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Multivariate statistical regression-supported multidimensional quantitative evaluation of county-level economies in Henan Province

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Abstract This paper takes the economic development of counties in Henan Province as its research object, using data from 82 county-level regions in Henan Province from 2011 to 2020 as its sample. From five dimensions—innovative development and transformation of growth drivers, coordinated development and structural optimization, green development and low-carbon actions, open development and efficiency reforms, and shared development and urban-rural coordination—a comprehensive evaluation index system for high-quality county-level economic development is proposed, comprising 21 tertiary indicators. The weights of each indicator are determined using the entropy weight method. Based on the established evaluation index system, the overall development trends of the research subjects from 2011 to 2020 were analyzed using PCA clustering analysis, preliminarily dividing the 82 county-level regions in Henan Province into three categories: steady development type, development divergence type, and weak development type. With the level of high-quality county-level economic development as the core explanatory variable and the digital finance development index as the explanatory variable, a multiple statistical regression model was constructed to explore the influence mechanism and threshold effect of the digital finance development index on high-quality county-level economic development. In the robustness test, the regression coefficients of the digital finance development index remained positive, and all three estimation results were significant at the 1% level, indicating that it indeed played a significant promotional role in driving the high-quality development of county-level economies in Henan Province.

Index Terms county-level economic development, entropy weight method, multiple statistical regression, threshold effect, cluster analysis

I. Introduction

County-level economies are a crucial component of national economic development, playing a pivotal role in accelerating high-quality regional economic growth, consolidating the achievements of poverty alleviation efforts, and realizing the Chinese Dream of national rejuvenation [1]. In 2021, the Chinese government explicitly outlined the importance of “accelerating the integrated development of urban and rural areas within counties,” identifying this as the key to achieving high-quality county-level economic development. This initiative holds significant implications for accelerating the integrated development of urban and rural areas within counties, narrowing the urban-rural gap, and enhancing the quality and level of county-level economic development [2]-[5]. As such, county-level economic development has entered a new phase of development and has been elevated to a new strategic height. As the process of high-quality economic development progresses, county-level economies are gradually transitioning toward a high-quality development phase, shifting from “non-existence” to ‘existence’ and from “low-quality” to “high-quality.” This transformation plays a crucial role in addressing the contradictions of unbalanced and inadequate development, consolidating poverty alleviation achievements, accelerating the construction of a new development pattern, and improving residents' quality of life, and serves as an important engine for high-quality economic development [6]-[8].

In recent years, the national economy of Henan Province has shown a good state of accelerated development, with steady improvement in economic aggregate, fiscal revenue and other major economic indicators, and the economic and social development of Henan Province has jumped to a new level, and its comprehensive economic strength has entered a new level [9]. In April 2020, Henan Province held a conference on the high-quality development of the county-level economy, pointing out that it is necessary to grasp the trend, enhance the sense of urgency and responsibility, and promote the high-quality development of the county-level economy in the new era [10]. In order to promote the high-quality development of the county economy from a new starting point, it is necessary to unswervingly implement the "three-in-one" county governance, with reform and development as the driving force, strengthening the county and enriching the people as the main body, urban and rural interconnection as the path, and giving full play to the advantages to find the position of the regional economic layout, so as to accelerate the formation of a new pattern with competitive development and outstanding characteristics [11], [12]. Based on the above background, the research on the quantitative evaluation of county economic development in Henan Province is helpful to promote the realization of the goal of building a strong province, solve the problem of unbalanced and insufficient development, and can also provide reference for the development of similar county economy in the central region [13].

Currently, many scholars and experts have developed reasonable indicator systems tailored to the characteristics of the regions they study, conducting in-depth analyses of economic development across various regions and achieving significant research outcomes. These findings have provided valuable insights for evaluating the development of county-level economies. Na, L, and Lili, G developed a comprehensive evaluation system covering 40 counties in Chongqing, using the entropy-weighted TOPSIS method to evaluate economic development from 2000 to 2010, revealing the spatial correlation of county-level economic polarization and differences in development speeds across regions [14]. Zhou, Y., et al. studied the spatial and temporal patterns of county-level economic development in China and found that from 1982 to 2010, there was a trend of increasing spatial concentration and dependence, with regional development policies being the key driving factor behind this trend [15]. Cao, P., and Tao, H. used economic indicators and various statistical analysis methods to evaluate the sustainable development potential of county-level economies in Gansu Province, revealing regional differences and identifying areas with higher levels of economic development and future growth potential [16]. Yu, B., et al. utilized NPP-VIIRS nighttime light composite data to evaluate the development status of Chinese counties, finding a good correlation between socioeconomic indicators and light data [17].

Regarding research on high-quality development of county-level economies, Wan, J., et al. examined the spatial-temporal differences in high-quality development of county-level economies in Sichuan Province, China, and their influencing factors, finding that they exhibit high coupling but low coordination [18]. Liu, Y., et al. studied the impact of financial marketization on high-quality economic development at the county level, finding that this impact exhibits a nonlinear relationship and is influenced by the degree of urbanization at the county level, which serves as a threshold factor determining the impact of financial marketization on overall growth and quality improvement [19]. Hua, X et al. evaluated the development efficiency and total factor productivity of county-level economies in China, explored their spatial-temporal distribution patterns and influencing factors, and found significant regional differences, with government, urbanization, and marketization having positive impacts [20]. Wu, Y et al. employed fuzzy set qualitative comparative analysis (fs-QCA) to study the causal mechanisms underlying county-level economic development, finding that it is influenced by multiple factors rather than a single condition, and identified four distinct pathways that can facilitate economic success in their research [21].

Many studies on county-level economies evaluate their development from different perspectives, such as the efficiency of county-level economic development and the efficiency of county-level agricultural economic development. Miao, H., and Zhou, H. evaluated the economic efficiency of 30 counties in Inner Mongolia and found that their economic efficiency has been steadily improving over time, with higher-efficiency counties concentrated in the eastern region [22]. Yang, Z., et al. examined the spatio-temporal patterns of the relationship between urbanization and economic development in China's county-level administrative regions. They found a high degree of matching between the two, significant regional differences, and changes in spatial dependence and heterogeneity over time [23]. Tang, R., et al. evaluated and analyzed the efficiency of 31 provincial governments in China from 2001 to 2010. The study found that there was a significant correlation between economic development and efficiency, with notable regional differences [24].

This paper first proposes a comprehensive evaluation index system for high-quality county-level economic development based on existing research and actual conditions, with a focus on describing the meaning and structure of first-level and second-level indicators. It then designs the preprocessing steps for county-level economic development data, briefly outlines the operational process of the entropy weight method, and determines the weights of the proposed evaluation system indicators based on the entropy weight method. Data on county-level economic development in Henan Province from 2011 to 2020 are selected as the research sample. Combining the proposed evaluation indicator system and cluster analysis methods, the economic development status is analyzed. Based on the characteristics of county-level economic development in Henan Province, research hypotheses are proposed. Benchmark regression equations, model testing, and dual threshold models are successively established to form an econometric model and set model variables. Finally, an empirical regression analysis of the influencing factors and mechanisms of county-level economic development in Henan Province is conducted.

II. Comprehensive Evaluation Index System for High-Quality Economic Development at the County Level

The existing indicator systems for high-quality economic development are primarily applied to provincial and municipal-level studies, with limited focus on the county level, resulting in a general scarcity of empirical research on high-quality economic development at the county level. Building on existing indicator systems, this paper primarily considers the availability and multidimensionality of indicator data. Based on principles of scientific rigor, comprehensiveness, appropriateness, and comparability among indicators, and guided by the new development philosophy with the practical experience of county-level economic development in Henan Province as a foundation, an evaluation indicator system for high-quality county-level economic development is constructed, as shown in Table 1. The system includes five primary indicators: innovative development and transformation of growth drivers, coordinated development and structural optimization, green development and low-carbon actions, open development and efficiency reforms, and shared development and urban-rural coordination. It also includes ten secondary indicators, such as innovation environment, transformation of growth drivers, economic coordination, and structural optimization, as well as 21 quantifiable tertiary indicators, including total power of agricultural machinery, number of large-scale industrial enterprises, and number of internet broadband users.

Table 1: Indicator system for high-quality development of county-level economy

Primary index	Secondary index	Three-level index	Indicator nature
(A)Innovative development and transformation of Growth drivers	(A1)Innovation environment	(A11)Total power of agricultural machinery	Positive
		(A12)Expenditure on science and technology/Fiscal expenditure	Positive
	(A2)Kinetic energy conversion	(A21)The number of industrial enterprises above designated size	Positive
		(A22)The number of Internet broadband access users	Positive
(B)Coordinated development and structural optimization	(B1)Economic coordination	(B11)Per capita GDP	Positive
		(B12)Public financial expenditure/public financial revenue	Negative
	(B2)Structural Optimization	(B21)Total industrial output value above designated size /GDP	Positive
		(B22)Added value of the tertiary industry /GDP	Positive
(C)Green Development and low-carbon Actions	(C1)Resource consumption	(C11)The usage amount of agricultural plastic film	Negative
	(C2) Environmental governance	(C21)Degree of haze pollution (annual average PM2.5 concentration)	Negative
		(C22)Pesticide usage per unit area of cultivated land	Negative
		(C23)The amount of chemical fertilizer applied per ton of cultivated land area	Negative
(D)Open Development and Efficiency Transformation	(D1)Open trade	(D11)Total retail sales of consumer goods /GDP	Positive
		(D12)The balance of loans from financial institutions per unit of GDP	Positive
	(D2)Efficiency Transformation	(D21)GDP growth rate	Positive
		(D22)Total industrial output value of designated-size enterprises/Number of designated-size enterprises	Positive
(E)Shared development and urban-rural synergy	(E1)Shared development	(E11)Nighttime light remote sensing luminance DN (VIIRS)	Positive
		(E12)The number of practicing physicians	Positive
		(E13)The number of beds in medical and health institutions	Positive
	(E2)Urban-rural synergy	(E21)The ratio of per capita disposable income between rural and urban residents	Negative
		(E22)Urbanization rate	Positive

Innovation aims to address the issue of driving forces for county-level economic development. The innovation environment serves as the soil and source of innovation development, while the transformation of new and old growth drivers is the goal and key to innovation development. Therefore, this paper reflects the concept of innovation development through innovation environment and growth driver transformation, specifically covering government investment and internet development. Coordination focuses on addressing the issue of unbalanced county-level economic development. Economic coordination is the basic requirement for coordinated development, while structural optimization is its intrinsic manifestation. Therefore, this paper reflects the concept of coordinated development through economic coordination and structural optimization, specifically covering indicators such as per capita GDP and the proportion of the tertiary industry. Green development focuses on addressing the issue of sustainable development in county-level economies. Low-carbon actions are the ultimate goal of green development, which implies lower resource consumption and better environmental governance. Therefore, this paper reflects the concept of green development through resource consumption and environmental governance, specifically covering indicators such as the use of agricultural plastic films and the severity of haze pollution. Openness focuses on addressing issues of internal and external connectivity in county-level economies. Counties are a key focus for promoting domestic economic circulation. Open trade is the foundation of open development, and efficiency transformation is its target direction. Therefore, this paper explores the concept of open development through open trade and efficiency transformation, specifically covering indicators such as the proportion of retail sales of consumer goods in GDP and GDP growth rates. Shared development emphasizes addressing issues of fairness and justice in county-level economic development. The ultimate goal of shared development is for the benefits of development to be shared by the people. Therefore, urban-rural coordination is an inherent aspect of shared development. This paper examines shared development and urban-rural coordination to illustrate the concept of shared development, specifically covering metrics such as the number of licensed physicians and the ratio of per capita disposable income between rural and urban residents.

III. Analysis and Evaluation of High-Quality Economic Development at the County Level

III. A. Data preprocessing

The data used in this study were mainly obtained from provincial and county statistical yearbooks, annual reports from agricultural departments, and raw data collected through field research. To ensure the reliability and validity of the data, a series of preprocessing steps were taken, including data cleaning and standardization, to eliminate biases between different data sources and ensure the accuracy of the final analysis results. This study uses the deviation standardization method (min-max standardization) to uniformly map the data to the interval [0,1], with the conversion function as follows.

Positive indicators are as in equation (1):

$$x_{ij}^{*} = \frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}} \tag{1}$$

Negative indicators such as equation (2):

$$x_{ij}^{*} = \frac{x_{j\max} - x_{ij}}{x_{j\max} - x_{j\min}} \tag{2}$$

In the formula, x_{ij}^{*} is the standardized value of indicator j for county i. $x_{j\max}$ and $x_{j\min}$ are the maximum and minimum values of indicator j, respectively.

III. B. Determining entropy weights using the entropy weight method

(1) Calculate the eigenvalue weight (P_{ij}) of the i th sample under the j th indicator as shown in Equation (3):

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{3}$$

(2) Calculate the entropy value (e_j) of the j th indicator as shown in Equation (4):

$$e_j = -\frac{\sum_{i=1}^{n} p_{ij} \ln p_{ij}}{\ln m}, 0 < e_j < 1 \tag{4}$$

(3) The coefficient of variation (g_j) is calculated as shown in equation (5):

$$g_j = 1 - e_j \tag{5}$$

(4) Determine the weighting of evaluation indicators $W = \left(w_1, \cdots, w_j, \cdots\right)$ as shown in Equation (6):

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \tag{6}$$

In the formula, w_j is the entropy weight of indicator j.

III. C. Evaluation Results and Analysis

This paper selects economic development data from 82 county-level regions in Henan Province between 2011 and 2020 as the research sample and conducts a preliminary analysis of development levels based on the comprehensive evaluation index system for high-quality county-level economic development mentioned above.

III. C. 1) Comparison of weight analysis using entropy values

The weighting results obtained using the entropy weight method are summarized in Table 2, where “e” represents the information entropy value, ‘d’ represents the information utility value, and “w” represents the weighting coefficient. (B11) The proportion of per capita regional GDP is 15.2%, (B22) the proportion of tertiary industry added value to GDP is 11.19%, and (A12) the proportion of science and technology expenditure to fiscal expenditure is 7.77%.

An explanatory analysis is conducted for the top 3 indicators in terms of importance among the tertiary indicators:

(1) Per capita regional GDP, as a core indicator reflecting regional economic development levels, directly reflects the average economic value created by each resident and is a key factor in evaluating the prosperity of a region or country.

(2) The tertiary industry's added value/GDP ratio highlights the important role of the service sector in the economic structure. This ratio not only represents the vigorous development of industries such as tourism, catering, finance, and education but also foreshadows that, with the deepening of economic development, the service sector is gradually becoming the engine of economic growth.

(3) Science and technology expenditure/fiscal expenditure refers to the proportion of total government fiscal expenditure allocated to funding activities related to science, technology, research, and development. This indicator signifies the level and quality of local economic development.

Table 2: Calculate the weight results by the entropy method

Primary index	Secondary Index	Three-level Index	e	d	W(%)
A	A1	A11	0.959	0.0273	3.94
		A12	0.913	0.0055	7.77
	A2	A21	0.973	0.0355	3.55
		A22	0.959	0.019	4.84
B	B1	B11	0.902	0.0132	15.2
		B12	0.961	0.0181	3.54
	B2	B21	0.964	0.0135	3.92
		B22	0.993	0.0139	11.19
C	C1	C11	0.985	0.0023	3.81
	C2	C21	0.928	0.0018	2.46
		C22	0.912	0.0297	3.03
		C23	0.909	0.0301	3.48
D	D1	D11	0.946	0.0297	3.1
		D12	0.956	0.0155	3.24
	D2	D21	0.965	0.0368	3.92
		D22	0.984	0.0394	3.01
E	E1	E11	0.982	0.027	2.7
		E12	0.97	0.0107	3.74
		E13	0.971	0.0226	3.51
	E2	E21	0.903	0.0351	4.24
		E22	0.925	0.0185	5.81

III. C. 2) Overall Evaluation Results and Analysis

Based on the proposed comprehensive evaluation index system for high-quality county-level economic development, a map was created showing the development levels of Henan Province's county-level economies from 2011 to 2020 in ten dimensions (Figure 1): (A1) innovation environment, (A2) momentum transformation, (B1) economic coordination, (B2) structural optimization, (C1) Resource Consumption, (C2) Environmental Governance, (D1) Open Trade, (D2) Efficiency Transformation, (E1) Shared Development, and (E2) Urban-Rural Coordination.

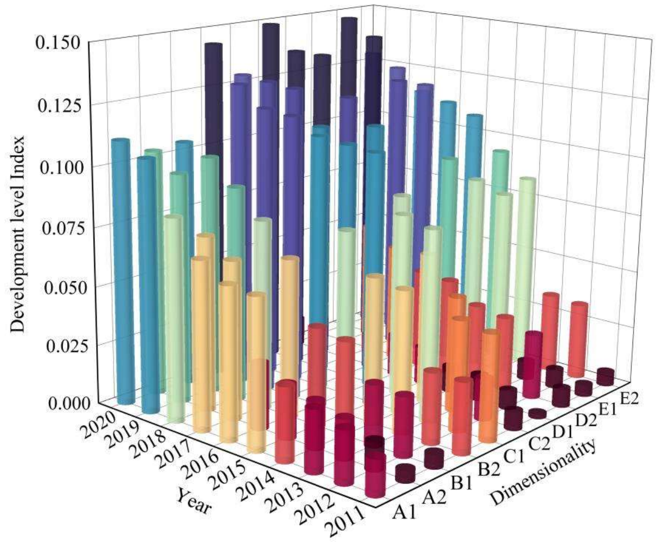


Figure 1: The trend of county-level economic development level in Henan Province

It can be seen that, whether in terms of overall economic growth or the quality of economic development, the county-level economies of Henan Province have maintained a steady and moderate-to-high growth trajectory. The pace of transition between old and new growth drivers has accelerated, injecting a steady stream of new vitality into economic growth. With the deep transformation and upgrading of traditional industries and the rapid rise of emerging industries, the industrial structure of Henan Province's county-level economies has been continuously optimized, laying a solid and stable foundation for high-quality development. The enhancement of innovation-driven capabilities is another highlight of the development of county-level economies in Henan Province. With the continuous deepening of scientific and technological innovation, an increasing number of enterprises are beginning to focus on technological research and development and product innovation, driving the innovative development of county-level economies. At the same time, the government has also increased its support for innovation, providing strong guarantees for the innovative development of county-level economies and further promoting their vigorous growth.

III. D. Clustering Structure and Analysis

Using an encoder, low-dimensional feature representations were extracted for 82 county-level regions in Henan Province. After obtaining the low-dimensional features, the K-means algorithm was selected to cluster the low-dimensional features of the county-level regions. Based on the clustering results, three clusters were selected as the optimal number of clusters. The three clusters are defined as follows: Cluster 0: Steady Development Type Region, Cluster 1: Development Diversification Type Region, Cluster 2: Weak Development Type Region. Using PCA, all feature indicators were reduced to two indicators. The clustering results are shown in Figure 2.

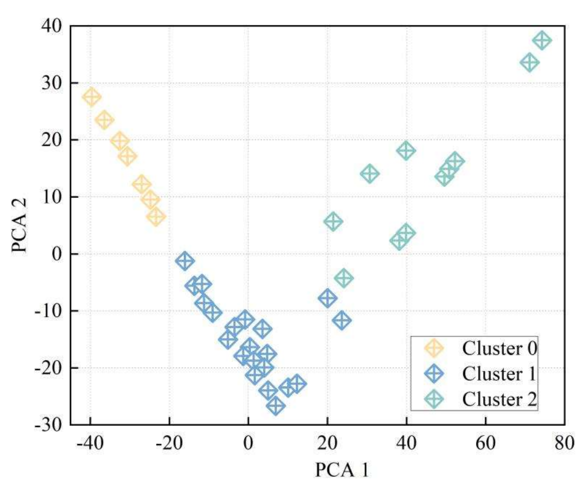
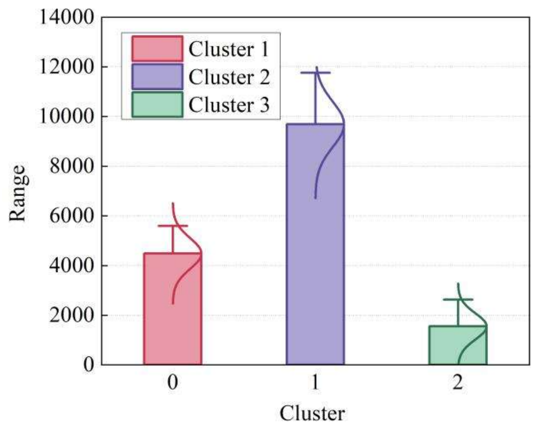
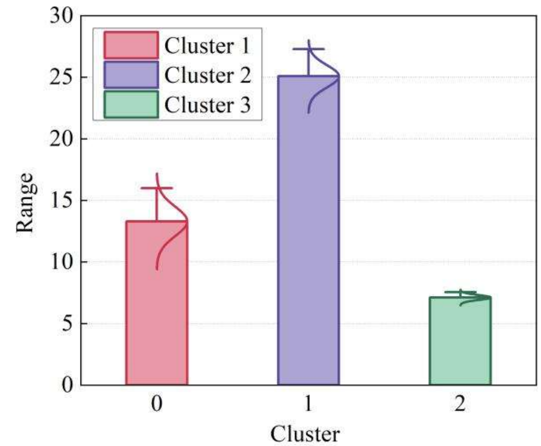


Figure 2: K-Means clustering visualization

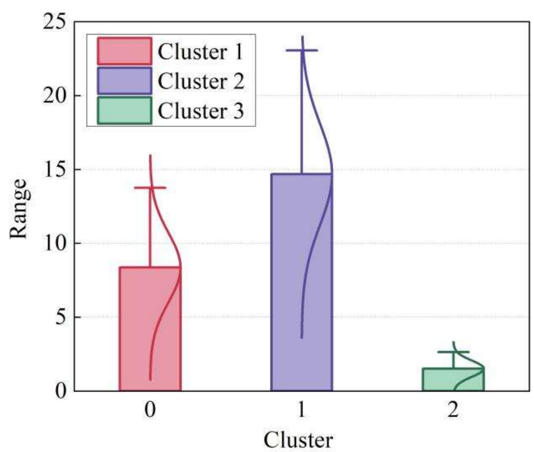
From the 21 tertiary indicators, the four indicators with the greatest differences between clusters were selected: (B11) per capita gross domestic product, (B22) tertiary industry added value/GDP, (A12) science and technology expenditure/fiscal expenditure, and (E22) urbanization rate. The distribution results of these four indicators across the 82 county-level regions in Henan Province are shown in Figure 3.



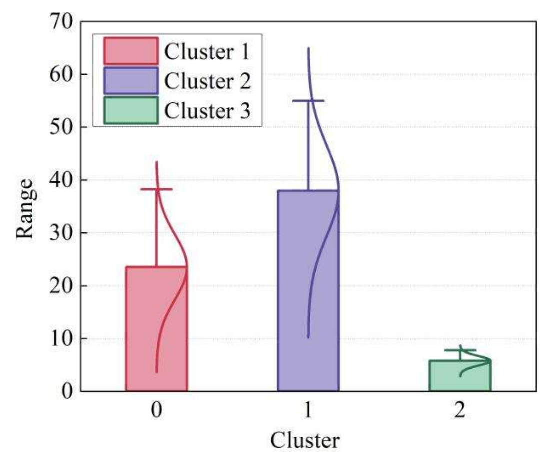
(a) B11



(b) B22



(c) A12



(d) E22

Figure 3: Cluster feature display

By analyzing Figure 3, the characteristics of different clusters of county-level regions can be summarized as follows:

(1) Steadily developing regions. Although the per capita GDP of these regions is relatively low, it is growing steadily. The added value of the tertiary industry generally accounts for a moderate proportion of the overall GDP. Scientific and technological expenditure in government fiscal expenditure is relatively low, and these regions have a certain level of urbanization, resulting in moderate population density. They may be undergoing a phase of industrial structure transformation and upgrading.

(2) Developmentally divergent regions. These regions are primarily located in the central and northern parts of Henan Province, with relatively high per capita GDP and more developed economies. Their industries are dominated by manufacturing, foreign trade, and high-tech industries, resulting in a higher proportion of scientific and technological expenditures in government fiscal spending. The private economy is active, and urbanization levels are high, with dense populations.

(3) Weak development regions. These regions are primarily located in remote areas of Henan Province, with low per capita GDP and relatively underdeveloped economies. The primary industries are agriculture and forestry, with low levels of industrialization and virtually no scientific and technological expenditures. These regions not only

have low levels of urbanization and sparse populations but may also face issues such as inadequate infrastructure and talent outflow, requiring greater government policy support and resource allocation.

IV. Empirical Analysis of the Driving Factors of High-Quality Economic Development at the County Level

Based on the analysis above and the needs of this study, the following research hypotheses are proposed in this section:

H1: The development of digital finance can directly promote high-quality economic development in Henan Province's counties.

H2: Digital finance in Henan Province's counties can promote high-quality economic development by facilitating industrial structure upgrading.

H3: When industrial structure upgrading serves as a threshold variable, the impact of digital finance development on high-quality economic development in Henan Province's counties exhibits a threshold effect.

IV. A. Model Construction and Variable Setting

IV. A. 1) Construction of measurement models

This paper is based on panel data from county-level cities in Henan Province from 2011 to 2020. Based on the research hypotheses proposed in the preceding section, a fixed-effects model is used to empirically test the impact of digital financial development on the high-quality economic development of county-level cities in Henan Province, and further explore its impact mechanism and threshold effects. First, for the proposed hypothesis H1, the following benchmark regression equation (7) is set:

$$CE_{it} = \alpha_0 + \beta_0 DF_{it} + \gamma_0 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{7}$$

In this context, i denotes the county level, and t denotes the year. CE represents the level of high-quality economic development at the county level, DF denotes the level of digital financial development, X denotes a set of control variables influencing county-level economic development, μ_i denotes the regional fixed effect, λ_t denotes the year fixed effect, and ε_{it} denotes the random disturbance term.

Second, based on the theoretical analysis in the preceding section, digital finance development may influence the high-quality development of county-level economies through its effects on urban-rural income gaps and industrial structure upgrading. To test hypothesis H2, this paper combines existing research to establish the following testing models as shown in Equations (8)-(11):

$$gap_{it} = \alpha_1 + \beta_1 DF_{it} + \gamma_1 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{8}$$

$$CE_{it} = \alpha_2 + \beta_2 gap_{it} + \gamma_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{9}$$

$$inc_{it} = \alpha_3 + \beta_3 DF_{it} + \gamma_3 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{10}$$

$$CE_{it} = \alpha_4 + \beta_4 inc_{it} + \gamma_4 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{11}$$

In equations (8)–(11), gap denotes the level of income disparity between urban and rural residents, inc denotes industrial structure upgrading, and the meanings of the remaining variables are consistent with those in equation (7).

Finally, this paper employs a panel threshold model to examine whether the impact of digital finance on the high-quality development of county-level economies is subject to threshold constraints imposed by the degree of industrial agglomeration. First, a single threshold model is constructed as in Equation (12), which is then extended to a double threshold model as in Equation (13), with the following specific settings:

$$\begin{aligned} CE_{it} = \alpha_4 + \beta_4 DF_{it} \times I\left(LQ \geq \theta_1\right) + \rho_4 DF_{it} \\ \times I\left(LQ \geq \theta_1\right) + \gamma_4 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned} \tag{12}$$

$$\begin{aligned} CE_{it} = \alpha_5 + \beta_5 DF_{it} \times I\left(LQ \leq \theta_2\right) + \rho_5 DF_{it} \times I\left(\theta_1 \leq LQ \leq \theta_2\right) \\ + \varphi_5 DF_{it} \times I\left(LQ \geq \theta_2\right) + \gamma_5 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned} \tag{13}$$

In equations (12) and (13), θ represents the threshold value, $I(\cdot)$ is the characteristic function, and the meanings of other variables remain unchanged.

IV. A. 2) Selection and description of variables

(1) Dependent variable: Set as the level of high-quality economic development at the county level, represented by the comprehensive evaluation index (CE) of high-quality economic development at the county level measured using the entropy weight method described above.

(2) Core explanatory variables: set as the Digital Finance Development Index (DF). Considering that the initial development stage of China's digital finance is dominated by the development of Internet finance, and the development level of digital finance of banking financial institutions in county-level areas is lacking, the digital inclusive finance index based on Internet financial user data can reflect the development process of China's digital finance to a certain extent. Combined with the existing research, the digital inclusive finance index based on Internet financial applications is used to measure the development level of digital finance at the county level. In addition, the dimensional heterogeneity of digital finance development is further explored from the perspective of its coverage breadth, depth of use and degree of digitalization, which are expressed by DF_{cov}, DF_{dep} and DF_{dtg}, respectively. Among them, the breadth of coverage mainly measures the popularity and accessibility of digital finance, the depth of use mainly reflects the ability to actually use digital financial services, and the degree of digitalization represents the convenience and real-sense degree of digital financial services. To make the data present intuitive and comparable, each index is divided by 100 to quantify.

(3) Mechanism variables: Two mechanism variables were selected: the urban-rural income gap (gap) and industrial structure upgrading (inc). The urban-rural income gap was represented by the ratio of per capita disposable income of urban residents to per capita net income of rural residents, while industrial structure upgrading was represented by the proportion of the sum of the added value of the secondary and tertiary industries to GDP.

(4) Control variables: To mitigate estimation biases caused by omitted variables, we select the fixed asset investment rate (kpl) and government expenditure (gov) as control variables. The fixed asset investment rate is measured by the ratio of total fixed asset investment to GDP. Government expenditure is measured by the ratio of fiscal expenditure to GDP. Additionally, the development of county-level economies relies on the aggregation of labor, and county-level population density (pd) and employment absorption capacity (wage) are also important factors influencing high-quality county-level economic development. Therefore, these two indicators are also included as control variables, measured by the number of permanent residents per unit area and the logarithm of the average wage of urban employed personnel, respectively. Furthermore, the scale of county-level economic development (GDP) has a significant impact on high-quality economic development. The scale of county-level economic development serves as both the foundation and a component of high-quality development, so it is included as a control variable. To eliminate the effects of price changes and heteroskedasticity, the logarithm of regional GDP deflated using 2015 as the base year is used as the measure.

(5) Threshold variable: industrial agglomeration level. Considering data availability and the representativeness of the selected indicators, this study uses location entropy (LQ) to measure the industrial agglomeration level of each county, calculated using formula (14):

$$\mathrm{LQ}_{it} = \frac{q_{it} / qa_i}{\sum_{i=1}^{104} q_{it} \Big/ \sum_{i=1}^{104} qa_{it}} \tag{14}$$

Among these, q_{it} represents the total value of the secondary or tertiary industries in region i in year t, and qa_i represents the gross domestic product (GDP) of region i in year t. When $LQ_{it} > 1$, it indicates that the level of specialization of industry i at the county level in year t is higher than the average level across all counties in Henan Province; conversely, it is lower than the average level. This paper uses the location entropy of the secondary industry (LQ2) and the location entropy of the tertiary industry (LQ3) as proxy variables for industrial agglomeration.

The descriptive statistics of the variables are shown in Table 3. The average value of the digital finance development index (DF) for counties in Henan Province is 0.251, with a standard deviation of 0.077. This indicates that the current level of digital finance development varies significantly across different counties in Henan Province.

Table 3: Descriptive statistics of variables

Types of variables	Variable	Sample size	Mean value	Standard deviation	Minimum value	Maximum value
Variable being explained	CE	82	0.440	0.012	0.302	0.578
Explaining variable	DF	82	0.251	0.077	0.109	0.376
Mechanism variable	gap	82	1112.941	543.87	111.12	2708.52
	inc	82	0.303	0.038	0.217	0.393
Control variable	kpl	82	0.199	0.024	0.138	0.288
	gov	82	0.303	0.011	0.245	0.387
	pd	82	1.091	0.078	0.962	1.175
	wage	82	77.343	1.891	61.615	93.233

	gdp	82	8024.210	689.23	5150.52	9648.6
Threshold variable	LQ2	82	0.674	0.096	0.091	0.946
	LQ3	82	0.669	0.087	0.278	0.967

IV. B. Analysis of empirical regression results

IV. B. 1) Benchmark Regression

This paper primarily uses the SYS-GMM model to examine the mechanism through which the digital finance development index influences high-quality economic development at the county level. Based on comparative analysis and robustness considerations, both the OLS model and the two-way fixed FE model are employed for estimation. The regression results are presented in Table 4.

Table 4: Benchmark regression result

	OLS		FE		SYS-GMM	
	(1)	(2)	(3)	(4)	(5)	(6)
CE					0.6799*** (0.095)	0.07011*** (0.075)
DF	1.1559*** (0.117)	0.8249*** (0.085)	0.0948*** (0.018)	0.1107*** (0.014)	0.7741*** (0.269)	0.2511*** (0.079)
gap		-0.0748** (0.049)		-0.0157** (0.011)		-0.0235** (0.0048)
inc	1.0147*** (0.248)	1.2480*** (0.259)	1.0133*** (0.341)	0.9852*** (0.333)	0.8653*** (0.278)	0.1469*** (0.087)
kpl		0.8651*** (0.074)		0.8943*** (0.086)		1.0145*** (0.083)
gov		0.0755*** (0.0049)		0.0185** (0.009)		0.3228*** (0.005)
pd		0.0433** (0.013)		0.0489** (0.026)		0.0521** (0.033)
wage		1.2347*** (0.226)		1.2874*** (0.238)		1.3132*** (0.255)
gdp		1.5478* (0.014)		1.6320** (0.015)		1.7841*** (0.015)
LQ2		-0.1261** (0.022)		-0.1342** (0.023)		-0.1357** (0.020)
LQ3		0.9874*** (0.784)		1.2567*** (0.763)		0.9986*** (0.775)
Fixed region	YES	YES	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES	YES	YES
_cons	-4.7899** (0.551)	-3.5671** (0.381)	-0.1842** (0.071)	-0.2741** (0.083)	-3.4874** (1.225)	-1.1126** (0.371)
N	82	82	82	82	82	82
R^2	0.352	0.657	0.209	0.286		
AR(2)					0.831	0.889
Sargan test					0.666	0.693

Note:"*", "**", and "***" respectively represent the significance levels of 10%, 5%, and 1%, with the robust standard error in parentheses. The same applies below.

Table 4, Column (6) presents the estimation results of the bidirectional fixed SYS-GMM model. The AR(2) value is 0.889, which is greater than 0.1, indicating that the residuals do not exhibit second-order or higher autocorrelation, suggesting that the model specification is appropriate. The Sargan tests all pass, indicating that there is no over-identification issue with the instrumental variables. The coefficient of the Digital Financial Development Index (DF) is 0.2511 and is statistically significant at the 1% level, indicating that the Digital Financial Development Index plays a positive role in county-level economic development and contributes to enhancing the quality of county-level economic development. At its core, digital finance can help improve the allocation capacity and efficiency of financial resources, narrow income gaps among county-level residents, and thereby promote high-quality economic development. Regarding control variables, the coefficient of government expenditure (gov) is 0.3228 and significant at the 1% level, indicating that increased government expenditure can effectively promote high-quality development of county-level economies. Increased government fiscal expenditure not only rationalizes the allocation of resource structures but also enhances resource utilization efficiency, thereby assisting in the improvement of high-quality development levels in county-level economies.

Comparing the regression results of the OLS model, FE model, and SYS-GMM model, it can be seen that regardless of whether control variables are included, the regression coefficient of the digital finance development index remains positive, with differences only in the intensity of the impact. However, all three estimation results are significant at the 1% level, indicating that the digital finance development index indeed plays a significant promotional role in driving county-level economies toward higher-quality development. This research result not only strongly validates the research hypothesis H1 but also lays a solid empirical foundation for further deepening the understanding and recognition of the important role played by digital finance in the high-quality development of county-level economies in Henan Province.

IV. B. 2) Robustness test

To further enhance the reliability of the benchmark regression results, this paper employs the following methods for robustness testing: first, replacing the explained variables. Although this paper uses the entropy method and the improved AHP method to comprehensively determine the indicator weights, there is still a possibility of some error. Therefore, based on the evaluation indicator system constructed earlier, principal component analysis is again used to recalculate the level of high-quality economic development at the county level in Henan Province. The results analysis revealed that the KMO value was 0.734, indicating that the data met the prerequisites for principal component analysis. Thus, the data could be used for principal component analysis research. Therefore, the results from the re-calculation were used as the dependent variable, and a two-way fixed SYS-GMM model was employed for estimation. The robustness results are presented in Table 5, and the results obtained through empirical analysis are shown in Column (1) of Table 5. It can be seen that the direction and significance level of the DF coefficient have not changed, indicating that the regression conclusions are reliable.

Second, replace the explanatory variables. This paper re-examines the empirical results using the coverage breadth DF_{cov}, usage depth DF_{dep}, and digitalization level DF_{dtg} of digital financial development as explanatory variables. As shown in Table 5, the three secondary indicators still have a positive impact on the high-quality development of county-level economies. The coverage breadth in column (2) and the usage depth in column (3) passed the 1% significance level test, while the digitalization level in column (4) passed the 10% significance level test.

Third, the data were trimmed. To eliminate potential interference from extreme values in the sample, all continuous variables in the regression model were trimmed at the 1% and 99% levels to obtain more accurate estimation results. Column (5) of Table 5 presents the regression results after trimming. After regression estimation and processing, the estimated coefficient of the core explanatory variable was 0.2301, which was statistically significant at the 1% level. This significance aligns with the experimental results of the benchmark regression, further demonstrating that the findings of this study are not only robust but also highly statistically significant, with the conclusions presented being both authentic and accurate.

Table 5: Robustness check

	Replace the explained variable	Replace the explanatory variable			Tail reduction treatment
	(1)	(2)	(3)	(4)	(5)
CE	0.7798*** (0.099)	0.7234*** (0.068)	0.7239*** (0.73)	0.8121*** (0.091)	0.7083*** (0.081)
DF	0.2198*** (0.088)				0.2301*** (0.082)
DF_{cov}		0.2833*** (0.095)			
DF_{dep}			0.1522*** (0.051)		
DF_{dtg}				0.1039* (0.062)	
Control Variable	YES	YES	YES	YES	YES
Fixed region	YES	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES	YES
N	82	82	82	82	82

AR(2)	0.678	0.958	0.822	0.987	0.704
Sargan test	0.111	0.679	0.691	0.733	0.597

IV. B. 3) Mediating effect analysis

As can be seen from the previous analysis, the digital finance development index directly drives the high-quality development of the county-level economy. This section will establish a regression model to explore the mediating role of industrial structure upgrading in the aforementioned impact effects, thereby revealing the impact mechanism of the digital finance development index on the high-quality development of the county-level regions in Henan Province. The results of the mediation effect regression are shown in Table 6.

Table 6: Regression results of mediating effects

	(1) CE	(2) LQ3	(3) CE
DF	0.1599*** (3.11)	19.0612*** (2.94)	0.1352*** (2.65)
gap	-0.0122 (-1.00)	-4.5387*** (-3.04)	-0.0059 (-0.57)
inc	-0.0003 (-0.31)	-0.0325 (-0.51)	-0.0002 (-0.22)
kpl	0.0308 (0.91)	-0.4813 (-0.15)	0.0321 (0.95)
gov	0.0014*** (3.57)	0.0463 (0.97)	0.0015*** (3.47)
pd	-0.0003 (-0.38)	-0.0192 (-0.54)	-0.0003 (-0.32)
wage	0.1700*** (3.34)	0.1298** (2.13)	0.0705* (1.78)
gdp	0.0446*** (2.91)	0.1581*** (3.08)	0.0838*** (4.29)
LQ2	-0.0015*** (-3.25)	-0.0002 (-0.29)	-0.0001 (-0.36)
LQ3			0.0015*** (2.59)
_cons	0.0239 (0.36)	26.8511*** (3.03)	-0.0098 (-0.16)
Individual effect	YES	YES	YES
Time effect	YES	YES	YES
N	82	82	82
R^2	0.9512	0.3766	0.9503

According to the stepwise regression analysis, the regression of the digital financial development index on industrial structure upgrading in column (2) of Table 6 is significant at the 1% significance level, with a coefficient of 19.0612. This indicates that the digital financial development index has a strong promotional effect on industrial structure upgrading at the county level in Henan Province. The coefficient for industrial structure upgrading in column (3) is 0.0015, and it is also significant at the 1% level. Industrial structure upgrading also has a positive promotional effect on the high-quality development of the county-level economy in Henan Province. Based on the validated hypothesis H1, the three coefficients set in the preceding text are simultaneously significant, indicating that industrial structure upgrading plays an intermediary transmission role in the influence process. Additionally, the regression coefficient of the digital financial development index in Column (3) is 0.1352 and is significant at the 1% level, indicating that industrial structure upgrading plays a partial mediating role in the influence process. This is also consistent with the actual situation, as there are inevitably other mediating transmission mechanisms through which the digital financial development index influences the high-quality development of the county-level economy in Henan Province in real life.

In summary, within the county-level regions of Henan Province, the digital financial development index promotes high-quality economic development by facilitating industrial structure upgrading, thereby validating hypothesis H2.

IV. B. 4) Threshold Effect Analysis

In order to verify whether there is a nonlinear relationship between the digital financial development index and high-quality economic development in Henan Province for the transformation and upgrading of different industrial structures at the county level. Combined with the above analysis, it is preliminarily inferred that there is a dual effect when the transformation and upgrading of industrial structure is used as a threshold variable. According to the threshold value estimation analysis, the single threshold value of industrial structure transformation and upgrading is -0.4425, which is within the 95% confidence interval [-3.0351, 0.3295], and the double threshold value is 7.2039, which is within the 95% confidence interval [6.6784, 7.2031], and the model regression results for the threshold effect are shown in Table 7.

Table 7: Threshold effect model regression results

Variable	Coefficient	Standard Deviation	T value	P>|t|	95% confidence interval	
gap	0.0019	0.2345	0.05	0.996	-0.049	0.0082
inc	-0.0002	0.0697	-0.45	0.993	-0.0379	0.0033
kpl	0.0422	0.1398	1.53	0.987	0.0363	0.0405
gov	0.0012***	0.1791	3.22	0.98	0.0154	0.0714
pd	0.0001	0.2372	0.11	0.979	-0.0652	0.018
wage	0.0025	0.2052	2.22	0.974	0.0426	0.0623
gdp	0.0002	0.1063	5.56	0.969	0.0167	0.0319
LQ2	0.0036	0.249	3.78	0.957	0.0415	0.0756
LQ3⩽-0.4425	0.0451**	0.2246	4.12	0.034	0.0029	0.0353
-0.4425⩽LQ3⩽7.2039	0.0808***	0.1886	1.78	0.000	0.0568	0.1052
LQ3>7.2039	0.0611***	0.1747	3.62	0.000	0.0733	0.1288

When the level of industrial structure transformation and upgrading is below -0.4425%, the estimated coefficient of the digital finance development index's impact on high-quality economic development passes the significance test at the 5% level, with a coefficient value of 0.0451. When the economic growth rate is above -0.4425% but below 7.2039%, the estimated coefficient passes the significance test at the 1% level, with a coefficient value of 0.0808. When the economic growth rate is higher than 7.2039%, the estimated coefficient passes the test at the 1% significance level, with a coefficient value of 0.0611. The above results indicate that within the county-level administrative regions of Henan Province, when the economic growth rate is below -0.4425%, the impact of the digital financial development index on high-quality economic development is relatively shallow. However, when the economic growth rate is higher than -0.4425% but lower than 7.2039%, the digital financial development index has a significant impact on high-quality economic development. When the economic growth rate exceeds 7.2039%, this impact decreases but remains greater than during periods of negative economic growth. This result validates the hypothesis H3 proposed in this paper.

V. Conclusion

(1) To measure the level of county-level economic development, this paper establishes a comprehensive evaluation index system for high-quality county-level economic development comprising 10 secondary indicators and 21 tertiary indicators, covering five dimensions: innovative development and transformation of growth drivers, coordinated development and structural optimization, green development and low-carbon actions, open development and efficiency reforms, and shared development and urban-rural coordination. The entropy weight method was used to determine the weights of each indicator, with the top three tertiary indicators being per capita regional GDP (15.2%), tertiary industry added value/GDP (11.19%), and science and technology expenditure/fiscal expenditure (7.77%).

(2) Economic development data from 82 county-level regions in Henan Province over a 10-year period from 2011 to 2020 were selected as the research sample. Based on the proposed evaluation indicator system, the level of economic development was evaluated and analyzed, and the county-level regions were classified into three types—steady development type, development differentiation type, and weak development type—based on the clustering results.

(3) Build an econometric model and set the high-quality development level of county-level economy as the core explanatory variable, and the digital financial development index as the explanatory variable. In the benchmark regression analysis of the three models, namely OLS model, FE model and SYS-GMM model, the regression coefficient of the digital financial development index is always positive and the three estimation results are significant at the level of 1%, indicating that the development of digital finance can directly promote the high-quality development of county-level economy in Henan Province. In the robustness test, the estimation coefficient of the digital financial development index is 0.2301 and shows significance at the statistical level of 1%, which is

consistent with the results of benchmark regression analysis. In the analysis of the intermediary effect, the regression coefficient of the digital finance development index to the upgrading of industrial structure is 19.0612, which is significantly below the significance level of 1%, indicating that county-level digital finance in Henan Province can promote high-quality economic development by promoting the upgrading of industrial structure.

(4) Furthermore, in the threshold effect analysis, the estimated coefficients of the digital finance development index (0.0451, 0.0808, 0.0611) for different levels of industrial structure transformation and upgrading all passed the statistical significance test, indicating that the development of digital finance has a threshold effect on the high-quality development of the county-level economy in Henan Province.

The digital financial development index plays a significant role in promoting high-quality economic development in Henan Province's county-level regions. Therefore, steadily developing and developmentally divergent county-level regions should strengthen innovation-driven development based on their own industrial structure, promote scientific and technological innovation and technological progress, and improve the quality and effectiveness of economic growth. Weakly developing regions should strengthen infrastructure construction, enhance human resource development, and promote the optimization and adjustment of industrial structure and the improvement of urbanization rates to drive high-quality economic development.

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