the western region. From the "progressing" provinces and "catching up" provinces, it can be seen that some of the

provinces in the western region, which are relatively lagging behind in terms of their economic development, on the contrary, are more efficient in terms of their digital economy. The reason is that the western region, with its own unique resources, environment, and climate advantages, according to local conditions, explores the development of the digital economy in line with its own interest path. For example, the Tibet Autonomous Region has built a number of national cloud computing data service centres based on the low-temperature and low-oxygen environment of the Snowy Plateau and abundant clean energy. The Guizhou Province, on the other hand, has become one of the regions with the largest number of mega data centres in the country by taking advantage of its superior geographical conditions.

(4) The "lagging" provinces include the three northeastern provinces, the Shanxi province in the central region, and the Guangxi Zhuang Autonomous Region, Gansu, Qinghai, and the Ningxia Hui Autonomous Region in the western region. The low inputs and outputs of the digital economies in these provinces have resulted in a low level of returns to scale. For example, the development of the three northeastern provinces and Shanxi Province relies heavily on the energy economy, while the factor inputs, labour productivity, and capital output rates needed for the development of the digital industry are low, and the industrial foundation for digital transformation is particularly weak, resulting in a low overall digital economic efficiency.

(5) On the time trend (Figure 3b), except for 2016, which showed a single-peak distribution, the rest of the years showed a bimodal distribution pattern, with a polarised distribution of efficiency values. The efficiency values in most years are concentrated between 0.3 and 0.5, indicating that the overall level of digital economy efficiency during the study period is low and that there is a significant regional variability. The degree of change in the shape of the kernel density curve of the efficiency values is small in most years, indicating that there is no significant change in the regional variability. Except for 2018, the violin plots of the remaining seven years have a significant trailing effect, indicating a positive trend in the efficiency of the national digital economy.

3.2. Analysis of the Synergistic Evolution of Resilience and Efficiency in the Digital Economy

3.2.1. Identification of Order Parameters

Based on the Haken model, this paper analyses the two subsystem covariates of digital economic resilience (DER) and digital economic efficiency (DEE). By proposing model assumptions, constructing model equations of motion, solving the relevant parameters, and judging whether the model assumptions are valid or not, the order parameters are finally obtained (Table 3). The results show that the digital economic resilience is the order parameter affecting the synergistic development of the digital economic system. Among them, a is -0.011, indicating that the national digital economic efficiency plays a facilitating role in the enhancement of the digital economic resilience. b is 0.014, indicating that the national digital economic resilience plays a facilitating role in the enhancement of the digital economic efficiency, but the strength of its facilitating effect is small. Therefore, the national digital economic resilience and efficiency have a synergistic effect of interaction, and the synergistic effect of the digital economic resilience on the digital economic efficiency is greater than the synergistic effect of the digital economic efficiency on the digital economic resilience. γ_1 is 0.004, indicating that the digital economic resilience establishes a negative feedback mechanism in the digital economic system that inhibits the development of system orderliness. γ_2 is 0.104, indicating that digital economic efficiency presents a negative feedback mechanism in the digital economic system that inhibits the development of system orderliness. However, the values of γ_1 and γ_2 are not large, indicating that the inhibitory effect of resilience and efficiency on the improvement in the orderliness of the digital economic system is not large. The negative feedback mechanism further indicates that the synergistic evolution of the resilience and efficiency of China's digital economy is still in the primary stage, with a large space for improvement.

Table 3. Analysis of order parameter of resilience and efficiency of digital economy.

Serial Number	Model Assumptions	Equations of Motion	Parameter Information	Model Conclusions
(1)	q_1 = DER	q_1 = 0.996 q_1 $(t-1)$ + 0.011 q_1 $(t-1)$ q_2 $(t-1)$ (0.000 ***) (0.077 **)	γ_1 = 0.004, γ_2 = 0.104 a = −0.011, b = 0.014	1. The equations of motion are valid. 2. The adiabatic approximation assumption is satisfied. 3. The model assumptions hold. DER is the order parameter.
	q_2 = DEE	q_2 = 0.896 q_2 $(t-1)$ + 0.014 q_1 $(t-1)$ q_1 $(t-1)$ (0.000 ***) (0.078 **)		
(2)	q_1 = DEE	q_1 = 1.005 q_1 $(t-1)$ + 0.003 q_1 $(t-1)$ q_2 $(t-1)$ (0.000 ***) (0.953)	γ_1 = −0.005, γ_2 = 0.117 a = −0.003, b = 0.286	1. The equations of motion are not valid. 2. The adiabatic approximation assumption is satisfied. 3. The model assumptions do not hold.
	q_2 = DER	q_2 = 0.883 q_2 $(t-1)$ + 0.286 q_1 $(t-1)$ q_1 $(t-1)$ (0.000 ***) (0.004 ***)		

Notes: t values are in parentheses. ** and *** indicate significance at the 5% and 1% levels, respectively. Source: Authors, 2023.

3.2.2. Potential Function Solution

From the parameter information in Table 2, the system evolution equation is obtained as:

$$\dot{q}_1 = -0.004q_1 + 0.002q_1^3 \tag{17}$$

The system potential function is:

$$v = 0.002q_1^2 - 0.0004q_1^4 \tag{18}$$

Let $\dot{q}_1 = 0$, to find the potential function of three solutions, 0, −1.61, and 1.61, respectively. Since the digital economy resilience indexes are greater than 0, the potential function only considers the value of $q_1 > 0$ to obtain the stability point (1.61, 0.003). The distance of any point in the system from the stabilization point constitutes the evaluation function of the system d (Equation (11)). The value of d determines the synergy value of the system. The smaller the value of d, the higher the synergy value, and vice versa, the lower the synergy value.

$$d = \sqrt{(q-1.61)^2 + (v(q) - 0.003)^2} \tag{19}$$

3.2.3. Analysis of Spatial and Temporal Differences in the Evolution of Resilience and Efficiency in the Digital Economy

In this paper, the initial synergy values are normalised using the extreme value method to obtain the final digital economy resilience and efficiency synergy values (Figure 4). Further, the natural breakpoint method is used to classify the synergy values into five levels (Table 4), which are very low synergy (0, 0.246], low synergy (0.246, 0.416], medium synergy (0.416, 0.535], high synergy (0.535, 0.742], and very high synergy (0.742, 1), and are represented by 1 to 5, respectively.

The time trend evolution is shown in Figure 4. The kernel density curve is characterised by a bimodal distribution, the distribution of the synergy values is polarised, the difference between the high and low values is large, and the overall distribution is clustered in the range of the low-value interval of 0.1–0.3, which indicates that the level of digital economic resilience and efficiency synergy is low, and that there are significant regional differences. Neither the degree of flattening nor the shape of the kernel density curve have changed significantly from 2013 to 2020, indicating that there is no further reduction in the regional variability of the level of digital economic resilience and efficiency synergy during the study period. The median, on the other hand, has an overall upward trend, indicating that the synergistic effect of the resilience and efficiency of the national digital economy has been increasing.

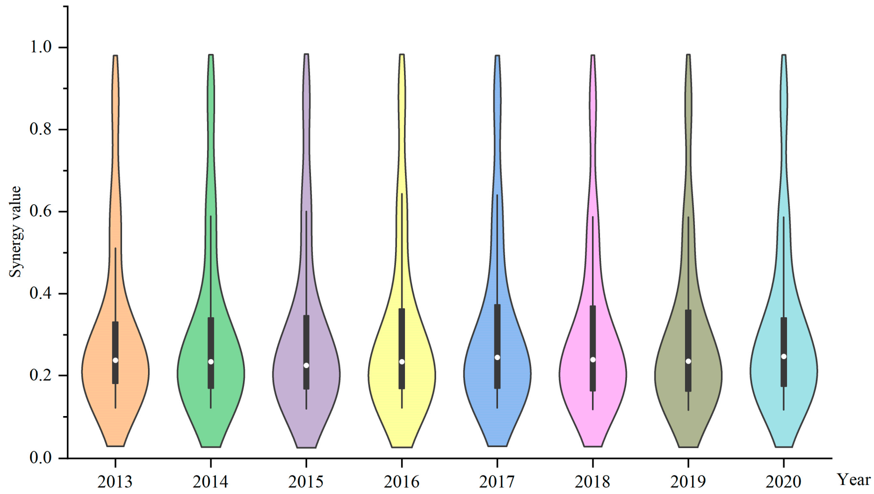


Figure 4. Kernel density analysis of the synergistic evolution of resilience and efficiency in the digital economy. Source: Authors, 2023.

Table 4. Classification of stages of synergistic evolution of resilience and efficiency in the digital economy.

Region	Province	2013	2016	2020	2013–2020
Eastern region	Beijing	5	5	5	5
	Tianjin	2	2	2	2
	Hebei	2	2	2	2
	Shanghai	4	4	4	4
	Jiangsu	4	4	4	4
	Zhejiang	4	4	4	4
	Fujian	2	2	2	2
	Shandong	3	3	3	3
	Guangdong	5	5	5	5
	Hainan	1	1	1	1
Central Region	Shanxi	1	1	1	1
	Anhui	2	2	2	2
	Jiangxi	1	1	1	1
	Henan	2	2	2	2
	Hubei	2	2	2	2
	Hunan	1	1	2	2
Northeastern region	Liaoning	2	2	1	2
	Jilin	1	1	1	1
	Heilongjiang	1	1	1	1
Western region	Inner Mongoria	1	1	1	1
	Guangxi	1	1	1	1
	Chongqing	1	1	2	2
	Sichuan	2	2	2	2
	Guizhou	1	1	1	1
	Yunnan	1	1	1	1
	Tibet	1	1	1	1
	Shaanxi	2	2	2	2
	Gansu	1	1	1	1
	Qinghai	1	1	1	1
	Ningxia	1	1	1	1
	Xinjiang	1	1	1	1

Note: 1 indicates very low synergy, 2 indicates low synergy, 3 indicates medium synergy, 4 indicates high synergy, and 5 indicates very high synergy. Source: Authors, 2023.

The spatial distribution stage division is shown in Table 4. Overall, the digital economy resilience and efficiency synergy evolution is in the low-synergy stage, but the synergy level varies greatly between regions. Specifically, none of the provinces in the eastern region changed their synergy stage during the study period, with only the Hainan Province being in the very-low-synergy stage. The Tianjin, Hebei, and Fujian provinces are in the low-synergy stage. The Shandong Province is in the intermediate-synergy stage. The Shanghai, Jiangsu, and Zhejiang provinces are in the high-synergy stage. Beijing and the Guangdong Province are in the very-high-synergy stage. Most of the provinces in the eastern region are the core cities of China's urban agglomerations, and their digital economic development leads the country, with their resilience and efficiency being at the "leading" level and less fluctuation occurring in their synergistic evolution, with the high and very high synergistic stages accounting for 50% of the total in the eastern region, which indicates that the synergistic level of the resilience and efficiency of the digital economy shows a tendency of high synergistic to very high synergistic evolution in the eastern region.

In the central region, except for the Shanxi Province and Jiangxi Province, which show a very-low-synergy stage, the other four provinces show the trend of low synergy evolution. Among them, the Hunan Province rose from a very-low-synergy stage in 2013 to a low-synergy stage in 2020. The reason for this is that most provinces in the central region are at the level of "catching up" provinces in terms of their digital economic resilience and efficiency, and need to further improve their levels of resilience and efficiency in the future.

In the northeastern region, the Liaoning Province declined from a low-synergy stage in 2013 to a very-low-synergy stage in 2020, and the Jilin Province and Heilongjiang Province maintained a very-low-synergy stage for a long time. Therefore, the three northeastern provinces, as a whole, show very low synergy and a low level of synergy evolution. The digital economy in the northeastern region is not resilient enough and is inefficient in terms of long-term economic transformation, so the synergy evolution shows a low level.

In the western region, except for the Chongqing Municipality, Sichuan Province, and Shaanxi Province, which show a low level of synergy, the other nine provinces have been in a very-low-synergy stage for a long time. The Sichuan Province is a "progressive" province in terms of both its digital economic resilience and efficiency, but its synergy level is low, indicating that the two subsystems of digital economic resilience and efficiency in the Sichuan Province show incompatible development trends, and that, in the future, while improving resilience and efficiency, we should pay more attention to balancing the compatibility between the two. Chongqing and Shaanxi are both "catching up" provinces in terms of their digital economy resilience and efficiency, and should improve both subsystems in the future in order to evolve into "progressing" provinces. Although the four provinces of the Tibet Autonomous Region, Guizhou, Yunnan, and the Xinjiang Uygur Autonomous Region are "progressing" or "catching up" provinces in terms of their digital economic efficiency, their digital economic resilience is in the lower "lagging" provinces, which leads to their synergistic evolution being at a very low stage. In the future, emphasis should be placed on improving the resilience of the digital economy in order to further evolve to a higher stage of synergy.

3.2.4. Stages of Synergistic Evolution of Resilience and Efficiency in the Digital Economy

(1) The very-high-synergy regions include the provinces of Beijing and Guangdong, where the synergy evolution process is smooth and the digital economy resilience and efficiency values are at a high level. Beijing and Guangdong are the first echelon of China's digital economy development, always leading in the development of high-tech manufacturing, the information industry, and other emerging industries. The region's strong comprehensive innovation capacity, good industrial foundation, and the economies of scale of its digital clusters have made it more resistant to external shocks, making it a "digital economy province". At the same time, the government has adopted an early digital strategy, increased its investment in digital development,

and adopted a "government + market" governance model. By continuously releasing the vitality of the digital economy market, it is easier to break the original path of dependence after encountering external impacts, adjust the industrial structure in a timely manner, and promote the efficient allocation of the factors, resources, and talents of the digital economy, thus effectively improving the inefficient operation state. The benign interaction of digital economic resilience and efficiency has prompted the formation of a new orderly structure of the digital economic system.

(2) The high-synergy regions include Shanghai, Jiangsu, and Zhejiang. The unbalanced development of the digital economic resilience and efficiency in Shanghai and Jiangsu suggests that a high level of synergy is not the same as the ability of the digital economy to maintain sustainable growth in the long term. In this case, the disorderly flow of resources and factors within the digital economic system leads to negative effects of synergistic development, namely, a mismatch between the level of digital economic resilience and efficiency development. In contrast, both the resilience and efficiency of the digital economy in Zhejiang have always been maintained at a high level, showing a positive synergistic effect of general improvement. However, compared to the very-high-synergy regions, there still exist issues such as the digital technology supply capacity not being sufficient, digital talent investment being insufficient, the difference between the regional factor resource agglomeration capacity being large, and a regional development imbalance problem, which are not conducive to the organic integration of the digital economy system structure. In the future, Zhejiang's digital economic resilience and efficiency will evolve to a higher level, and there is a large upside of this.

(3) The medium-synergy region is the Shandong Province, where the synergistic development of digital economic resilience and efficiency is in the middle and upper reaches of the country. The level of digital economic resilience in the Shandong Province is significantly higher than its efficiency level, and through the implementation of the "digital province" strategy, the overall coverage of 5G, narrow broadband, and other emerging digital infrastructure is high. The gap between the development of new digital economies in each city in the province is gradually narrowing, and the supporting capacity of digital economy development has been significantly increased, which has a certain ability to resist external shocks. Its digital economy input and output efficiency as a whole is not high, and its digital innovation ability is not strong, making the inputs in the existing economies of scale under the conditions of the optimal goal being difficult to achieve, and the advantages of these economies of scale have not yet appeared. In the future, through the optimisation of resource allocation, the efficiency of the use of resources in the digital economy will be enhanced, and the rebalancing path of the resilience and efficiency of the digital economy will be sought out.

(4) The low-synergy-regions include Tianjin, Hebei, Fujian, Anhui, Henan, Hubei, Hunan, Liaoning, Chongqing, Sichuan, and Shaanxi, and the level of synergy in these provinces is in the lower middle of the national scale. In terms of spatial distribution, most of the provinces in this type of region are in low-level agglomeration areas, except for Tianjin and Hebei. For example, Chongqing, Sichuan, and Shaanxi in the western region, Anhui, Henan, Hubei, and Hunan in the central region, and Liaoning in the northeastern region all have a low value for the synergistic development of their digital economic resilience and efficiency, and they rely only on the development of the digital economy in their own provinces, which is relatively weak in terms of their ability to withstand external risks. The possibility of industrial transformation and upgrading is not high, there is a lack of regional cooperation and spatial support, which makes it difficult to form a regional-scale agglomeration of the digital economy, and the operational efficiency has been low for a long period of time, so that the overall effect of "1 + 1 > 2" has not yet been realised.

(5) The very-low-synergy regions include Hainan, Shanxi, Jiangxi, Jilin, Heilongjiang, Inner Mongolia, Guangxi, Guizhou, Yunnan, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang. The digital economic toughness and efficiency of the provinces in this category are at a double low level, especially the level of digital economic toughness, which has been hovering at a low value for a long time, and some of the provinces are in a declining area of industrial innovation and development. For example, the northeastern region has long relied on the energy-manufacturing industry and formed a strong path dependence, industrial transformation, and upgrading difficulties, leading to its digital economic resilience and efficiency synergy not being high for a long time. Most provinces in the western region lack overall planning for the development of the digital economy, favouring the construction of "digital cities" in provincial capitals and highlighting the problem of unbalanced development within the provinces. There are also limitations in the digital infrastructure, human resources, data sharing, and network infrastructure between these provinces. Especially in the western region, the terrain is complex, except for some regions that have established big data service centres by taking advantage of their climate, terrain, policies, and other advantages, and there are also provinces that have driven regional development through "digital poverty alleviation", but it is more difficult to build digital infrastructure in most of these regions. Therefore, to achieve the goal of "digital catching up", it is necessary to have step-by-step, hierarchical, and precise differentiated positioning, focusing on improving the disordered structure of the factor flows within the digital economic system, optimising the efficiency of the digital economic supply and industrial structure, and promoting the dual enhancement of the resilience and efficiency of the digital economy.

4. Path Identification Analysis of the Synergistic Evolution of Resilience and Efficiency in the Digital Economy

4.1. Causality Analysis

According to the above Formulas (9) to (14), we can obtain the influence degree, influenced degree, and cause degree of each influencing factor (Table 5). From the table, it can be seen that the influencing factors of the cause type have two indicators, OR and Input, and the influencing factors of the result type have three indicators, EA, TI, and Output, which are influenced by the above two cause factors.

Table 5. Results of analysing the degree of influence, influence, and cause of indicators.

Factor	Influence Degree	Influenced Degree	Cause Degree	Type of Factor
OR	1.9329	0.9359	0.9970	cause factor
EA	0.9803	1.8502	−0.8699	result factor
TI	1.1677	1.5636	−0.3959	result factor
Input	2.1552	0.8325	1.3227	cause factor
Output	0.9168	1.9707	−1.0539	result factor

Source: Authors, 2023.

4.2. Analysis of Synergy Configuration

The fsQCA method is used to conduct the path identification analysis of synergistic development, with the synergy value of the digital economy resilience and efficiency as the dependent variable, and OR, EA, TI, Input, and Output as the independent variables. The dependent qualitative comparative analysis is a kind of asymmetric causality analysis, namely, the emergence of the desired outcome and the emergence of the non-desired outcome is not a simple yes–no relationship. Therefore, the existence of a condition under high digital economic resilience and efficiency synergy is not the same as the non-existence of that condition under ~ ("~" stands for "not" in logical operations) high digital economic resilience and efficiency synergy, for which it is necessary to carry out a path identification analysis of the evolution of ~ high digital economic resilience and efficiency synergy.

The configuration paths of high digital economy resilience and efficiency synergy levels and ~high digital economy resilience and efficiency synergy levels are shown in Table 6. From the table, it can be seen that there are a total of four configuration paths that generate the high digital economy resilience and efficiency synergy level. The coverage of the overall solution is 0.9251, indicating that these four groupings can explain 92.51% of the cases of high digital economic resilience and efficiency synergy levels. The consistency level of the four groupings with the overall solution is greater than 0.8, indicating that all four configurations can be regarded as sufficiently conditional combinations for high digital economic resilience and efficiency synergy levels.

Table 6. Configuration path analysis of the level of digital economic resilience and efficiency synergy.

	High Level				**~High Level**		
	A1	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**
OR	●	●	●		⊗	⊗	
EA	●	●		●		⊗	⊗
TI	●		●	●	⊗		⊗
Input		●	●	●	⊗	⊗	⊗
Output		⊗	●	●	⊗	⊗	●
Raw coverage	0.8606	0.1967	0.8851	0.8479	0.8947	0.8358	0.1492
Unique coverage	0.0143	0.0066	0.0475	0.0103	0.0825	0.0193	0.000
Consistency	0.9977	0.9948	0.9928	0.9952	0.9919	0.9947	0.9444
Solution coverage	0.9251				0.9208		
Solution consistency	0.9894				0.9798		
Cases	Guangdong, Jiangsu	Shaanxi, Liaoning, Hunan	Shanghai, Zhejiang	Beijing, Shandong	Qinghai, Xinjiang, Tibet, Ningxia	Hainan	Chongqing

Note: "●" means that the core condition exists, "•" means that the edge condition exists, "⊗" means that the core condition does not exist, "⊗" means that the edge condition does not exist, and "null" means that the condition may or may not exist. Source: Authors, 2023.

There are three configuration paths that generate ~high levels of digital economy resilience and efficiency synergy. Among them, the path of configuration B1 is ~ OR * ~ TI * ~ Input * ~ Output, the path of configuration B2 is ~ OR * ~ EA * ~ Input * ~ Output, and both paths present organizational resistance, recovery ability, and digital economy inputs as the core non-existent conditions, indicating that, in the case of a smaller digital industry scale, weaker industrial digital empowerment, and insufficient inputs, the level of digital economic resilience and efficiency synergies is low. The path of configuration B3 is ~ EA * ~ TI * ~ Input * Output, presenting digital economy output as the core existing condition, and the environmental adjustment, adaptive capacity, technological innovation and transformation capacity, and digital economy output as the core non-existent condition, indicating that, even if the digital economy output level is higher, but its response to external shocks to adjust the adaptive capacity of the weaker innovation and investment capacity is insufficient, the same will lead to a lower degree of synergy between digital economic resilience and efficiency. From the perspective of the ~ high digital economy resilience and efficiency synergy level of the three configurations, those with a high digital economy resilience and efficiency synergy level of the four configurations did not exist with simple non-correspondence, verifying the asymmetric causality of the fsQCA method species.

4.3. Synergistic Path Analysis

The improvement in digital economy resilience and efficiency synergy level has obvious differences in its choice of path. Based on this, this paper summarises four paths to achieve a high level of digital economic resilience and efficiency synergy for the four configurations.

(1) Resilience Dominates Driven Path

Configuration A1 is OR * EA * TI, showing a high environmental adjustment and adaptation ability, high technological innovation and transformation ability as the core conditions, and complementary organisational resistance and recovery ability as the edge conditions to form a high level of digital economic resilience and efficiency synergy. Configuration A1 is consistent with the identification results of the above order parameters, can be summarised as the Resilience Dominates Driven Path (Figure 5), and the provinces in this configuration include the Guangdong Province and Jiangsu Province.

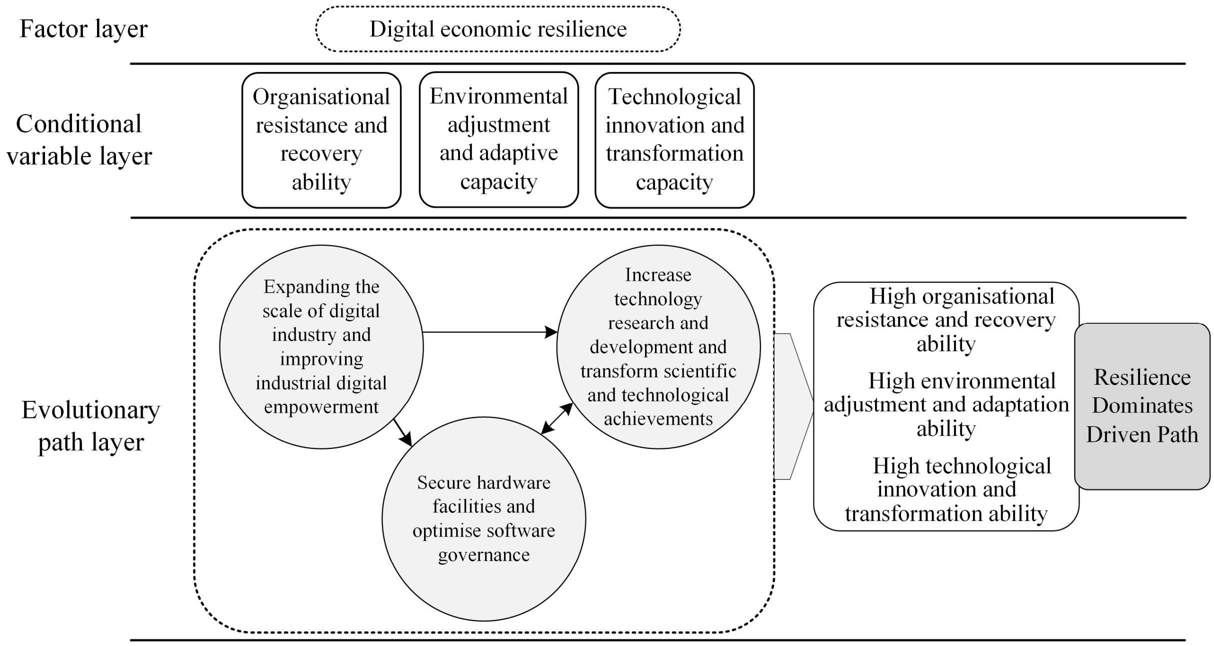


Figure 5. Resilience Dominates Driven Path. Source: Authors, 2023.

The resilience-led driving path forms the key path of "Digital economic resilience—Organisational resistance and recovery ability—Environmental adjustment and adaptive capacity—Technological innovation and transformation capacity—Creating a virtuous cycle of the system". This path reflects the leading role of resilience in the synergistic development process of digital economy resilience and efficiency, which promotes improvement in resistance and recovery ability through a larger digital industry scale and higher digital industry empowerment, improves adjustment and adaptation ability through the development and governance of hardware and software, and improves technological innovation and transformation ability through the support of technological research and development and the transformation of digital product achievements, in order to further expand the scale of the digital industry and digital empowerment of the industry. Through the virtuous cycle of the digital industry resilience system, the synergistic development within the digital economy system will be gradually established.

(2) Basic Driven Path

Configuration A2 is OR * EA * Input * ~ Output, which presents a high organisational resistance and recovery ability, high environmental adjustment and adaptive capacity, and high digital economy inputs and non-high digital economy outputs as the core conditions to form a high level of digital economy resilience and efficiency synergy. Configuration A2 is categorised as the Basic Driven Path because the core variables involved are all fundamental to the operation of the digital economy system (Figure 6), and the provinces in this configuration include the Shaanxi Province, Liaoning Province, and Hunan Province.

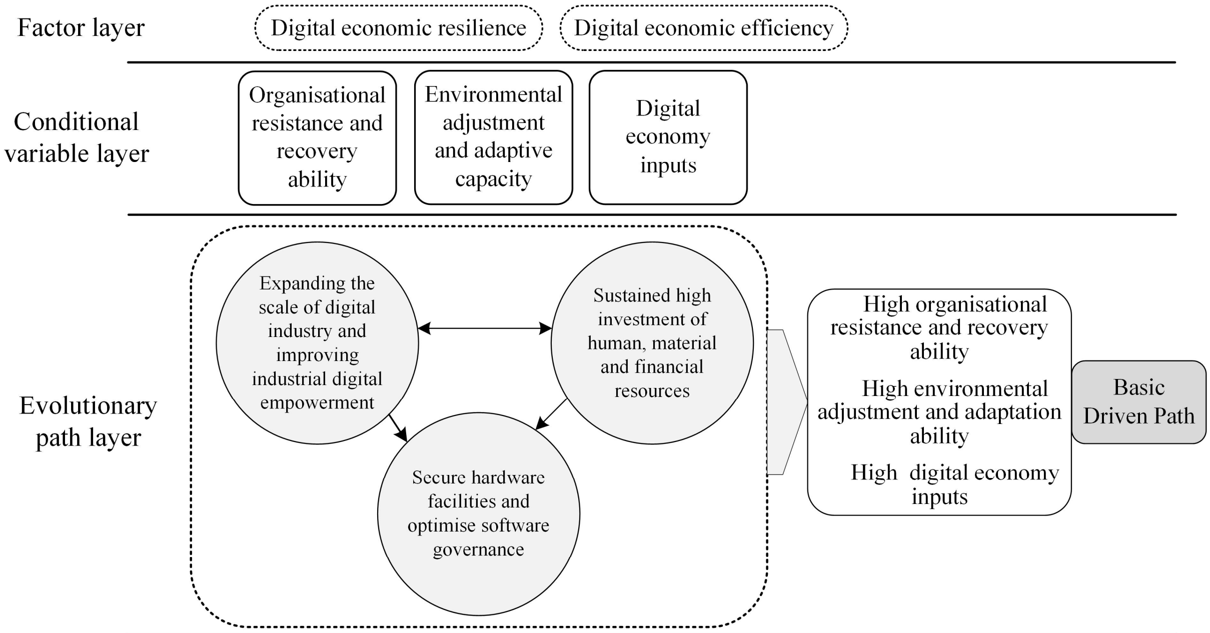


Figure 6. Basic Driven Path. Source: Authors, 2023.

This driven path is made up of the following two key paths:

① Digital economy resilience—Organisational resistance and recovery ability—Environmental adjustment and adaptive capacity—Infrastructure to ensure the operation of the system

This path reflects that the basic environment for the operation of the digital economy system needs to have a strong organisational resistance, recovery ability, environmental adjustment, and adaptive capacity. This requires that the construction of the digital economy should, on the one hand, expand the digital scale and improve digital industrial empowerment, and, on the other hand, safeguard the hardware development environment and optimise software governance and regulation. Only on the premise that the infrastructure and basic environment are fully guaranteed can the system be operated normally.

② Digital economy efficiency—Digital economy inputs—Sustained high investment of human, material and financial resources

This path reflects the need for sustained high investment in human, material, and financial resources to ensure the development of the digital economy. Through the precise introduction of policies to support industrial development and technological innovation, improvement in existing scientific and technological innovation infrastructure, an increase in R&D funding, the introduction and training of more scientific and technological innovation talents, and the level of synergy of the digital economy system can be realised.

(3) Innovation Driven Path

Configuration A3 is EA * TI * Input * Output, which presents a high technological innovation and transformation capacity and high digital economy input as the core conditions, complemented by a high organisational resistance and recovery ability and high digital economy output as the edge conditions, which together form a high level of synergy between digital economy resilience and efficiency. The core condition of configuration A3 is the technological innovation transformation of the system, so it is summarised as the Innovation Driven Path (Figure 7), and the provinces in this configuration include Shanghai and Zhejiang.

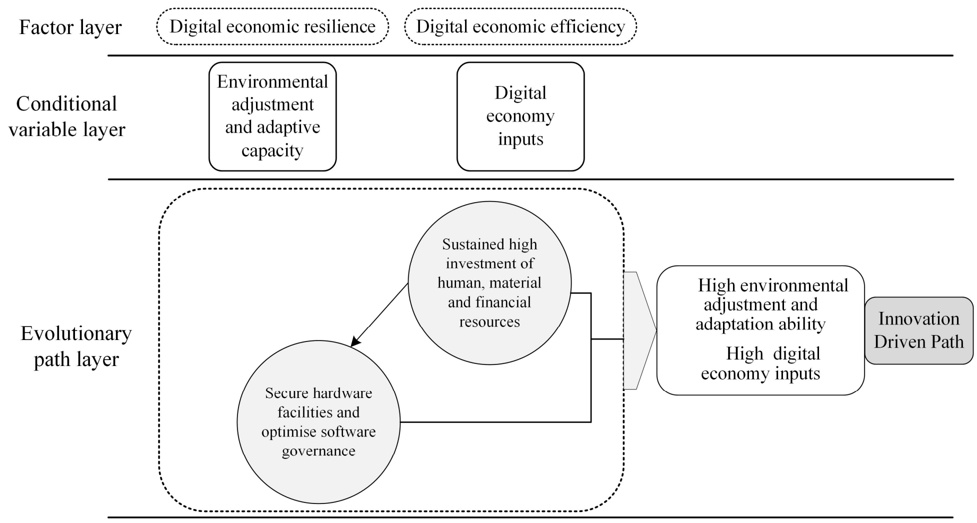


Figure 7. Innovation Driven Path. Source: Authors, 2023.

In addition to the key path of "Digital economy efficiency—Digital economy investment—Sustained high investment in human, material and financial resources", this driving path also includes the path of "Digital economy resilience—Technological innovation and transformation capacity—Increasing the transformation of R&D results". This path reflects the importance of technological innovation in the digital economic system. Innovation is an important factor in social development and change, so the development of the digital economy should focus more on technological innovation. This requires provinces to increase their technological research and development, improve the transformation of technological achievements, and promote the integration of research and development into the market.

(4) Balanced Driven Path

Configuration A4 is EA * TI * Input * Output, which presents a high environmental adjustment adaptive capacity, high technological innovation and transformation capacity, and high digital economy input as the core conditions, and complementary digital economy output as the peripheral condition to form a high level of synergy between digital economy resilience and efficiency. The core conditions of configuration A4 focus on environmental adjustment, technological innovation and transformation, and digital economy input, forming the Balanced Driven Path of both resilience and efficiency (Figure 8), and the provinces in this configuration include Beijing and the Shandong Province.

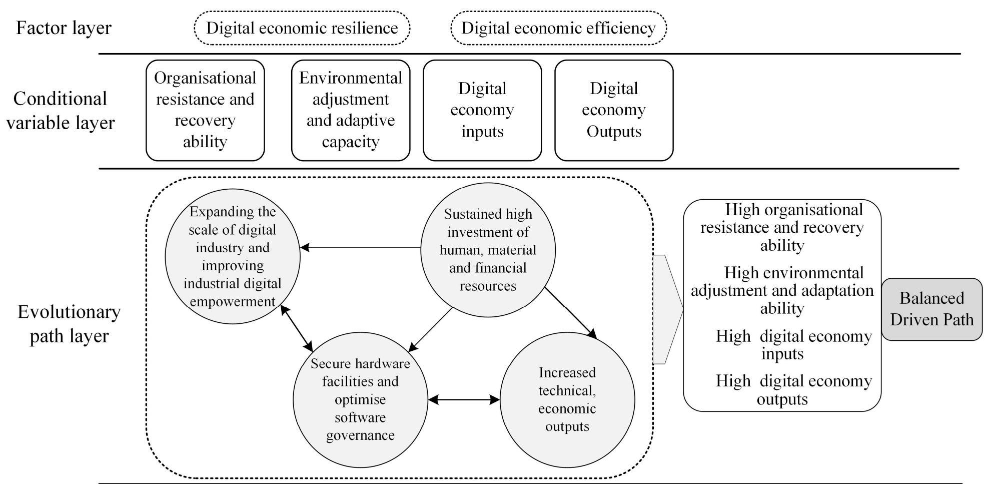


Figure 8. Balanced Driven Path. Source: Authors, 2023.

This driven path is made up of the following two key paths:

① Digital economy resilience—Environmental adjustment and adaptive capacity—Technological innovation and transformation capacity—Strengthening the system's capacity for sustainable development

This path reflects the fact that the sustainable development of the digital economy follows the dynamic development model of "adjustment + innovation". The development of the digital economy system is constantly changing, which leads to the innovation environment of the digital economy being full of uncertainties, and only through continuous adjustment and adaptation can innovation be carried out more efficiently, which strengthens the system's sustainable development capacity.

② Digital economy efficiency—Digital economy inputs—Digital economy outputs—Improving system operational efficiency

This path reflects the role of efficiency in the digital economy system, through the continuous high input of human, material, and financial resources, and then through the market to guide the flow of these innovative resources, thereby promoting the transformation of innovation results in the market and thus improving the economic returns of innovation. Through this continuous input–output model, the system can be operated with a high efficiency.

5. Conclusions and Discussions

5.1. Conclusions

This paper used the evolutionary resilience theory and TOE theory to construct a digital economy resilience evaluation index system considering the three aspects of organizational resistance and recovery ability, environmental adjustment and adaptive ability, and technological innovation and transformation ability, and adopted the entropy value method, Super-SBM model, and Haken model to measure the level of digital economy resilience, efficiency, and synergistic development, respectively. The spatio-temporal evolution pattern of China's digital economy efficiency and resilience was explored, as well as the synergistic evolution trend, in order to provide certain theoretical references for the high-quality sustainable development of the digital economy. The main conclusions of the study are as follows.

First, digital economic resilience had a fluctuating upward trend, but the resilience index was polarized, indicating that the overall level of national digital economic resilience was not high, and there were obvious regional differences. The digital economy resilience ratings for the eastern, central, northeastern, and western regions were broadly distributed according to "leading", "advancing", "catching up", and "lagging" provinces.

Second, the efficiency of the digital economy, as a whole, had a moderately high development trend, but the distribution of the efficiency value was polarized, indicating that the overall level of the efficiency of the digital economy during the study period was low, and that there was significant regional variability. The digital economy efficiency ratings for the eastern, central, northeastern, and western regions were broadly distributed according to "leading", "advancing", "catching up", and "lagging" provinces.

Third, digital economic resilience was an order parameter for the synergistic evolution of the resilience and efficiency of China's digital economy. The digital economy is an open sharing system, and there was a synergistic effect between resilience and efficiency, but the synergistic effect of digital economic resilience on digital economic efficiency was greater than the synergistic effect of digital economic efficiency on digital economic resilience during the study period. Both established a negative feedback mechanism that inhibited the orderly development of the system, indicating that the synergistic evolution of the resilience and efficiency of China's digital economy is in the primary stage and has large room for improvement in the future.

Fourth, the degree of synergy between the resilience and efficiency of China's digital economy was low, at a low level of synergy, with large differences in the levels of synergy between regions. Most provinces in the eastern region were at the "leading" level of digital economic resilience and efficiency, and the synergy level showed a trend of high synergy to very high synergy evolution. Most of the provinces in the central region were at the level of "catching up" in terms of their digital economic resilience and efficiency, and the synergy level showed a trend of low-level synergy evolution. The three northeastern provinces were less resilient in the digital economy and had lower efficiency levels in terms of long-term economic transformation. Therefore, the synergy evolution showed a very low level. Most of the provinces in the western region were "progressing" or "catching up" in terms of their digital economic efficiency, but they were "lagging" in terms of their digital economic resilience, resulting in a very low level of synergy evolution.

Finally, the four paths that drive the synergistic evolution of resilience and efficiency in a high digital economy are the "Resilience Dominates Driven Path", the "Basic Driven Path", the "Innovation Driven Path", and the "Balanced Driven Path".

5.2. Research Contributions

First, this study improved the theoretical connotation of the digital economy. The existing literature focuses on the conceptual connotation, formation mechanism, and influencing factors of the digital economy, while the discussion on the resilience of the digital economy needs to be deepened. Based on the technical characteristics of the digital economy, this study constructed a multi-dimensional assessment system for digital economic resilience based on the three dimensions of "technology-organization-environment" of the TOE theory, which is based on technological innovation and transformation capacity, organizational resistance and recovery ability, and environmental adjustment and adaptive capacity.

Second, this study enriched the toolbox of research methods in the field of system synergy. Currently, most of the existing studies dealing with system synergy are limited to the measurement of linear relationships in coupled synergy models. However, system synergy emphasizes the dynamic equilibrium and optimization of a system, and the ordered or disordered interactions between resilience and efficiency determine the non-linear characteristics of the evolution of system synergy. In this context, this study introduced the Haken model into the study of digital economy resilience and efficiency synergy, thus bridging the shortcomings of the previous literature in terms of the research methodology in this area.

Finally, this study provided a more standardized theoretical perspective on the complex mechanism of the synergistic evolution of resilience and efficiency and its influencing factors, and also enriched the practical cases of the application of the TOE theory. With the help of a qualitative comparative analysis, this study incorporated the "technology-organization-environment" factors of the TOE theory into the analysis of synergistic paths, and explored the "joint effect" of multiple variables on the synergistic enhancement of resilience and efficiency (Figure 9). Four development paths were proposed to promote the synergistic enhancement of the resilience and efficiency of the digital economy, which are theoretically novel.

5.3. Practical Implications

On the one hand, in terms of enhancing the resilience of the digital economy, we can start from the synergistic development of the three aspects of "technology—organization—environment" and scientifically design a resilient development system for the digital economy. Specifically, from a holistic perspective, we can build a resilience system that links multiple dimensions, such as technology, policy, R&D, finance, and investment, to promote the orderly and efficient flow of innovation factors and resources within the system, and to promote the high-quality development of the digital economy.

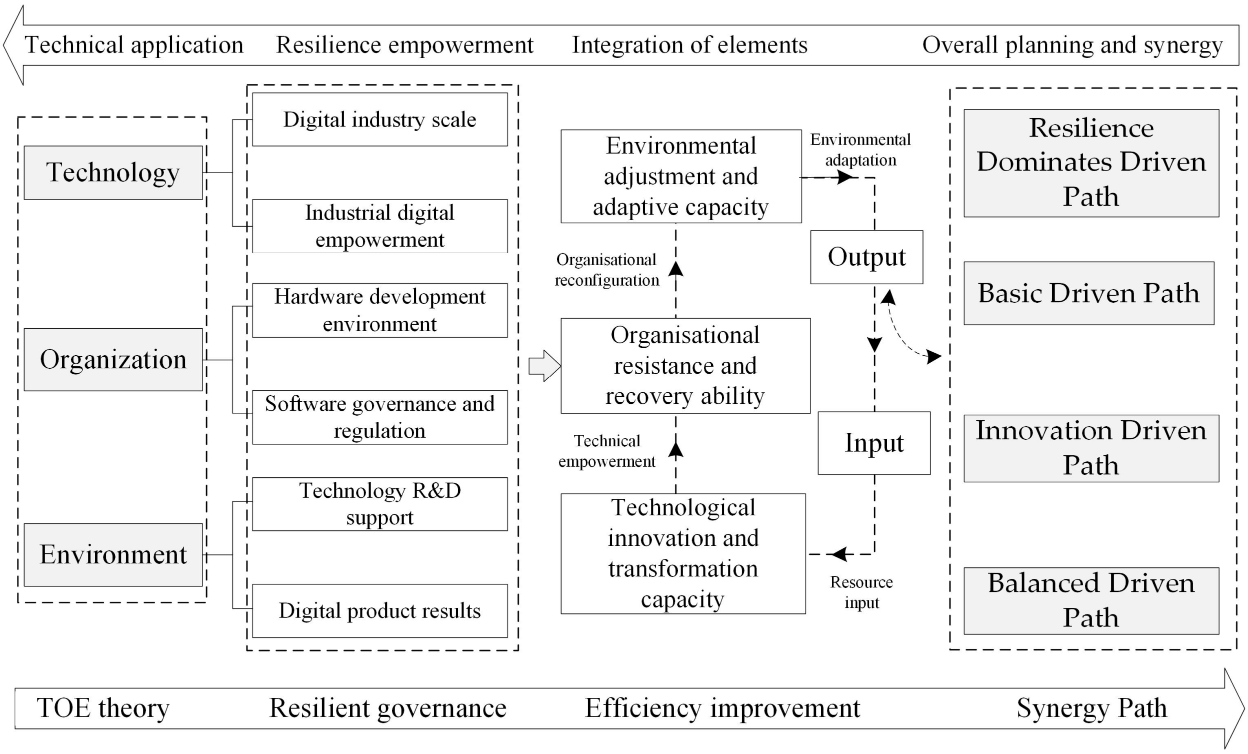


Figure 9. Synergistic mechanism of digital economy resilience and efficiency based on TOE theory. Source: Authors, 2023.

On the other hand, in terms of formulating resilience-oriented policies, we should create a favourable environment for innovation and development through the "technology-organization-environment" perspective and implement policies in a categorical manner, taking into account the actual development of the region. First, for regions that are lagging behind in the development of digital technology and resilience, priority should be given to improving digital-technology-related infrastructure. Second, if the development of digital economic resilience is at an average level in a region, there is a need to enhance the innovation vitality of the main body of its digital enterprises and further release the potential of its digital economic development. Finally, for regions with a high level of digital economic resilience, they should take the lead in improving the development environment, and through a diversified input mechanism, build an efficient and convenient innovation network to enhance the resilience space for digital economic development.

5.4. Research Limitations

Due to the availability of data related to the digital economy, this paper studied the time interval from 2013 to 2020 and analysed the synergistic evolution based on provincial data. With the continuous development of the digital economy, further research is needed at the city and county levels.

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Conflicts of Interest: The authors declare no conflict of interest.

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