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Original scientific paper

Research on the Dynamic Evolution Model of the Influence of Foreign Trade on Economic Resilience Level Based on Triangular Fuzzy Entropy

Hui HU*, Gennian TANG

Abstract: As an important indicator of economic development, the degree of opening to the outside world measures the dependence of a country or region on foreign trade and foreign capital, which plays an important role in promoting economic growth and adjusting economic structure. On the contrary, regions with high dependence on foreign capital can show strong economic resilience. In this paper, the optimal weights of indicators are determined by the combination of the entropy value method of objective weighting and the triangular fuzzy method of subjective weighting. A dynamic evolution model of comprehensive economic evaluation based on the combination weighting is established. By evaluating indicators of criterion layers such as sustainable development and economic structure, the principle of the square sum of deviations between one indicator and another indicator is adopted. The multi-attribute comprehensive evaluation value of each evaluation object is dispersed as much as possible, so as to reflect the difference of index comparison more clearly, and change the situation that the index difference is not obvious due to the average weight in the existing portfolio empowerment research. In addition, it also adopts the research methods of literature research, comparative research, normative analysis and empirical analysis, and analyzes the degree of openness to the outside world into the degree of import dependence, export dependence and foreign capital dependence, and empirically explores the influencing factors of economic resilience from the above three perspectives, The results show that the main and objective weights are 0.471 and 0.529. Through empirical analysis, it can be seen that export dependence and import dependence have a significant negative impact on regional economic resilience, while foreign capital dependence has a significant positive impact on regional economic resilience. In the post-financial crisis period, when economic fluctuations are severe, the positive impact of foreign capital dependence on economic resilience is significantly increased.

Keywords: dynamic evolution model; economic resilience; foreign trade; optimal weight; triangular fuzzy entropy

1 INTRODUCTION

The fluctuation of the external environment and malicious competition not only bring more economic risks to enterprises, but also bring more uncertain factors to the national development path. In order to curb the impact of this systemic risk on the market competition of enterprises, prevent people's lives from being subjected to excessive external shocks, utilize the domestic economic cycle as the primary impetus, fostering a bidirectional economic cycle between local and foreign spheres within a novel development framework.

According to the idea that the final weight and the known weight are as close as possible, an optimization model for determining the weight is established [1]. A combinatorial weighting method is proposed to minimize the deviation between the combinatorial evaluation weight vector and the evaluation weight vector of all other methods [2]. These two kinds of evaluation methods either do not rely on actual data, unwarranted average weight allocation, or fail to dynamically reflect the deviation degree of index scores and the difference in index comparison. Second, there is a lack of combinatorial weighting evaluation methods that can reflect the contrast difference of indicators and comprehensively consider subjective and objective information.

Based on the principle of square sum and maximum deviation, this paper establishes an economic evaluation model based on the combination of entropy value method and triangle fuzzy method to solve the problem that the existing urban economic evaluation system does not reflect the principle of scientific development view. It changes the existing research situation that the average weighting results in not obvious difference of indicators and lack of comprehensive consideration of subjective and objective information. Based on the analysis of China's regional economic resilience and the process of promoting the opening to the outside world policy, this paper empirically tests the data of economic resilience, total import, total export and actual utilization of foreign capital of each province and municipality directly under the central government. The objective is to examine the appropriate perspective on the foreign economy during China's economic development as it enters a new phase and establishes a dual circulation system both domestically and internationally. Examining the impact and mechanisms of economic resilience through the lens of external openness provides valuable insights for comprehending the effects of the international economy on China's economic development. The first part is introduction and the second part is related work. The third part is the establishment of economic resilience evaluation model of foreign trade based on triangular fuzzy entropy, the fourth part is study on the influence measurement and factors of foreign trade on the level of economic resilience, the fifth part is simulation verification, and the sixth part is conclusion.

2 RELATED WORK

On the basis of the evolution of the concept of resilience, some progress has been made in establishing corresponding indicators to measure the resilience of urban economy. Due to the different research perspectives of domestic and foreign scholars, the established indicator system and the empirical measurement method adopted have not formed a unified standard. Evaluation indicators [3, 4] were constructed from five aspects: economy, society, infrastructure, institution and environment to assess the level of action-oriented resilience of communities in Chennai, India. Twelve indicators were constructed from three aspects of economy, society and community management capacity to assess the resilience and vulnerability of Slovak urban economy [5]. The geographical distribution of community resilience to disaster was studied based on 27 indicators from five aspects: society, economy, infrastructure, institution and

environment [6]. An urban comprehensive risk assessment and resilient city analysis model [7] is established to investigate urban economic resilience. The analytic hierarchy process (AHP) was used for this purpose. The panel fixed effect model was used to analyze the mechanism of urban economic resilience [8]. Based on "ecological economic and social engineering", an evaluation system was constructed [9]. Examining the spatial-temporal pattern evolution and dynamic modeling of the urban economic resilience of cities at the prefecture level, the BP neural network model, ARCGIS spatial analysis tool, and the entropy power-TOPSIS assessment model were adopted [10]. Researchers also look at the metropolitan economy's resilience level from other angles. For example, from the perspective of sustainable development, grey evaluation method is used to measure the resilience level from five perspectives: economic resilience, infrastructure and social service resilience, ecological resilience, information resilience and disaster prevention resilience [11], and exploratory spatial analysis is used to study its spatial characteristics. In addition, the topic of research on the resilience of urban economies has been expanded. From the study of resilient city, it extends to the study of concepts such as "sponge city" and "park city". Taking the pilot projects of sponge cities and climate-resilient cities in China as an example [12], the urban economic resilience index, which includes urban development capacity, green infrastructure capacity and gray infrastructure capacity, is constructed by taking rainstorm as a disaster risk factor to study the proportion of resilient cities in sponge cities and climate-resilient cities of different degrees. Some other scholars studied the level of urban economic resilience in the context of new urbanization [13, 14], it investigated the agglomerations of the Yangtze River Delta in relation to the coordination and coupling of new urbanization with economic resilience in metropolitan areas.

Multi-attribute decision making refers to the process of making preference decision from a certain number of alternatives after comprehensively weighing each attribute. Deterministic multi-attribute decision making, as a classical multi-attribute decision making theory and method, has been relatively detailed, while non-classical uncertain multi-attribute decision making (random, fuzzy, linguistic, etc.) has also been greatly developed, such as literature [15, 16]. However, most of the current fuzzy multi-attribute decision models are based on Zadeh's fuzzy set or possibility measure and necessity measure. Although possibility measure and necessity measure are a pair of dual measures, they do not have self-duality. However, both in theory and in practice, self-dual measures are necessary [17]. The credibility measure with self-duality is introduced [18], and the credibility theory is established. According to the credibility theory, the weighted arithmetic average operator model of the fuzzy distance between the attribute value and the ideal point is constructed by using the newly defined entropy meaning to obtain the weight and the distance between the fuzzy variables [19]. For instance, we determined the high-quality economic development level of 77 prefecture-level cities in the Yellow River Basin by combining the entropy value method with equal weighting [20]. We discovered that the density function has a skewed distribution, with Matthew effect and spatial dependence. In a study that examined the quality of provincial economic development using the entropy power method, researchers discovered that overall, China's economic development is not very good, but it is getting better. However, there are clear issues with coordination, and the gap between different regions is getting smaller. Results show that high-quality economic development in China is increasing, with diverse causes influencing different regions, according to an entropy value approach study of four regions [22]. Innovation helps promote high-quality economic development, according to the entropy value way of measuring it [23], but its effects on other places are diverse. An evaluation of the Yellow River Basin's urban agglomerations' quality of economic development using the entropy weight technique [24], it is found that the gap between different cities has a widening trend, showing a tiered two-level differentiation pattern. Some scholars combined the entropy value method with other methods to measure the high-quality economic development level, and applied the PCA-EM (Principal Component Analysis Expectation-maximization algorithm) quadratic weighting model to measure the quality level of economic development in eight regions of China, and found that the degree of variation within regions was heterogeneous [25], and the development of different dimensions showed significant imbalance.

The effect of openness degree on economic resilience has been the subject of much research since it is a key metric for gauging regional economies. In his view, international trade has a dual impact on the growth of regional economic systems, acting as both an engine and a brake [26]. He draws the conclusion that regions with greater economic openness are less resilient economically because they are more susceptible to the effects of the external economy, which he sees as a regional pressure on trade demand. According to research on the Yangtze River Delta region's economic resilience, the degree to which the region's economy is dependent on outside forces has a favorable effect on the agglomeration's ability to weather economic storms [27], which is contrary to the traditional view that the high degree of economic openness is vulnerable to external shocks that will weaken the economic resilience. By analyzing the sustainability and recovery of various provinces and municipalities, it is concluded that the foreign trade dependence has a stronger explanatory power for regional economic sustainability in the Asian financial crisis [28], while the total utilization of foreign capital, the proportion of state-owned enterprises, per capita fiscal expenditure and other factors have a stronger explanatory power in the global financial crisis. On the whole, the main factors affecting the second economic cycle are different, such as location factors, per capita fixed investment and per capita GDP have completely different effects in the second economic cycle.

3 ESTABLISHMENT OF ECONOMIC RESILIENCE EVALUATION MODEL OF FOREIGN TRADE BASED ON TRIANGULAR FUZZY ENTROPY

3.1 Idea of Establishing the Evaluation Model of Economic Resilience of Foreign Trade

The ideal indicator weights are determined in this work using the entropy approach and the triangular fuzzy method, and an economic evaluation model based on the principle of the sum of squares of deviation is established. The characteristics of the model are as follows :(1) Using the principle of square sum of deviation between one index and another index, the multi-attribute comprehensive evaluation value of each evaluation object is dispersed as much as possible, so as to reflect the difference of index comparison more clearly. It changes the situation that the index difference is not obvious due to the average weighting in the existing portfolio weighting research. (2) Through the combination of weights, it not only retains the true reflection of the actual situation and the speculation of future factors of objective weights such as entropy value method, but also reflects the importance of index attributes reflected in the evaluation of subjective weights such as triangle ambiguity and the knowledge and experience of experts. The specific schematic diagram is shown in Fig. 1.

In order to score the positive signs, this study uses the normalization method. When the index value is positive, it indicates that the economy is doing well. Assume that, following standardization, the value of the *i*-index in the *J* th assessment city is d_{ij}; *N* is the total number of cities that were examined, and *i* is the value of the *i*-index for the *J* th city. The variables in this paper are shown in Tab. 1.

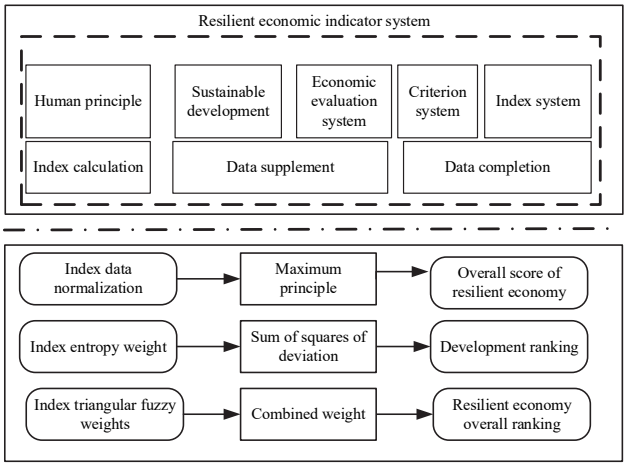

Figure 1 Schematic diagram of comprehensive evaluation of resilient economy

Table 1 Variables

Variables	Meaning
d_{ij}	the i-index in the Jth assessment city
N	the total number of cities
e_j	Jth evaluation index
f_{ij}	the characteristic proportion of the i system in the j index
x_{ij}	the observed data of the j index in the i system
w_{ij}	stands for weighted combinations
J (W)	disperse the multi-attribute comprehensive evaluation values
Di	evaluation object

Tab. 2 is added to explain the meaning of the abbreviations.

Table 2 Meaning of the abbreviations

Abbreviations	Meaning
PCA-EM	Principal Component Analysis Expectation-maximization algorithm
GDP	Gross Domestic Product
FDI	Foreign Direct Investment

According to the scoring formula of positive indicators, d_{ij} is:

$$d_{ij} = \frac{V_{ij} - \min\limits_{1\le j\le n} V_{ij}}{\max\limits_{1\le j\le n} V_{ij} - \min\limits_{1\le j\le n} V_{ij}} \tag{1}$$

According to the scoring formula of negative indicators, d_{ij} is:

$$d_{ij} = \frac{\max\limits_{1\le j\le n} V_{ij} - V_{ij}}{\max\limits_{1\le j\le n} V_{ij} - \min\limits_{1\le j\le n} V_{ij}} \tag{2}$$

Moderate index refers to the indicator that the closer to a specified value, the better. For example, GDP growth rate, too large means that the economy is overheating, too small is not conducive to economic development, so the closer this indicator is to the value stipulated by the national macro-control, the better. According to the scoring formula of moderate indicators, d_{ij} is:

$$d_{ij} = 1 - \frac{V_{i0} - V_{ij}}{\max[V_{i0} - \min\limits_{\substack{1\le j\le n \\ 1\le j\le n}} V_{ij}, \max\limits_{1\le j\le n} V_{i0} - V_{i0}} \tag{3}$$

Let x_{ij}(i = 1, 2, n; j = 1, 2, …, m) be the observed data of the JTH index in the i th system. According to the entropy value calculation formula, the entropy value of the JTH evaluation index is e_j.

$$e_j = \frac{1}{\ln n} \sum_{i=1}^{n} f_{ij} \ln(f_{ij}) \tag{4}$$

where e_j and f_{ij} are the characteristic proportion of the i system in the j index, x_{ij} is the observed data of the j index in the i system, and $\sum x_{ij}$ is the sum of the observed data of all systems in the J index. The entropy weight of the J th evaluation index:

$$w_j^{'} = \frac{1 - e_j}{m - \sum\limits_{j=1..m} e_j} \tag{5}$$

Put the J th index weight, which follows the combination of two weighing procedures, into the set W, the index combination weight. The variable w_{ij} stands for weighted combinations.

$$w_j = \lambda w_j^{'} + (1 - \lambda) w_j^{''} \tag{6}$$

where r is the weight of the combination divided by the weight of the objective preference coefficient.

With the aim of maximizing the sum of the square deviations of the comprehensive evaluation values of the i evaluation object and other evaluation objects, an objective function J(W) is defined to disperse the multi-attribute comprehensive evaluation values of each evaluation object as much as possible:

$$J(W) = \sum_{i,j=1}^{n} (b_{ij} - b_{i_1 j}) w_j \tag{7}$$

The existing research is either based on the principle of minimum deviation of subjective and objective weights or the principle of minimum difference of subjective and objective evaluation results. These two types of research methods either do not rely on actual data, unwarranted average weight allocation, or fail to dynamically reflect the deviation degree of index scores and the difference in index comparison. In this paper, by using the principle of square sum of deviation between one index and another index, the multi-attribute comprehensive evaluation value of each evaluation object is dispersed as much as possible, so as to reflect the difference of index comparison more clearly. It changes the situation that the index difference is not obvious due to the average weight in the existing research of combination weighting method.

3.2 Economic Resilience Evaluation Model Based on Triangular Fuzzy Entropy Combination Weighting

So, let's pretend that: the linear weighted comprehensive evaluation formula yields the following score for the D_i evaluation object:

$$D_i = \sum_{j=1}^{m} d_{ij} w_j \tag{8}$$

d_{ij} is the evaluation index score; w_j is the combined weight of the J th evaluation index.

First of all, net export as one of the important factors to promote China's economic growth, maintaining a trade surplus can directly promote the improvement of economic level. At the same time, according to the theory of comparative advantage, the international division of labor is carried out according to the level of comparative cost. A country exports products with lower production cost compared with other countries, and imports products with higher production cost compared with other countries, which enables it to obtain the products it needs more cheaply while exporting its surplus products to other countries. Therefore, through the participation in international trade, the production factors of each country will flow to the sectors with comparative advantages, thus saving social labor, improving the level of national income, thereby stimulating domestic demand, and then promoting economic growth. In China's international trade practice, the eastern region has a comparative advantage in international trade due to its geographical location, which attracts a large number of labor forces and production factors from other regions, resulting in a higher income level in the eastern region compared with other regions, and thus a faster improvement in the economic level of the eastern region. With the continuous promotion of the construction of an all-round open system in China in recent years, inland regions can directly export their products with comparative advantages to the international market, which has brought an increase in the income of inland regions to a certain extent, and improved the level of economic resilience of these regions. As shown in Fig. 2.

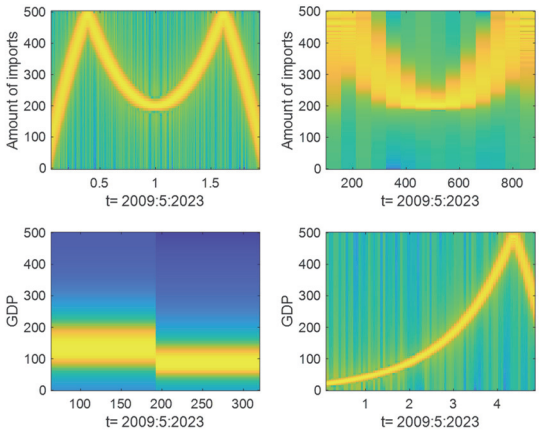

Figure 2 Import and export value and national GDP output value

By observing Fig. 2, we can know that the overall trend of China's foreign trade and economic development is consistent, and we can even find that the impact on foreign trade industry is directly reflected in the gross national product. This also shows that foreign trade is an important part of China's GDP and has a key impact on economic resilience.

Combined with the actual situation of China, China's early opening to the outside world is to attract foreign investment through cheap means of production and labor. Even in the relatively developed eastern region, the price of factors is still at a low level in the world, so it can attract many large multinational companies to establish factories in the eastern region, and thus absorb the influx of labor from other regions. It has improved the overall employment level in China, in order to promote the improvement of regional and even the overall economic level and economic resilience, as shown in Tab. 3.

Table 3 Foreign direct investment and employment data 2005-2023

Year	Number of employed people (10000)	Foreign investment (US $100 million)
2005	72085	4072000
2006	72797	4687800
2007	73280	5274300
2008	73736	5350500
2009	74264	6063000
2010	74647	6032500
2011	74978	6302100
2012	75321	7476800
2013	75564	9240000
2014	75828	9000000
2015	76105	10573500
2016	76420	11601100
2017	76704	11171600
2018	76977	11758600
2019	77253	11956200
2020	77451	12626700
2021	77603	12600100
2022	77640	13103513
2023	77586	13497000

Fig. 3 is a scatter plot of the correlation between employment and total FDI depicted in Tab. 1, where the dotted line is a trend line drawn on a polynomial basis. According to Fig. 3, it can be seen that from 2005 to 2023, the total amount of imports and exports is positively correlated with the number of national employment. Research into Keynesian theory leads us to believe that FDI affects economic resilience through changing the employment rate.

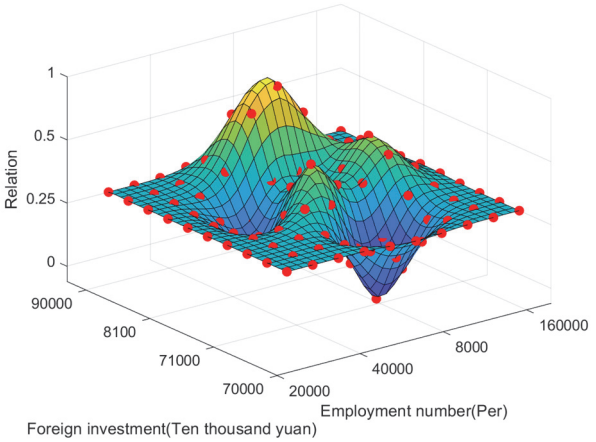

Figure 3 Scatter chart of correlation between employment and total FDI

The five indicators that make up urban economic resilience are as follows: income within the general budget of local finance, per capita disposable income of urban people, total assets of industrial firms above designated size, and actual utilized foreign capital. Each of these contributes to the overall picture. One more unbiased indicator of economic health is GDP, or gross regional product. To get the per capita GDP, which is an indication of urban economic resilience, this article divides the yearly GDP of the six provinces in the central region by the total population of the provinces. Funds received by the state and allocated to the state budget are known as "revenue within the general budget of local finance." This is in accordance with the rules and regulations of the state's financial system. One measure of the urbanites' quality of life is their per capita disposable income, which is the sum of all household incomes used to pay for necessities and plan for everyday activities. The real sum of foreign capital utilized is the sum of money that is actually available once a contract is signed between China and foreign investors. This sum may represent China's commerce with other countries.

Table 4 Evaluation index system of urban economic resilience

System layer	Index level	Unit	Attribute
Economic resilience	Gross regional product per capita	Yuan	+
	Revenue within the general budget of local finance	Hundred million yuan	+
	Per capita disposable income of urban residents	Hundred million	+
	Total assets of industrial enterprises above designated size	Yuan	+
	Actual amount of foreign capital used	Ten thousand dollars	+

The regional GDP per capita, local finance general budget revenue, urban residents' disposable income per capita, total assets of industrial enterprises above designated size, and the amount of actually used foreign capital are all positive indicators that show how resilient the urban economy is. See Tab. 4 for details.

4 STUDY ON THE INFLUENCE MEASUREMENT AND FACTORS OF FOREIGN TRADE ON THE LEVEL OF ECONOMIC RESILIENCE

4.1 Study on Evaluation Model of Economic Resilience of Foreign Trade

Using the entropy weight method to calculate the data can ensure the credibility of each weight of the original index data. First, this paper selects m (m = 1, 2, ..., 31) provinces, n (n = 1, 2, ..., 13) indicators; Secondly, let x_{ij}(i = 1, 2, ..., m; j = 1, 2, …, n) be the value of the J th indicator of the I th provinc. Finally, the specific value is standardized and the information entropy is calculated. The specific steps are as follows:

(1) Standardized processing: Due to the different units and measurement standards of the results, the dimensions and positive and negative directions of the indicators will be inconsistent and other problems, so it will have an irreversible impact on the evaluation results, so the first step of the research is the standardization of the data (also known as quantization) processing. The handling method of indicator direction difference is as follows:

$$h_{ij} = \frac{x_{ij} - \min(x_{1j} \ldots . x_{mj})}{\max(x_{1j} \ldots . x_{mj}) - \min(x_{1j} \ldots . x_{mj})} \tag{9}$$

(2) The information entropy of the J th indicator is computed by first determining its fraction in the i province. Here is the exact formula:

$$e_j = -\ln\frac{1}{m} * \sum_{i=1}^{m} \frac{p_{ij}}{\sum p_{ij}} \tag{10}$$

(3) Comprehensive score determination: index weight determination, comprehensive score calculation:

$$w_{ij} = \frac{e_j}{\sum_{j=1}^{n} e_j}$$
$$y_j = \sum_{j=1}^{n} w_j * p_{ij} \tag{11}$$

As the number of regions at the city and county level in China is much larger than that at the provincial level, the economic differences between regions are relatively more complex, Fig. 4 demonstrates that there are also significant changes in the distribution pattern of the nuclear density distribution map.

Considering the data at the provincial level in particular, it is clear that China's regional economic resilience level has been steadily rising over the past few years, as evidenced by a small rightward shift in the center of the horizontal core density distribution curve for

regional economic resilience at all three levels in 2008, 2010 and 2015.

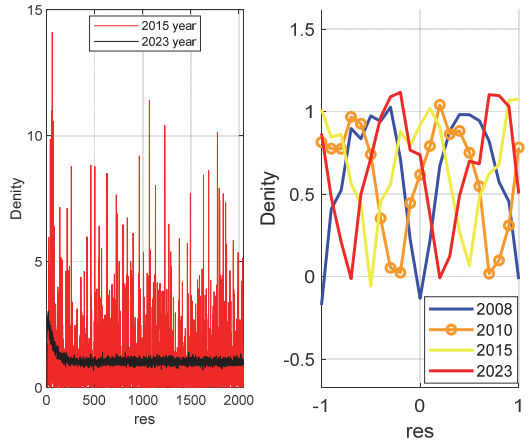

Figure 4 Distribution of regional economic resilience core density

At all three tiers of core density for regional economic resilience, the curve's center moved slightly to the left in 2020. During this period, China's regional economy has become less resilient. This could be because the country has shifted its focus from a development mode that prioritizes speed above quality to one that seeks economic innovation, coordination, and high-quality development. As a result of these changes, the evaluation criteria for regional economic resilience have also evolved.

From the perspective of kurtosis, the main peak of the distribution curve of regional economic toughness core density at the provincial level decreased significantly during the study period, and both 2008 and 2015 were "double peaks". In 2008, there was a sharp peak on the right side of the main peak, and in 2015, there was a sharp side peak on the left side of the main peak, which was mainly due to the increase of areas with high toughness level in 2015. It is caused by the decrease of regions with low resilience level, indicating that the level of regional economic resilience in 2008 and 2015 presents a significant "polarization". The main peak of the regional economic resilience kernel density distribution curve of city and county showed a decreasing state year by year.

Moreover, it shows a convergence trend on the left side year by year, indicating that the proportion of regions with low toughness level continues to decline, and the right trailing distance of the regional economic toughness core density curve of cities and counties is reduced year by year, but it still exists, indicating that the number of regions with low level of regional economic resilience is higher than that of regions with high level.

Morphologically speaking, there was an upward trend in the width of the three levels' curves, which pointed to a more discrete horizontal distribution of regional economic resilience, particularly at the provincial level, and a shift from a "high" to a "smooth curve" distribution of core density scores for these regions. The distribution of city and county curves did not change significantly in 2008, 2010 and 2015, but the width of the curve increased in 2020, indicating a slight increase in the degree of dispersion between regions.

4.2 Evaluation of Economic Resilience of Foreign Trade and Impact Analysis of Spatial Differences

The comprehensive index evaluation system of specific foreign trade resilience is shown in Tab. 5.

Table 5 Foreign trade resilience evaluation index system and weight distribution

Primary index	Secondary index	Three-level index	Index property	weight
Resistance and resilience	Regional economic base	Gross regional product	+	0.036
		Urbanization rate	+	0.020
	Location and transportation infrastructure	The distance between the provincial capital and its largest trading country	+	0.060
		Number of first-class ports	+	0.132
	Foreign trade development status	Total import and export trade	+	0.165
		Proportion of exports to total imports and exports	+	0.016
		The top three trading partners accounted for the total trade volume	-	0.008
Reconfiguration capability	Economic support	Total foreign investment	-	0.005
		Year-end loan balance of financial institutions	+	0.036
		Per capita disposable income	+	0.059
	E-commerce support	Number of comprehensive experimental zones for cross-border e-commerce	+	0.278
	Government support	Number of comprehensive bonded zones	+	0.074
		Government expenditure on science and technology	+	0.111

In order to break down the impact of openness on economic resilience from three perspectives and avoid endogenous problems caused by substitution and complementarity between trade and investment, $N > t$ panel data is used. The influence of time trend on the regression results is limited, the unit root test has been carried out to determine the stability of the data, and since external shocks with time have important implications for economic resilience, this data feature may be eliminated if the traditional two-way fixed effect model is adopted. Therefore, this paper decides to adopt the fixed effect model:

$$RES_{ix} = \lambda_0 + \lambda_1 e^{ix} + ...\lambda_n fit_{ix} \quad (12)$$

where i and t represent provinces (or municipalities directly under the central government) and years respectively. Since the influence of investment dependence and fixed investment growth rate on the economy has a significant lag, the two variables lag one stage for regression analysis. The meanings of the main variables are shown in Tab. 6.

Two systems' relationships in terms of coordination development can be examined using the coupling coordination degree model. Among these, the coupling degree is a measure of how much two systems affect one another. Coordinative quality can be expressed as the level of harmless coupling in the coupling interaction connection. The three index values that make up the coupling coordination degree model are the coupling degree D value,

the coordination index C value, and the coupling coordination degree D value. Our final tally for each item's coupling coordination degree includes the classification standard of D value of coupling coordination degree.

Table 6 Main variables and calculation methods

Type	Variable	Variable name	Measure mode
Dependent variable	RES	Economic resilience	Elias formula
Independent variable	exp	Degree of dependence on exports	Total exports /GDP
	imp	Import dependence	Total imports /GDP
	inv	Foreign capital dependence	Total utilized foreign capital /GDP
Control variable	agdpv	Economic development trend	g coffee per capita growth rate
	fixv	Investment attractiveness	Growth rate of fixed investment
	fin	Financial position	Fiscal revenue/fiscal expenditure
	In-peo	Population number	Logarithm of the number of people

In order to gauge the degree of economic development and coupling coordination in the center region, we employ the coupling coordination degree model. That model in particular looks like this:

$$C = \frac{2\sqrt{U_1 \times U_2}}{U_1 + U_2} \tag{13}$$

C, which can take on values between zero and one, stands for the degree of coupling between the level of economic development and the resilience of metropolitan areas. The degree of linkage between urban economic resilience and economic development level is inversely proportional to its distance from zero and positively proportional to its distance from one. The index values of $U1$ and U: range from 0 to 1, which represent the degree of economic development in the central region and the resilience of the urban economy in the region, respectively.

There may be inconsistencies between the levels of economic development and the degree to which urban areas are resilient to economic downturns. For instance, there may be a high coupling degree between urban economic resilience and economic development level, even though both may have a low development degree simultaneously. So, the coupling degree model is also introduced because the coupling degree alone is insufficient to support the overall effect and synergy effect of the two systems' development C, T. Here is the exact model:

$$D = \sqrt{C \times T}, T = \alpha U_1 + \beta U_2 \tag{14}$$

D is the coupling coordination degree in the given formula; a bigger value for D indicates a stronger degree of coupling between the central region's economic development level and urban economic resilience, while a smaller value indicates the opposite. T is the economic development level and comprehensive coordination indicator for urban areas. Given the equal importance of economic development level and urban economic resilience, both a and b are set to 0.5.

Tab. 7 shows the grades for the coupling degree and Tab. 8 shows the grades for the coupling coordination degree. These grades are used to categorize the empirical analysis coupling degree index.

Table 7 Coupling degree grade evaluation criteria

Coupling degree C	System phase
$0 <= C <= 0.3$	Separation stage
$0.3 <= C <= 0.6$	Antagonistic stage
$0.6 < C <= 0.8$	Run-in stage
$0.8 < C <= 1$	Coupling phase

Table 8 Evaluation criteria of coordination degree

Coordination degree D	Coordination level	Coordination degree D	Coordination level
$0 < D < 0.1$	hyperdysregulation	$0.5 <= D < 0.6$	Forced coordination
$0.1 <= D < 0.2$	Severe disorder	$0.6 <= D < 0.7$	Primary coordination
$0.2 <= D < 0.3$	Moderate coordination	$0.7 <= D < 0.8$	Intermediate coordination
$0.3 <= D < 0.4$	Mild disorder	$0.8 <= D < 0.9$	Good coordination
$0.4 <= D < 0.5$	Borderline disorder	$0.9 <= D < 1$	Quality coordination

5 SIMULATION VERIFICATION

The research determines each province's level of urban economic resilience using data from six central provinces from 2007 to 2023. Fig. 5 shows the results.

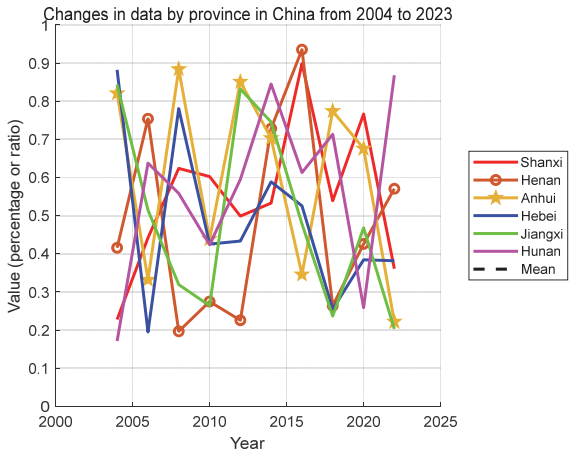

Figure 5 Development trend of urban economic resilience of each province in central China based on triangular fuzzy entropy

From the perspective of time, the evaluation value of urban economic resilience of the six provinces in the central region all showed a trend of steady growth, and the growth of urban economic resilience of each province was different. Among them, Henan province had the largest growth value, which increased from 0.1998 in 2007 to 0.9038 in 2023, with an increase of 0.704. It was followed by Anhui Province, Hunan Province, Hubei Province, Jiangxi Province and Shanxi Province, which increased by 0.6358, 0.5734, 0.5422, 0.4434 and 0.3791 respectively. It is worth noting that from 2004 to 2019, the resilience of urban economy in Hubei Province has maintained a steady growth trend, but there is a sudden decline in 2020, which is related to the major impact of the novel coronavirus epidemic on Hubei Province in 2020. On average, from 2004 to 2023, the urban economic resilience rating of the central region increased from 0.1313 to 0.6778 in 2020, an

increase of more than four times. In addition, from 2005 to 2023, the range of urban economic resilience of the six provinces in the central region gradually widened. Although the growth of Shanxi Province was 0.4396, it was much worse than that of Henan Province (0.9048), and the development of urban economic resilience of various provinces was uneven.

It can be seen from Fig. 6 that the coupling coordination degree increases year by year, but the growth pace is inconsistent.

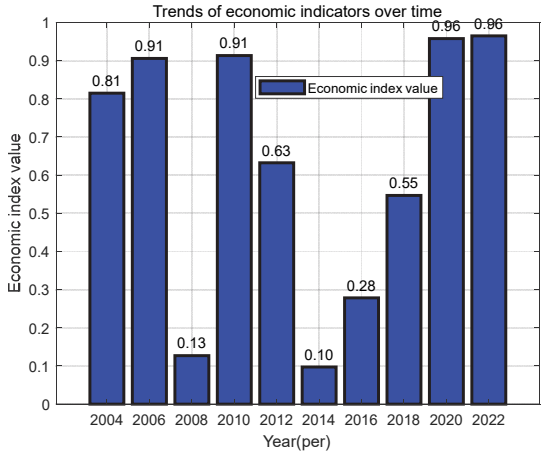

Figure 6 Coupling coordination degree between urban resilience and economic development level of provinces in central China

From the perspective of annual coupling coordination degree, the coupling coordination degree of Henan Province always ranks first, because its urban resilience and economic development level maintain a growing trend and the development gap is getting smaller and smaller, thus promoting the steady improvement of coupling coordination degree. Apart from Henan Province, Hubei Province ranked second in the central region in terms of coupling coordination degree from 2004 to 2019, but was overtaken by Anhui Province and Hunan Province in 2020, and its economic development level declined due to the major impact of the novel coronavirus epidemic on Hubei Province. In addition, in order to minimize the risk caused by the impact of the novel coronavirus epidemic and ensure the adequate supply of medical and health service facilities, the establishment of shelters and other medical facilities has also consumed huge financial expenditure, and people's living standards have been greatly affected.

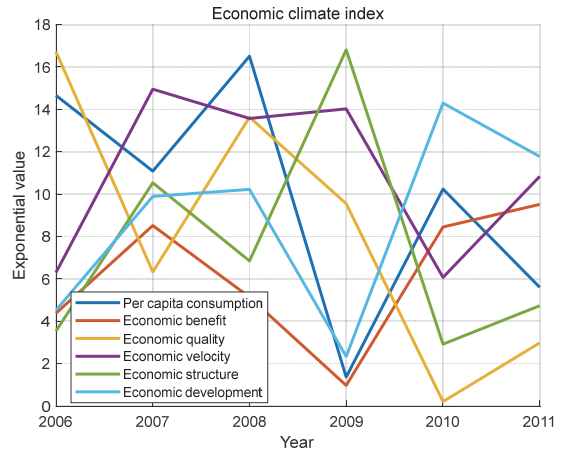

Figure 7 Comparison of scores of each criterion layer

Therefore, the coupling coordination degree of Hubei Province showed a downward trend in 2020.

The development analysis of the influence of foreign trade on the level of economic resilience through triangular fuzzy entropy is shown in Fig. 7.

As can be seen from Fig. 7, 10 typical sub-provincial cities have balanced development in terms of economic structure and economic development speed, and are in a good trend. However, there is a large gap between cities in terms of per capita economic achievements, and there is an obvious imbalance. In terms of economic benefit, quality of economic operation and sustainable development, all cities are at a low level.

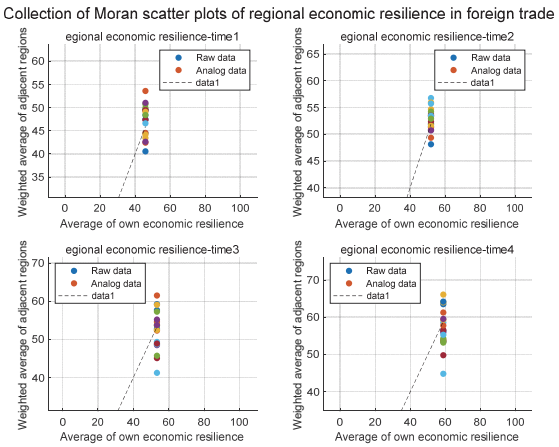

Figure 8 Moran scatter plot of economic resilience of foreign trade region

Cities with a high concentration tend to be located in more developed regions, as illustrated in Fig. 8 of the distribution map of economic resilience throughout four time sections. These cities are highly interconnected, have a strong diffusion effect of core cities, work together to develop, have a relatively advanced level of economic development over the long term, innovate at a high level in science and technology, and are economically resilient as a region. Low- and medium-sized cities, mostly located in the northeast and central regions, tend to have low economic resilience due to issues like factor sharing, limited resources and environment, and a lack of economic development. Nevertheless, the regional economies of the central and western regions have become more resilient, development speeds have been steadily increasing, and investments in infrastructure and other areas have been boosted thanks to the national strategy that aims to promote the development of these cities. There is a city siphon effect, which has a poor radiation driving effect on surrounding cities, and the center and western cities are still in the stage of cultivation and development, so there is a concentration of high-low agglomeration cities in province capitals and core cities.

During the resistance and recovery periods, Fig. 9 shows the distribution of resilience and resistance in 284 Chinese cities. Strong resistance and resilience were demonstrated by 46 out of 284 cities. Fig. 9 shows that 59 cities are in spots with low resistance and high resilience, 77 cities are in spots with high resistance and low resilience, and 102 cities are in category 4 (low resistance and low resilience), which means they are both less resilient and less resistant than the average American city.

The scores of each index in Harbin and the data of the combined weights of indicators were substituted to obtain the scores of each criterion layer and the comprehensive economic evaluation scores of Harbin, as shown in Tab. 9. Similarly, the scores of criterion layer and comprehensive economic evaluation of other 9 cities can be obtained, as shown in Tab. 9. From the data in Tab. 9, it can be seen that Nanjing has the highest score in economic evaluation, while Harbin has the lowest score. This shows that Nanjing's economic development is the best, Harbin's economic development is the worst, Dalian, Jinan and other cities are in the middle.

Index level summary.

(1)Per capita green GDP restricts urban economic development

As can be seen from the results, per capita green GDP of Shenzhen, which ranks first in comprehensive ranking, is the highest, and per capita green GDP of Harbin, which ranks last in comprehensive ranking, ranks the second from the bottom, indicating that per capita green GDP is an important factor restricting urban economic development.

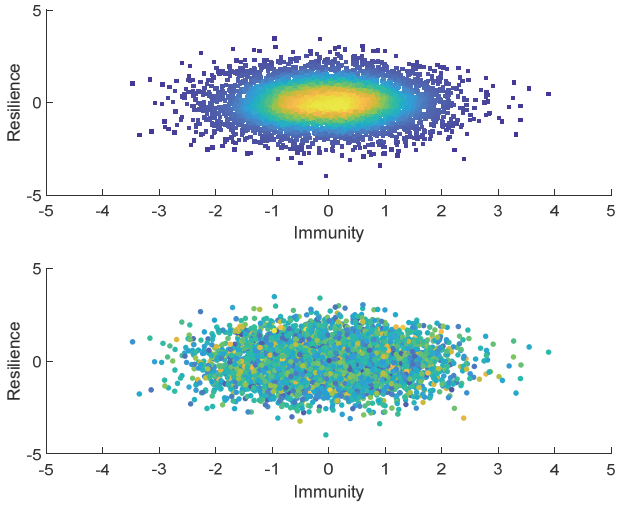

Figure 9 Scatter plot of resistance and resilience distribution

Table 9 Economic development status and ranking of 10 sub-provincial cities in China

No.	index	Haerbin	Shenyang	Xian	Nanjing	Jinan	Chengdu	Shenzhen	Qingdao	Guangzhou	Dalian
1	Per capita economic output	0.009	0.034	0.015	0.168	0.035	0.018	0.127	0.048	0.168	0.054
2	Economic benefit	0.032	0.048	0.038	0.035	0.036	0.072	0.095	0.032	0.055	0.045
3	Quality of economic operation	0.059	0.056	0.082	0.074	0.071	0.036	0.046	0.046	0.053	0.046
4	Speed of economic development	0.010	0.039	0.093	0.051	0.104	0.069	0.072	0.063	0.105	0.105
5	Economic structure	0.034	0.115	0.061	0.108	0.049	0.052	0.108	0.092	0.093	0.012
6	Sustainable development	0.038	0.028	0.041	0.115	0.068	0.034	0.012	0.064	0.027	0.032
7	Economic evaluation score	0.272	0.317	0.334	0.542	0.363	0.278	0.465	0.345	0.513	0.378
8	Comprehensive ranking	10	8	7	1	5	9	3	6	2	4

(2) The life satisfaction of urban residents is better.

According to the criteria proposed by the Food and Agriculture Organization of the United Nations, the Engel coefficient is 30 to 40% rich. It can be seen from the results that except Dalian, the rest of the cities are between 30 and 40%, indicating that with the rapid economic development, the residents of 10 sub-provincial cities are well-off.

(3) The problem of inflation is serious in developed cities.

It can be seen from the results that the inflation rate of Shenzhen, Guangzhou and other cities is too high, far from the reasonable range (l%, 3%), which seriously affects the quality of their economic operation.

(4) Urban economic growth is overheating, and the cost of resources is too high.

The ideal GDP growth rate of our country is 7%. According to the results, all the 10 cities far exceed 7%, indicating that each city has the problem of overheated economic growth and excessive resource cost while obtaining economic benefits.

(5) Investment in fixed assets has not been effectively controlled.

It can be seen from the results that except for Nanjing, the average annual growth rate of fixed asset investment is 15%, which is about 18% of the ideal value, the other cities are far from the ideal value, and the phenomenon of investment overheating or undercooling is obvious.

(6) The low proportion of investment in environmental governance restricts the sustainable development of the economy.

It can be seen from the results that compared with developed countries, the proportion of environmental protection investment in GDP is higher than 2%, except Nanjing 3.06%, the other 9 cities are significantly lower than 2%, and the lowest is Shenzhen 0.02%. It shows that the environmental protection investment of Chinese cities is less, far lower than that of developed countries.

6 CONCLUSION

Through the evaluation of sustainable development and economic structure, it reflects the basic requirements of the scientific concept of development. By using the principle of square sum of deviation between one index and another index, the multi-attribute comprehensive evaluation value of each evaluation object is dispersed as much as possible, so as to reflect the difference of index comparison more clearly. It changes the situation that the index difference is not obvious due to the average weighting in the existing portfolio weighting research. The results show that the main and objective weights are 0.471 and 0.529, respectively, based on the cross section data of sub-provincial cities in China and the principle of the square sum maximum deviation of index scores. By combining the objective weighted entropy method with the subjective weighted triangle fuzzy method, the problem that the larger the index, the better or the smaller the unreasonable in the existing economic evaluation is solved by setting the appropriate optimal interval indicators such as GDP growth rate and inflation rate. The degree of foreign capital dependence has a significant impact on economic resilience, and the higher the degree of foreign capital dependence, the stronger the economic resilience. The foreign capital in this paper has a huge sunk capital effect, if the foreign investor enters the investment market after hasty withdrawal, it is easy to cause losses. In addition,

the pooling effect of investment will also promote the continuous accumulation of foreign capital, while investment is often accompanied by technology spillover effect. The technology brought by foreign investors can greatly improve the productivity and competition intensity of local enterprises. Even if foreign investors stop investing in technology, the spillover effect can effectively improve the production level of local enterprises. Therefore, foreign capital dependence has a significant positive impact on economic resilience.

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Contact information:

Hui HU
(Corresponding author)
School of Management, Zhejiang University of Technology,
Hangzhou City, Zhejiang Province, 310023, China
E-mail: hhui_smzjut@163.com

Gennian TANG
School of Management, Zhejiang University of Technology,
Hangzhou City, Zhejiang Province, 310023, China
Zhijiang College, Zhejiang University of Technology,
Shaoxing City, Zhejiang Province, 312030, China