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Model Study on the Impact of Foreign Trade on Economic Resilience Based on Improved Self-Regulating Annealing Particle Swarm Optimization (China Yangtze River Delta as an Example)

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Abstract: In order to improve the global search ability of PSO and avoid falling into local extreme value, an improved self-regulating tabu annealing PSO was proposed to study the impact of foreign trade on economic resilience model (China Yangtze River Delta as an example). Firstly, improving the inertial adaptive weights and introducing adjustment factors to constrain the learning particles can make the algorithm have stronger searching ability. The improved algorithm can realize the self-adjustment of inertia weights. Secondly, the improved simulated annealing particle swarm optimization algorithm is verified and compared with the former algorithm through two different functions, and the results show that the convergence speed and accuracy are improved. According to the sensitivity calculation, the compensation node is determined for reactive power compensation. The final results show that the resilience of tourism economy in the Yangtze River Delta urban agglomerations presents a changing trend of "rising first and then decreasing", and the resilience level of all cities is on the rise. The cities with high resilience are mainly distributed in the central and eastern regions, and the resilience level of tourism economy in each city has a certain spatial agglomeration characteristic. The resilience of tourism economy is comprehensively affected by economic development level, economic development structure, infrastructure and government intervention, among which the speed of tourism development has a significant negative impact on the resilience of tourism economy, and other factors have a significant promoting effect.

Keywords: adaptive parameter; economic resilience; foreign trade; self-regulating annealing particle swarm; Yangtze river delta urban agglomeration

1 INTRODUCTION

Research on resilience has been growing in recent years, analyzing how cities or regions recover after shocks or build resilience to future shocks. Based on the "ecological resilience" proposed by engineering resilience, evolutionary resilience was gradually deduced and concepts such as urban resilience and social resilience were proposed to focus on the impact of the Great Economic Depression [1]. Some scholars engaged in disaster-related research have cited the regional resilience mentioned in the topic "Creating Resilient Regions" and combined with the proposed theories and methods related to resilience, put forward the regional economic resilience theory to analyze how to solve the problems of regional economic recovery and sustainable development in the post-crisis era [2, 3]. Subsequently, some scholars tried to apply the resilience theory to relevant studies on urban agglomerations, replacing employment scale with per capita GDP or GDP to describe economic output and measure regional economic resilience [4]. Some scholars use the entropy weight method to measure regional economic resilience or ecological resilience, combined with social network analysis methods, spatial Durbin fixed effect model, gravity model, etc., and take some domestic urban agglomerations as research objects to analyze the correlation network and influencing factors of the economic resilience of urban agglomerations [5].

Among these relevant studies, the research on the Yangtze River Delta urban agglomeration is more oriented to the original 26 cities, and whether the relevant conclusions are applicable to the expanded scope needs further analysis. The planning scope of the Yangtze River Delta city cluster has been continuously adjusted to cover all regions of the four provinces and cities. At the same time, the period of closest data involved in existing studies failed to reflect whether COVID-19 had a significant impact on the original economic resilience pattern, and these studies did not include the impact of zoning adjustment in the research system. Therefore, this paper describes and calculates the economic resilience of the Yangtze River Delta urban agglomeration, analyzes the spatial evolution and influencing factors of the economic resilience of the urban agglomeration by combining the gravity model and the spatial Dubin model, and analyzes whether the zoning adjustment in 2011 has reached the expected goal of adjustment. We will explore ways to enhance the economic resilience of urban agglomerations, promote integrated urban and regional development, and strengthen the effect of growth poles. The development of the concept of "resilience" has roughly experienced three stages: engineering resilience, ecological resilience and evolutionary resilience [6]. At present, the academic community's understanding of resilience is changing from engineering resilience and ecological resilience in equilibrium theory to evolutionary resilience in evolution theory, and the focus is shifting from improving the ability to cope with crises to achieving sustainable development goals [7]. In the early stage, some foreign scholars explored the application of resilience theory in the field of tourism. For example, with the help of resilience, they explained how the Italian tourism industry could resist the pressure brought by national economic recession through self-mitigation and adjustment [8]. This paper studies the vulnerability and resilience of tourist destinations. The outbreak of COVID-19 (Corona Virus Disease) is one of the most influential events in the 21st century [9]. Under the epidemic, the flow of population between regions has been curbed, the flow of tourists in scenic spots, restaurants, accommodation, entertainment and other places has decreased, and tourism enterprises are facing a major survival crisis. Therefore, the academic community has paid extensive attention to the resilience of tourism economy [10]. The reality of current tourism development shows that although the tourism industry always faces the impact of various risks, it can recover from the crisis and produce certain adaptability [11].

When describing the economic resilience of urban agglomerations, the scale of employment is the most intuitive manifestation of resilience. The diversification of industrial structure can reduce the destructive power of external shocks on regional economy, and is conducive to the rapid recovery of regional economy, and its impact on the economic resilience of urban agglomerations cannot be ignored. The conclusion that innovation ability has a positive impact on the sustainable self-repair ability of regional economy has also been verified by some literatures at home and abroad, and ecological resilience has been included in the regional economic resilience system for many times to better support the sustainable development needs of regional economy. Based on this, from the perspective of toughness, this paper constructs the tourism economy toughness index evaluation system according to the simulated annealing particle swarm optimization algorithm model, introduces the basic process of simulated annealing particle swarm optimization algorithm, and puts forward an improved scheme of simulated annealing particle swarm optimization algorithm. The two parameters of inertia weight and adjustment factor are modified and the optimized process of simulated annealing particle swarm optimization algorithm is refined. Four different functions are used to verify the feasibility and advantages of the improved simulated annealing particle swarm optimization algorithm compared with the previous algorithm for one or more approximate optimal solutions. This paper measures the resilience of the tourism economy in the Yangtze River Delta city cluster and analyzes its influencing factors to provide a certain basis for further improving the resilience of the urban tourism economy.

2 RELATED WORK

The economic system is based on the comprehensive development and utilization of tourism resources and the tourism public service, social and economic support system and tourism ecosystem of tourist destinations. It develops under the coordinated operation of tourism related industries and is highly comprehensive and complex [12]. Based on the perspective of evolutionary resilience and combined with the characteristics of tourism industry itself, the resilience of tourism economy refers to the ability of tourism economic system to maintain its own stability, restore the original state and move to a new equilibrium state after suffering external shocks [13]. Current research topics on tourism economic resilience mainly involve measurement evaluation, analysis of influencing factors, spatio-temporal evolution, tourism economic resilience and high-quality tourism development [14], and domestic research scales involve provinces, cities, major economic belts, etc. [15]. The factors affecting the resilience of tourism economy can be divided into two categories: first, external factors, namely regional social and economic factors, including regional economic level [16], regional industrial structure [17], traffic conditions [18], government intervention [19], etc. Second, the internal factors, namely the development status of tourism industry, can be specifically divided into tourism economic level [20], tourism service capability, etc. Diversity is an important factor affecting regional economic resilience. In the event of shock disturbance, the diversified structure acts as a "shock absorber", which can quickly allocate the negative impact caused by shock disturbance to other industries [21]. The higher the diversity of the economic structure, the less the impact of the shock disturbance, so the higher the other resilience, the more likely to return to the original state. In addition to the characteristics of diversification, inter-industry correlation also affects economic resilience. If the inter-industry correlation is higher, the impact disturbance of individual industries is more likely to spread rapidly to all industries in the economic system [22]. Excessive diversification may result in the failure to form industrial clusters due to weak linkages and less communication. The external characteristics generated by industrial agglomeration will be weakened, which is not conducive to the generation and spillover of innovation, resulting in the difficult survival of enterprises [23].

The higher the specialization of the regional economic system, the higher the degree of economic correlation, the easier it is to enter the locked state, the innovation ability declines, and it is difficult to evolve a new path. Once hit, the economic structure cannot disperse the impact, and the possibility of regional resistance and recovery decreases, which may eventually lead to a long-term decline and development path [24]. Adaptability is an important factor in the economic system's resistance to shocks, and it can also promote the formation of industrial specialization in the economic system. Although the specialized economic structure can optimize and update the economic structure by strengthening the contacts and exchanges between industries, and achieve high economic efficiency, it will greatly weaken the adaptability of the system, which is an important factor in determining the innovation ability of the system. At the same time, it is also conducive to the improvement of the degree of diversification. Once it is weakened, it means that it is difficult for the system to change the original path and create a new development path, so the economic system needs to balance specialization and diversity reasonably. In this regard, the theory of related variety emerged [25]. This theory pays attention to the correlation between various parts of the economic system, and believes that the spatial agglomeration generated by different industries that are only connected at the technical level is a very important factor. The correlation diversity can realize the technical connection between different industries in the region, and also realize the integration and utilization of technologies between industries in different fields. In this way, it can actively promote the full technical connection and knowledge spillover between industries. In the face of impact fluctuations, it can actively optimize and adjust, explore and discover new breakthrough paths, and finally form a new development path.

To solve this problem, a simplified particle swarm optimization algorithm with escape strategy is designed [26], and an escape mechanism is introduced to jump out of the local optimal solution. This method solves the local extreme value problem, but the result is not good. A kind of inertia coefficient decision [27] based on hyperbolic tangent function model is proposed, and nonlinear adaptive transformation is carried out to improve the solution level. A strategy for adjusting inertia weights and learning factors is proposed [28], which attempts to establish the change function of learning factors and weight coefficients to improve the optimization accuracy of the algorithm. In addition to the improvement of parameter adaptation, the performance of PSO can be improved by improving the updating formula. Add the leading search term [29] for particle individuals towards global optimization, so that particle swarm can obtain more perturbations and avoid local extreme values. There is also a black hole particle swarm [30] introduced into black hole theory. The fusion of multiple intelligent optimization algorithms is also favored by scholars, which combines the simulated annealing idea with particle swarm to improve the processing ability of discrete optimization problems [31], while avoiding falling into local optimality. By integrating differential evolution algorithm and particle swarm [32], the fast convergence of the former is maintained while the search diversity of the latter is maintained. According to the current state of the particle, the weight coefficient and learning factor are modified to further improve the precocious defects [33] and enhance its local search ability.

3 IMPROVED ADAPTIVE TABOO ANNEALING PARTICLE SWARM OPTIMIZATION

The variables are shown in Tab. 1.

Table 1 Variables

Variable	Meaning
x_i	D-dimensional vector
V_i	velocity vector
pb_i	i-th particle individual
$W_{\max}$	maximum of the given inertia coefficient
c_1 and c_2	learning factors
$T(i)$	temperature adaptation value of particle

Inspired by the behavior of birds, PSO is a random search algorithm with fast convergence speed and global search ability. Suppose that in the D-dimensional search space, N particles form a population, and each particle is a D-dimensional vector x_i; its velocity vector is V_i; the optimal position of the i-th particle individual pb_i; particle swarm optimal location gb; each particle vector is a potential solution to the optimization problem, and in PSO particle updates:

$$v_i^{t+1} = wv_i^t + c_1 r_1 (pb_i^t) + c_2 r_2 (gb^t - x_i^t) \tag{1}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{2}$$

3.1 Improved Parameter Adaptive Strategy

In the standard particle swarm optimization algorithm, parameters w, c_1 and c_2 are important parameters to control the direction of particle motion. In most algorithms, their values are mostly based on experience, but the given values are difficult to meet the requirements of different iteration periods. The inertia coefficient w represents the degree of inheriting the speed of the previous generation, which directly affects the search ability of the algorithm. When w is large, it is greatly affected by the velocity of the previous generation particle, the flight speed is fast, and the global search ability is strong, but it is difficult to achieve local convergence. When w is small, it is less affected by the previous generation of particles, and it is easy to fall into the local extreme value when conducting detailed search for the local area, and the solution effect is poor. Aiming at this characteristic, a new method based on inverse tangent function is proposed. Control strategy of coefficient:

$$w = \frac{w_{\max} - w_{\min}}{2} \times \left(\arctan\left[\frac{t}{n} - \frac{M}{2n}\right] \Big/ \arctan\frac{M}{2n} \right) \tag{3}$$

$W_{\min}$ and $W_{\max}$ are the minimum and maximum of the given inertia coefficient respectively. t, M are the current algebra and the given maximum algebra respectively; n is the attenuation coefficient. The larger n is, the faster the intermediate decay rate is, and the opposite is true. Enable in the early phase of the algorithm. Keep large value, increase global search ability, avoid falling into local extreme value. In the medium term, maintain a certain rate of gradual reduction. To gradually enhance its local search capability, in the later stage, the value of w is small, and the small value can carry out fine search for the region near the extreme value, so that the particle converges towards the global optimal position. The control between global search ability and local search ability can be realized by adaptive strategy.

For the learning factors c_1 and c_2, if c_1 is larger, more particles move toward the individual optimal position, and the global search ability of particle swarm is improved, but it is difficult to find the optimal value and difficult to converge. If c_2 is large, its convergence speed is fast, and it is easy to fall into local extreme values. Therefore, the nonlinear learning factor strategy of cosine function is adopted:

$$c_1 = 1.5 + 1.3\cos(\pi \times t / M) \tag{4}$$

$$c_2 = 2.1 - 1.3\cos(\pi \times t / M) \tag{5}$$

At the initial stage of the algorithm, $c_1 = 2.5$ and $c_2 = 0.8$. As the number of iterations t increases, $c1$ gradually decreases to 0.1, while c_2 gradually increases to 3.2. This setting can ensure the global search ability in the early stage, and the change speed is slow, and the global search is more comprehensive. In the middle and late stages, c_1 decreases rapidly and c_2 increases rapidly, which makes the local search ability to improve rapidly and the convergence speed to accelerate.

3.2 Improved Taboo Annealing Perturbation Strategy

In the process of particle swarm evolution, the algorithm has a certain global search ability through parameter adaptation, but its global search ability is limited. In the process of particle iteration, it is difficult to avoid the phenomenon of a large number of particles gathering, resulting in a lack of particle diversity. The "premature" phenomenon of a large number of particles gathering occurs before and in the middle of the iteration, and it is easy to fall into the local area through location update. It is difficult to jump out of the local extreme value, and introduce the annealing selection mechanism of taboo excitation to select the alternative solution Xbr to replace *gb* in the global optimal position, and use its jump probability to avoid the occurrence of "premature" situation to a certain extent.

The simulated annealing algorithm is a global optimization algorithm that learns from the physical annealing process, utilizes the Metropolis criterion and timely controls the temperature drop to solve the global optimization problem [14]. Combined with the Metropolis criterion, the temperature adaptation value of particle i is defined as $T(i)$, and the process of obtaining it is as follows:

$$T(i)=e^{-\frac{pbest(i)-gbest(i)}{T_c}},\ pbest(i)\neq gbest \tag{6}$$

where: $T(i)$ is the temperature adaptation value corresponding to the i-th particle; $pbest(i)$ is the individual optimal value of the i-th particle, and the corresponding optimal position of the individual particle is *pb*; *gbest* is the global optimal value, and the corresponding global optimal position of the particle is *gb*; T_c is the annealing temperature corresponding to the current algebra, and its initial value and updating method are as follows:

$$T_c(t)=K\times T_c(t-1),t\neq 1 \tag{7}$$

In the formula, K is the cooling coefficient of annealing, and the general value is the value close to 1 between [0, 1], and the value is 0.9.

Combined with the tabu search idea, the algorithm should avoid excessive repetition of local search before and in the middle of iteration, resulting in particle waste, record the global optimal position reached by the previous generation, and reduce the search for this position in the next generation search, so that the earlier particle update more functions in the global scope search, and improve the global search ability.

According to the Euclidean distance between particles, "excitation" is given to particles far from the global optimal position:

$$D(i)=\sqrt{\sum_{k=1}^{D}(x_{i,k}^{t}-gb_{k}^{t})^{2}} \tag{8}$$

$$M_{fit}(i)=\frac{D(i)}{\sum_{i=1}^{N}D(i)} \tag{9}$$

In order to avoid excessive disturbance in the later iteration period and ensure the convergence ability of the algorithm, only the first 3 particles with $D(i)$ values in descending order are considered in this paper, and other particles *Mfit* are not considered as having no excitation degree.

Linear combination of *Tfit* and *Mfit* was performed and the overall fitness value was obtained by normalization:

$$Fit(i)=\frac{T_{fit}(i)+\frac{M-t}{M}\times M_{fit}(i)}{\sum_{i=1}^{n}(T_{fit}(i)+\frac{M-t}{M}\times M_{fit}(i))} \tag{10}$$

The probability of selecting *gb* for *Xbr* is shown in Fig. 1.

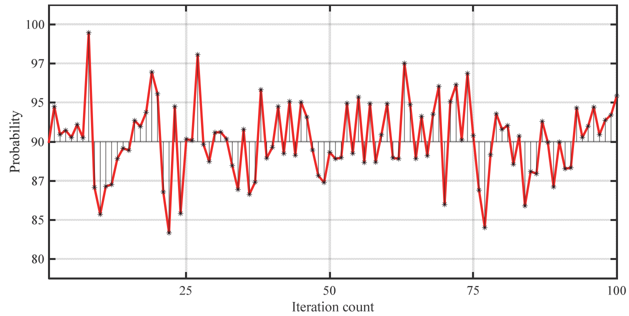


Figure 1 Probability of *Xbr* selecting *gb* after taboo excitation

As can be seen from Fig. 1, in the early stage of iteration, the influence of taboo excitation degree is greater. The disturbed particle *Xbr* has a greater probability to choose the individual optimal solution pb corresponding to the excitation particle far from the optimal location *gb* of the previous generation to replace *gb* to guide the particle to conduct global search, avoiding the "prematurity" phenomenon to a certain extent. In the middle and late iterations, with the widening of the temperature adaptation value gap and the gradual decay of the excitation coefficient ($M-t/M$), the taboo excitation effect decreases, and the probability of *Xbr* selecting *gb* 'particle gradually increases, and finally approaches 1, so as to ensure the convergence ability of the algorithm.

3.3 Improved Self-Regulating Annealing Particle Swarm Optimization Algorithmand Flow

The improved strategy in this paper will introduce adaptive inertia weights and adjustment factors to the simulated annealing particle swarm algorithm, because the simulated annealing particle swarm algorithm is improved, it has Metroplis criterion for a single particle swarm to skip the local optimal solution. In order to increase the tolerance level, it is continued to be included in the range when the particles are approximately up to standard. On this basis, adjusting the inertia weight and adjusting factor parameters will make the improved simulated annealing algorithm more accurate in local search and approximate optimal solution location. In the region of the approximate optimal solution, the speed of searching for the optimal solution is faster and the degree of convergence is higher. When there may be multiple optimal solution values for specific problems, the situation that only one approximate optimal solution is searched can be completely avoided. The more complex the actual situation, the better the degree of convergence and accuracy will be. This improved simulated annealing particle swarm optimization algorithm is feasible in terms of improving strategy and selecting influencing factors. The flow chart of the improved simulated annealing particle swarm optimization algorithm is shown in Fig. 2:

The main body of this improved algorithm is the particle swarm algorithm with rapid calculation process. It refers to the Metroplis criterion in simulated annealing algorithm, jumps out of the local optimal solution of particle swarm. In simulated annealing particle swarm algorithm, it introduces improved inertia weight parameters and adjustment factors to constrain the learning particles. The improved algorithm has the advantages of stronger global search efficiency and more accurate approximation ability to deal with multiple approximate optimal solutions, and more accurate selection of the wide range of optimal solutions in the early search area and more accurate positioning of the region approaching the approximate optimal solution in the later stage during the return calculation, speeding up the calculation speed and improving the calculation efficiency. Make the final optimal solution value more accurate and reliable. It also eliminates the repeated inaccurate calculation in the local optimal solution region, jumps out of the scope frame, and searches for a more reliable accurate optimal solution.

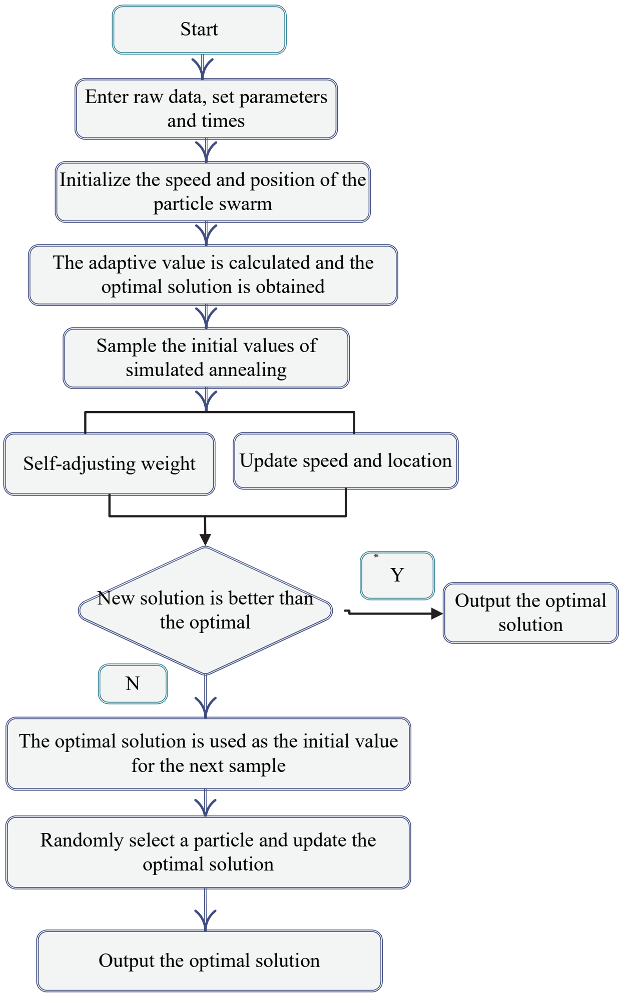


Figure 2 Flowchart based on improved simulated annealing particle swarm optimization algorithm

4 ECONOMIC RESILIENCE IMPACT ALGORITHM OF FOREIGN TRADE IN YANGTZE RIVER DELTA REGION BASED ON SELF-REGULATING ANNEALING PARTICLE SWARM IMPROVEMENT ALGORITHM

4.1 Index Construction of Economic Resilience of Foreign Trade

Principles of indicator selection:

a. Scientific: Scientifically learn from previous research results, comb through the layers of indicators in the literature, try to ensure that the level of indicators is clear, the number is appropriate, reduce the multi-angle selection of indicators, and clarify the relationship between indicator repetition.

b. Comparability: indicators should be unified caliber and scale, clear positive and negative direction, measured economic resilience indicators, can be compared horizontally and vertically.

c. Availability: The construction of the index system requires a large amount of data. In this paper, indicators with more complete data are given priority on the basis of considering scientificity and comparability, and missing data of individual indicators are supplemented by scientific methods. At the same time, the integrity and authenticity of indicator data are guaranteed as much as possible to avoid missing large amounts of data.

Based on the above three principles, this paper divides the evaluation indicators of economic resilience into three dimensions: shock coping ability, organizational adjustment ability and self-renewal ability, including 10 underlying indicators, as shown in Tab. 2.

Table 2 Economic resilience evaluation index system

Primary indicator	Secondary indicator	Indicator interpretation	Directivity
Indicators of economic resilience	Shock coping ability	Per capita GDP	Positive tropism
		Urban registered unemployment rate	Positive tropism
		Total imports and exports as a proportion of GDP	Negative tropism
		The proportion of tertiary industry in GDP	Negative tropism
	Organizational adjustment ability	Growth rate of fixed asset investment	Positive tropism
		Fiscal expenditure/revenue	Positive tropism
		Number of students enrolled in regular institutions of higher learning	Negative tropism
	Self-renewal ability	Number of patents granted	Positive tropism
		The proportion of financial employees in total employment	Positive tropism
		Actual amount of foreign direct investment used	Positive tropism

Due to the large differences in dimensions, positives and negatives and orders of magnitude of each indicator, it is necessary to conduct standardization processing. X_{ij} is the formula for selecting positive indicators:

$$X_{ij}^{'} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \tag{11}$$

The negative index adopts the formula:

$$X_{ij}^{'} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \tag{12}$$

Calculate the proportion of the index value of the year i (region) of the J index:

$$Y_{ij} = \frac{x_{ij}^{'}}{\sum_{i=1}^{m} x_{ij}^{'}} \quad (13)$$

The specific gravity matrix $Y = \{Y_{ij}\} m \cdot n$ is established, where m is the number of years or regions, and n is the index number.

The weighted summation method is used to calculate the comprehensive evaluation score of each year (region), the each year weight is W:

$$F = \sum_{i=1}^{n} W_j \cdot X_{ij}^{'} \quad (14)$$

Based on the comprehensive evaluation framework of toughness, the self-adjusting annealing particle swarm improvement algorithm is used to calculate the toughness value of the foreign trade area. Here, only the values of 4 years and the total value and ranking are selected for comparison and analysis, as shown in Tab. 3.

Table 3 Values of regional economic resilience

District	Total	2005	2010	2015	2020
Shanghai Municipality	12.227	0.532	0.449	0 .508	0.446
Jiangsu Province	11.169	0.405	0 .360	0.496	0.468
Guangdong Province	11.116	0.621	0 .553	0.468	0.420
Zhejiang Province	8.920	0.332	0 .324	0.419	0.353

According to Tab. 2, it can be found that the difference between provinces and cities is obvious. From the perspective of total value, the total value of Beijing, which ranks the first, is as high as 13.510, while that of Chongqing, which ranks the lowest, is only 7.47, and the total value of Beijing is twice that of Chongqing. By year, in 2005, the top five were Guangdong, Shanghai, Beijing, Jiangsu and Tianjin, with an average of about 0.481. The coastal provinces of Guangdong and Jiangsu are relatively open to the outside world, attracting a large number of foreign investment, high-tech industries and tertiary industries are developed, and the innovation level is among the best in the country, which is a good foundation for improving economic resilience.

4.2 Economic Resilience Model of Foreign Trade in Yangtze River Delta Region Based on Self-Regulating Annealing Particles Warm Optimization Algorithm

The influence of urban registered unemployment rate X_1, number of practicing (assistant) doctors X_2, number of hospital beds X_3 and other factors will be analyzed. At the same time, the innovation platform promoted by the integration of education and science and technology has promoted the transformation and development of the economy, and there are more paths to choose in the impact, so it is also necessary to consider the proportion of education expenditure X_4, the proportion of science and technology expenditure X_5 and other factors. Material circulation has a significant impact on the economic activity of urban agglomerations and inter-city economic ties. From the perspective of ensuring the spatial flow of resources, factors such as the proportion of logistics GDP X_6 and highway density X_7 are considered.

The analysis with a single city background ignores the possible influence of the interaction pattern between cities. In this paper, the spatial correlation of dependent variables and independent variables is analyzed comprehensively by using the spatial Durbin model SPDM. The model constructed in this paper is as follows:

$$LnRe_i = p\sum_{j=1}^{n} W_{ij} Re_i + b \ln X_{it} + \sum_{j=1}^{n} W_{ij} \ln X_{jt} + y_t + u + r \quad (15)$$

where: Re is the economic resilience of the region; X_{it} is an influential factor for economic resilience; W is the spatial weight matrix reflecting the spatial proximity relationship of regions; p is the spatial regression coefficient; b and e are parameters to be estimated; a is the spatial fixed effect; y_t is a time-fixed effect. u is the random error term; r is the coefficient of spatial error.

The spatial Durbin model test is conducted on the data, and p is all greater than 0 and passes the 1% test, indicating that there is a significant positive spillover effect on the economic resilience of the Yangtze River Delta urban agglomeration. The direct, indirect and total effects of the economic resilience of the Yangtze River Delta urban agglomeration are analyzed, as shown in Tab. 4.

Table 4 Estimates of direct effect, indirect effect and total effect of self-regulating annealing particle swarm improvement algorithm

Period	2011-2023 year								
Fixed effect	Space fixed			Time Fixed			Space time fixed		
Influencing factor	Direct	Indirect	Total effect	Direct	Indirect	Total effect	Direct	Indirect	Total effect
X_1				–5.926	32.534	26.63			
X_2	97.829	210.145	307.965	222.36			58.56		
X_3	–42.818	–84.321	–127.23	–84.81			–26.93		
X_4					–0.05	–0.054			
X_5				0.08		0.087			
X_6				–0.039			–0.02		–0.043
X_7	–0.035	–0.244	–0.283					–0.145	–0.163

In Tab. 3, there are relatively more influencing factors that have passed the test in the results of time fixed effects, which is more conducive to analyzing the development of economic resilience of urban agglomerations combined with spatial differences. The direct effect and the total effect of the two time cycles have the same direction and similar values. X_2 and X_5 are conducive to improving economic resilience, and X_2 has a much greater impact than X_5, and the influence of X_2 is more obvious during 2011-2023, which is inseparable from the huge impact of the novel coronavirus epidemic on the demand for medical conditions in the later period. X_1, X_3 and X_6 are all factors hindering the improvement of the city's economic resilience, among which X_3's hindering effect is similar to X_2's, and the hindering effect is more obvious in the period from 2011 to 2023, indicating that the number of beds in medical conditions has not yet met the needs of the city in responding to emergencies.

X_1 of the neighboring cities has a driving effect on the economic resilience of the city, while X_4 is an obstacle to the economic resilience of the city, indicating that the employment security means of the neighboring cities of the Triangle city cluster will also have a significant stabilizing effect on the economic resilience of the related cities, providing a basis for the construction of a security system. However, the investment in education attracts the students from related cities and the related employment talents, which weakens the educational attraction of the city. In the total effect, X_1 has an obvious pulling effect on the economic resilience of the Yangtze River Delta urban agglomeration, and X_5 can also promote the improvement of the economic resilience of the urban agglomeration, but its promoting effect needs further development. On the contrary, X_4 in the urban agglomeration system is an obstacle to the improvement of economic resilience. Education is not only an incubation platform for talents, but also a transportation mechanism for innovative talents in the field of science and technology. The output efficiency of education investment will have a resonance impact on the entire economic resilience system, but it is far from playing its role at this stage. At present, its hindering effect is relatively weak, and relevant policies should be analyzed to change its effect into a positive one, and provide talents to achieve adaptation, recovery and improvement.

5 SIMULATION VERIFICATION

The panel quantile regression model was used to analyze the main driving factors of tourism economic resilience in the Yangtze River Delta urban agglomeration from 2011 to 2023. In the model, a total of 5 sub-sites were selected: 10%,25%,50%,75% and 90%. In order to avoid pseudo-regression, unit root test is carried out on panel data to investigate its stationarity. The test results are shown in Tab. 5. The original data of TER,EDS and GI3 variables are not stable, but the results after first-order difference are stable, indicating that the panel data has stationality in time series. At the same time, multicollinearity test was carried out for each variable, and the results showed that the maximum variance expansion factor between the explained variable and the explanatory variable was 1.42, indicating that there was basically no multicollinearity problem between the variables.

Table 5 Unit root test of panel data

Variable	p(LLC)	p(ADF)	Result
TER	0.0000	0. 8026	Unsteady
OTER	0.0000	0.0055	Smooth and steady
EDL	0.0000	0.0000	Smooth and steady
EDS	0.0000	0.2006	Unsteady
REDS	0.0000	0.0000	Smooth and steady
TDS	0.0000	0.0001	Smooth and steady
TC	0.0963	0.0175	Smooth and steady
EL	0.0000	0.0538	Smooth and steady
IL	0.0000	0.0182	Smooth and steady
GI	0.9934	0.9998	Unsteady
RGI	0.0000	0.0091	Smooth and steady

The influence coefficient of economic development level (EDL) is significant at each sub-point, which has a strong promotion effect on the resilience of tourism economy. The influence coefficient at each sub-site showed an inverted N-type trend, and the influence coefficient at the high-score loci was higher than that at the low-score loci, and had different positive and negative correlation with TC and EL, indicating that improving the economic development level is the main way to improve the economic resilience level of cities with high resilience. When the economic resilience of cities reaches a higher level, the influence of economic development level on resilience decreases. But it is still an important influencing factor. Cities with high economic resilience usually have the characteristics of a better tourism environment and relatively sound infrastructure. On this basis, further improving the level of economic development is conducive to consolidating the sustainable development of urban tourism industry, as shown in Fig. 3.

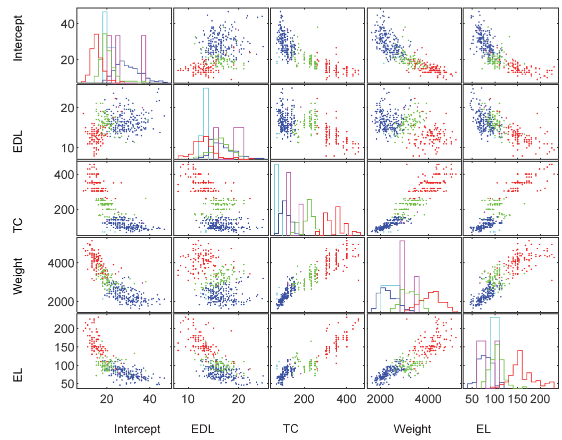


Figure 3 Visualized quantile regression results of economic development level

As shown in Fig. 3, the influence coefficient of tourism development speed (TDS) is at each sub-point, which has a certain inhibitory effect on the resilience of tourism economy. The negative effect is relatively large at 50% and 75% points, indicating that this variable is an obstacle factor for the resilient development of tourism economy in cities with high resilience. In the process of tourism development, there may be imbalance between tourism and regional economic development. The tourism industry in cities with medium and high resilience has experienced rapid development of tourism, so it is more likely to produce such imbalance in the short term, resulting in reduced resilience. However, with the further follow-up of technology and resources, this imbalance will gradually become more balanced. Therefore, the negative impact of tourism development speed on the resilience of tourism economy is gradually reduced.

As shown in Fig. 4, the influence coefficients of economic development structure (EDS) are all significantly positive, and the influence coefficient of EDS on the resilience of tourism economy is the lowest at 50% sub-points, and the influence coefficient at 75% and 90% sub-points is significantly higher than other sub-points, indicating that the balance of economic development structure is an important factor for cities with high resilience to continue to improve their tourism economic resilience. For medium and low resilience cities, the economic development structure plays a relatively small role in improving resilience. Education level (EL) also has a significant positive impact on the resilience of tourism economy, and the influence coefficient at the low score point is significantly higher than that at the high score point, indicating that improving education level is an important way for cities with low resilience to improve their tourism economic resilience. The gradual weakening of the positive effect is mainly due to the strong awareness of rational planning, green travel and rational shopping among residents of cities with high education level. Infrastructure (IL) has a significant promoting effect on the improvement of tourism economic resilience, and the influence coefficient at each sub-point shows an overall upward trend, and the influence coefficient is the smallest at 10% sub-point, while the difference is not significant at the other points, indicating that infrastructure has a greater promoting effect on the tourism development of cities with certain resilience. Tourism infrastructure provides a stable foundation for the resilience of tourism economy. When urban tourism develops to a certain stage, it is urgent to strengthen the construction of infrastructure and promote the high-quality development of tourism. Government intervention (GI) has a certain positive impact on the resilience of tourism economy, with the lowest impact coefficient at the 10% sub-point, and the impact coefficient at the high-score site is greater than that at the low-score site, indicating that the moderately resilient cities need to rely on external policy tools to improve the resilience of tourism economy.

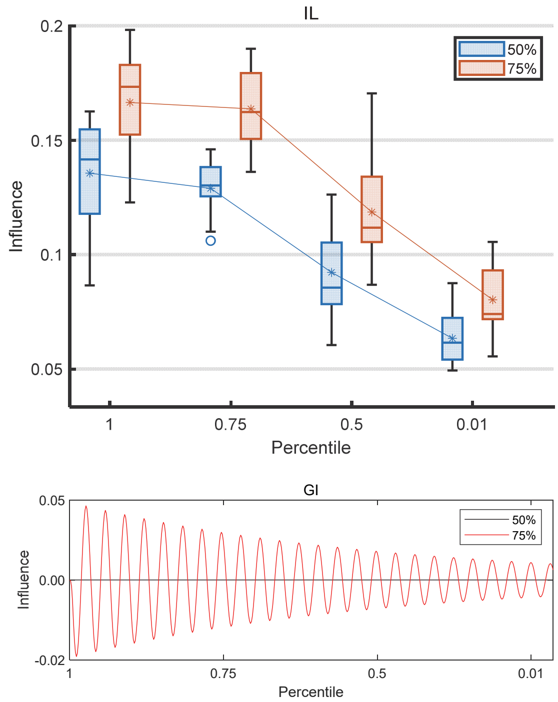
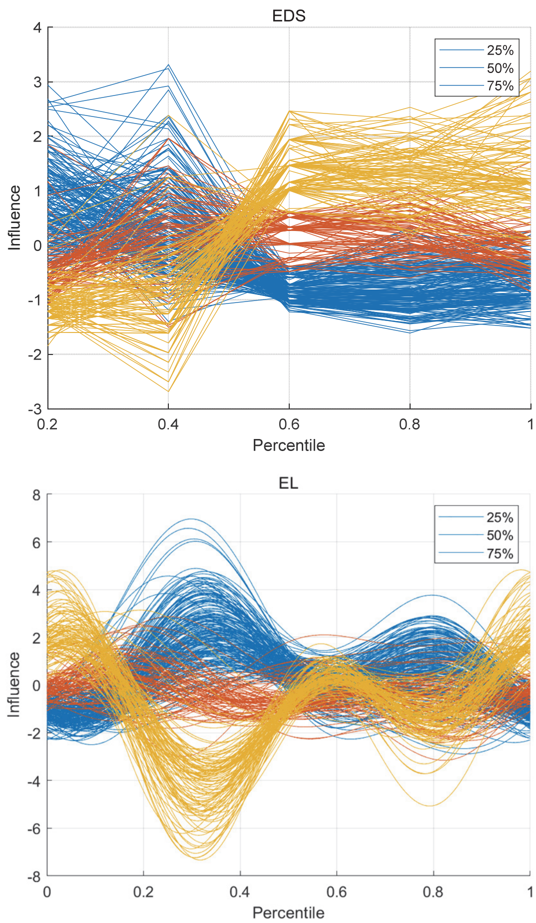


Figure 4 Quantile regression visualization results

It is necessary to avoid the particularity and contingency of the improved simulated annealing particle swarm optimization algorithm, so two different functions are used for comparison and verification. The algorithms before and after improvement are used for comparison and verification of test functions, as shown in Fig. 5 and Fig. 6.



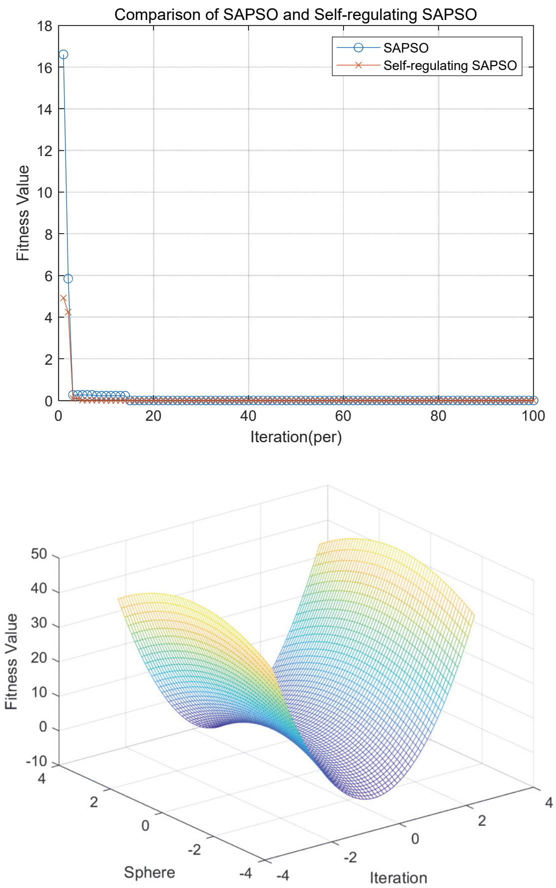
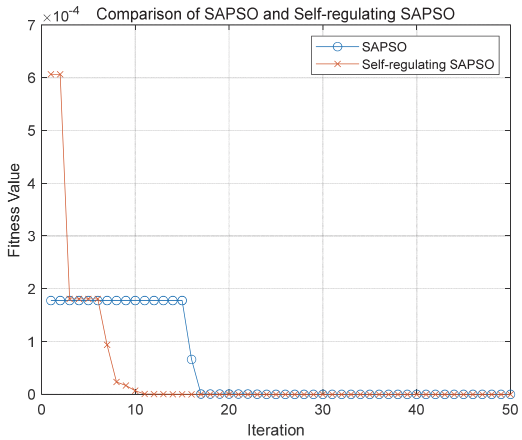


Figure 5 Compares the diagram using Sphere functions



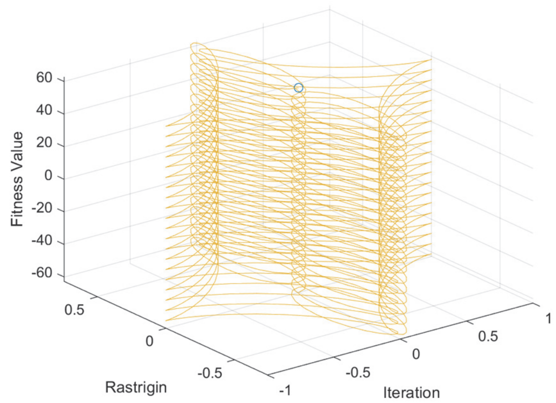


Figure 6 Compares the Rastrigin function

As shown in Fig. 5, when there is a single optimal solution problem, the improved algorithm can better display convergence advantages in terms of accuracy and speed, reach the ideal state, and meet the improvement requirements. As shown in Fig. 6, for problems with multiple approximate optimal solutions, the improved simulated annealing particle swarm optimization algorithm will not be entangled in the range of several approximate optimal solutions, but jump out of the local optimal search region instead of repeatedly seeking within the range, and the results converge faster and better to the approximate global optimal solution, with visible improvements in efficiency and accuracy. It shows that the improved simulated annealing particle swarm optimization algorithm is superior and meets the expectation.

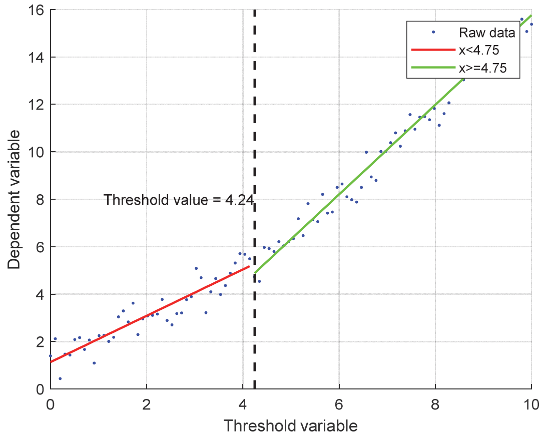


Figure 7 Threshold effect test

In order to test whether the threshold estimate is true, this paper adopts the likelihood ratio test (LR) for further verification, as shown in Fig. 7. It can be seen that the corresponding value when LR = 0 is the threshold value, and the interval when LR < 4.75 (below the dotted line) is the 95% confidence interval of the threshold value. Therefore, the threshold value in this paper is placed in the confidence interval, verifying the authenticity of the threshold estimate.

For actual lines, annealing particle swarm optimization algorithm and improved self-regulating annealing particle swarm optimization algorithm were used for reactive power optimization operations and the results were compared. The changes in the influence of foreign trade on economic toughness were shown in Fig. 8.

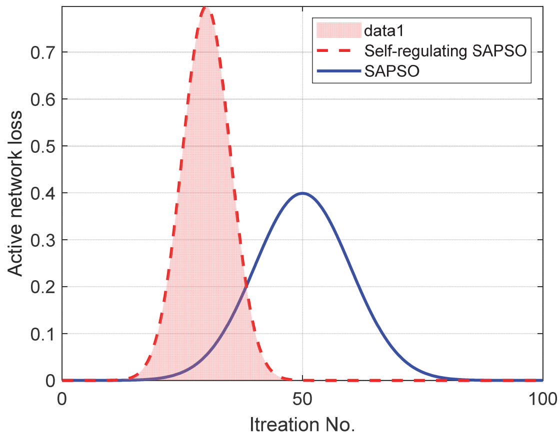


Figure 8 Comparison of the impact of foreign trade on economic resilience before and after the improved algorithm

First of all, the self-regulated annealing particle swarm optimization verifies that foreign trade has a significant impact on economic resilience, so the government should pay more attention to how to make good use of foreign capital. Especially nowadays, with the deepening of globalization and the increasingly close economic links between countries, how to rationally utilize foreign capital has become a more unavoidable issue for all countries and regions. Foreign trade has a certain negative effect on economic resilience, but this does not mean that a region should reject foreign investment. On the contrary, the policy focus should be on coordinating the relationship between foreign investors and domestic enterprises, taking into account the healthy development of the independent innovation ability of Chinese enterprises, while making full use of the spillover effect of foreign investment into knowledge and technology. Foreign investment should be organically combined with the development of independent innovation ability of Chinese enterprises. When formulating relevant policies to encourage foreign investment, certain measures should be taken to protect local smes in the same industry, so as to avoid the innovation and development of local enterprises being suppressed after transnational corporations obtain monopoly status by relying on advantages such as technology and preferential policies. This will promote the long-term development of Chinese enterprises and the rapid progress of Chinese social economy, build a good cooperative partnership between Chinese and foreign enterprises, and achieve a win-win situation.

6 CONCLUSION

In the composition of the economic resilience of the Yangtze River Delta urban agglomerations, the level of opening up is the main driving force, and the innovation ability also plays a significant role in promoting the economic resilience. The following suggestions are put forward to improve the economic resilience of the Yangtze River Delta urban agglomerations: narrow the development gap and strengthen contacts and cooperation. At present, cities with low resilience and low resilience still account for the majority in the region, while cities are closely connected and complex, and the "backwardness" of a certain system will also have an impact on other systems. Therefore, establishing the idea of "chess game", strengthening exchanges and cooperation, and narrowing the development gap between cities can provide stable support for the development of urban tourism economy. Cities can form a very resilient "network" between them and tide over difficulties together in mutual influence. We will rationally allocate investment in production factors and steadily promote economic development. For cities with low levels of resilience, attention should be paid to high-quality resource development, talent introduction, infrastructure construction, etc., to enhance exposure and attract more tourists to achieve leapfrog development. For cities with high resilience, too fast economic growth is easy to lead to unbalanced development, but not conducive to the improvement of economic resilience, so we should pay attention to improving the quality and grade of reception, curb excessive commercialization, and strengthen connotative construction. The next step will be to study the impact of economic development level, economic development structure and infrastructure on higher resilient cities, the impact of tourist carrying capacity and government intervention on medium resilient cities, and the level of economic development, economic development structure, education level, tourist carrying capacity, infrastructure, government intervention, and tourism development speed.

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