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Multi-objective evolutionary optimization of industrial upgrading in ethnic minority regions in the context of the digital economy

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Abstract Minority areas are generally backward areas with lagging economic development level, low level of industrial structure and obvious dual structure characteristics, but these areas often contain rich natural resources and unique national culture, so it is of great significance to explore the path of upgrading industrial structure in minority areas. The article firstly introduces the input-output analysis method and constructs a multi-objective evolution model of industrial structure adjustment in ethnic minority regions from the perspectives of low carbon, employment and economy, and solves the model by using the multi-objective genetic algorithm with improved genetic operation (I-NSGA-II). Using the method proposed in this paper to carry out comprehensive and detailed quantitative calculations and effect analysis on the industrial structure of ethnic minority areas, the influence coefficient of computers, audio-visual equipment, communication equipment, and cultural and office supplies machinery is larger as an industry with higher scientific and technological content, and each increase in one unit of production has a larger pulling effect on all other sectors, and it is considered that low-carbon development, economic growth and promotion of employment are equally important. Minority areas can upgrade their industrial structure in the aspects of strengthening basic agriculture, upgrading traditional industries and accelerating the development of service industry.

Index Terms I-NSGA-II, input-output analysis method, ethnic minority areas, industrial structure upgrading

I. Introduction

In recent years, with the rapid development of information technology, the emergence of emerging technologies such as the Internet, big data, artificial intelligence, etc., has provided strong support for the rapid rise of China's digital economy and become an important engine of economic development [1]-[3]. The digital economy, centered on the Internet, big data, artificial intelligence, etc., has promoted the deep changes in the mode of production, economic structure and social form, and has played a crucial role in upgrading the industrial structure of each region [4]-[7].

Minority regions are an important part of China, with rich cultural heritage and resources [8]. For a long time, the economic development of ethnic minority regions has been relatively backward and social problems have been prominent, and the economic development of ethnic minority regions has been affected by many factors, including geographic environment, resource endowment, and infrastructure construction [9]-[12]. Due to historical and cultural influences, social problems in ethnic minority areas are also more serious, including greater inequality in education, health care, employment and other aspects [13], [14]. In order to promote the economic and social development of ethnic minority areas, the government and the community need to adopt a series of solution strategies, including increasing policy support for ethnic minority areas, strengthening infrastructure construction, promoting industrial transformation and upgrading, and improving the allocation of education and medical resources [15]-[18]. And with the development of digital technology, it constantly promotes the development of industrial digitization and digital industrialization, while the digital economy shows the characteristics of strong industrial permeability, which can effectively empower the industrial digital transformation of ethnic minority regions [19]-[22]. The integration of digital economy development with the three industries to different degrees can effectively improve the production efficiency of each industry and optimize the factor allocation capacity among industries [23], [24]. And the development of digital industrialization derives more new industries, new forms and new modes, which are triggering a new round of industrial change, thus promoting the economic development of minority regions [25], [26].

The article firstly explains the calculation method of input industry analysis and then designs a multi-objective evolution model of industrial structure adjustment in ethnic minority areas. Then I-NSGA-II algorithm is proposed

based on existing research on NSGA-II algorithm, which ensures the evolutionary direction of the population and accelerates the convergence speed of the population by introducing the crossover operator based on normal distribution and adaptive variation operator. The input-output analysis method is used to quantify all the subsectors of the ethnic minority regional industries in 2024, and three different optimization and adjustment schemes are given based on the different emphasis on low-carbon environmental protection, employment growth and economic development. Finally, based on the experimental results, the optimization path of industrial structure upgrading in ethnic minority areas is proposed.

II. Multi-objective evolutionary algorithm for industrial structure upgrading

II. A. Calculation methods for input-output analysis

The input-output table is an important part of the economic accounting system in ethnic minority areas, which is an important tool for economic analysis by systematically, concretely and graphically describing the process of economic production, income formation and utilization in the form of a checkerboard balance sheet. The input-output technique has not only gained wide application in the macro- and micro-economic fields but has also achieved promising results in its application in the micro-economic field.

II. A. 1) Coefficient of influence in a sector

The coefficient of influence reflects the extent of the ripple effect of the demand generated by the addition of one unit of end-use in a sector of the economy of a minority region on the sectors of the economy of a minority region, calculated by the following formula:

$$F_j = \frac{\frac{1}{n}\sum_{i=1}^{n} b_{ij}}{\frac{1}{n^2}\sum\sum b_{ij}} = \frac{\sum_{i=1}^{n} b_{ij}}{\frac{1}{n}\sum\sum b_{ij}} (j = 1,2,\cdots,n) \tag{1}$$

where F_j is the coefficient of influence of sector j, $\sum_{i=1}^{n} b_{ij}$ is the sum of column j of the Leontief inverse matrix, b_{ij} is the coefficient of full consumption of sector j over sector i, and n is the number of sectors of the national economy.

When F_j is greater (less) than 1, it means that production in sector j has a ripple effect on other sectors to a degree that exceeds (falls below) the average level of impact in society (i.e. the average value of the ripple effect produced by each sector). The higher the coefficient of influence F_j, the greater the pull of the sector on other sectors.

II. A. 2) Sensibility factor for a sector

The coefficient of inductivity reflects the extent to which a sector is inducted into the demand, i.e., the amount of output that it is required to provide for the production of other sectors, when each sector of the economy adds a unit of end-use. The formula is as follows:

$$E_i = \frac{\frac{1}{n}\sum_{j=1}^{n} k_{ij}}{\frac{1}{n^2}\sum\sum k_{ij}} = \frac{\sum_{j=1}^{n} k_{ij}}{\frac{1}{n}\sum\sum k_{ij}} (i = 1,2,\cdots,n) \tag{2}$$

where E_i is the coefficient of inductivity for sector i, $\sum_{j=1}^{n} k_{ij}$ is the sum of row i of the Leontief inverse matrix, k_{ij} is the coefficient of full distribution of sector i to sector j, and n is the number of sectors of the national economy.

When E_i is greater (less) than 1, it means that sector i is exposed to a level of inductance that is higher (lower) than the average level of inductance in society (i.e., the average value of the level of inductance to which each sector is exposed). The larger the coefficient of inductivity E_i, the more the sector is constrained by other sectors.

II. B.Model construction for optimization and adjustment of industrial structure

II. B. 1) Model assumptions

This paper tries to adopt multi-objective optimization method to study the current structure of manufacturing industry in ethnic minority areas, hoping that the current industrial structure can be adjusted to coordinate the contradictions existing in the three dimensions of economic development, employment increase and environmental protection. It is assumed that the manufacturing industry can be divided into m specific industry, and the terminal energy consumption is not differentiated from the specific energy consumption on the macro level.

II. B. 2) Problem description

Using set I to denote the set of manufacturing industries, the m specific industries in the manufacturing industry can be denoted as $I=\{I_1,I_2,\cdots,I_m\}$. For a given year, the total output of the i th industry I_i in that year is X_i, and for all industries in the manufacturing sector, there is $X=[X_1,X_2,\cdots,X_m]^T$. The GDP of the i th industry I_i is Y_i, and for all industries in the manufacturing sector, there is $Y=[Y_1,Y_2,\cdots,Y_m]^T$. In the current year, the real total inputs of the manufacturing industry are recorded as $\tilde{X}$, the real GDP of each manufacturing industry is recorded as y_i, the sum of the real GDP of non-manufacturing industries is recorded as $\tilde{Y}$, the total carbon emissions of the manufacturing industry is recorded as $\tilde{C}$, the total number of people employed is recorded as $\bar{P}$, the total integrated energy consumption of non-manufacturing industries is recorded as $\bar{M}$, and the integrated energy consumption per unit of GDP is recorded as $\tilde{E}$. The i th industry I_i has end-use energy carbon emissions of c_i, total combined energy consumption of e_i, and employment of p_i. Matrix of direct consumption coefficients for inputs and outputs:

$$A=\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \tag{3}$$

where $a_i j=x_{ij}/x_j, i,j\in\{1,2,\cdots,m\}$.

Here x_{ij} denotes the amount of industry j's operations that consumes industry i products or services, and x_j denotes the total inputs of industry j [27]. The value of a_{ij} denotes the degree of dependence of industry j on industry i. The larger the value of a_i, the stronger the dependence. Conversely, the smaller the value of a_i, the weaker the dependence. The carbon emission intensity of the i th industry I_i:

$$\tau_i=c_i/y_i \tag{4}$$

The carbon intensity of each manufacturing sector is then $\tau=[\tau_1,\tau_2,\cdots\tau_m]^T$. The energy intensity of the i nd sector I_i:

$$\varepsilon_i=e_i/y_i \tag{5}$$

Then the energy intensity of each manufacturing industry $\varepsilon=[\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_m]^T$. Labor coefficient for the i nd industry I_i:

$$\lambda_i=p_i/y_i \tag{6}$$

Then the labor force is coefficient for each manufacturing industry $\lambda=[\lambda_1,\lambda_2,\cdots,\lambda_m]^T$.

II. B. 3) Model construction

Based on the above assumptions and descriptions, the mathematical model of industrial restructuring of manufacturing industries in ethnic minority areas can be obtained as follows:

$$\min \quad f_1=\tau X \tag{7}$$

$$\max \quad f_2=i^T Y \tag{8}$$

$$\max \quad f_3=\lambda X \tag{9}$$

$$s.t. \quad X - AX \geq Y \tag{10}$$

$$\tau X \leq \bar{C} \tag{11}$$

$$(\varepsilon X + \bar{M}) / (i^T Y + \bar{Y}) \leq \bar{E} \tag{12}$$

$$\lambda X \geq \bar{P} \tag{13}$$

$$i^T X = \bar{X} \tag{14}$$

$$X, Y \geq 0 \tag{15}$$

Eq. (7) represents the objective of minimizing the carbon emission protection dimension. Eq. (8) represents maximizing GDP, which represents the objective of the economic growth dimension. Eq. (9) denotes maximizing employment, representing the objective of the employment increase latitude. Eq. (10) is the input-output balance element, which portrays the interrelationships among industries, and this constraint is used to ensure the coordination among industries and the healthy development of the national economy. Eq. (11) and Eq. (12) are the environmental protection requirements, respectively, to reduce the total carbon emissions of manufacturing industry and reduce the comprehensive energy consumption per unit of GDP, so that the adjusted industrial structure can realize the low-carbon development. Eq. (13) is the employment security factor, ensuring that the adjusted industrial structure will bring in no less than the number of people employed under the current situation. Eq. (14) is the production input factor, which ensures that the current input quantity of each industry is consistent with the total input quantity planned years ago. Finally, Eq. (15) is the decision variable attribute [28].

II. B. 4) Data sources

To unify the caliber, the data in this paper are used in 2024, and the direct consumption coefficient matrix A is calculated from the collation of the input-output table of 139 industries in ethnic minority areas. Carbon emission coefficient 1 adopts the value of 0.67 recommended for use by the Energy Research Institute of the National Development and Reform Commission, i.e., the carbon content in the CO_2 produced by the complete combustion of η ton of standard coal is 0.67 tons of carbon A tons of standard coal (Tc/Tce), and then the carbon dioxide emissions of terminal energy in industry i are calculated as follows:

$$c_i = \eta \cdot e_i \tag{16}$$

In order to ensure the smooth solution of the model, according to the data released by the National Bureau of Statistics, the other parameters in the model are as follows: real total input of the manufacturing industry in the year $\bar{X}$ = 810,669 billion yuan. The sum of real GDP of non-manufacturing industries $\bar{Y}$ = 162967 billion yuan. Total carbon emissions from manufacturing industries $\bar{C}$ = 501.502 million tons. Total employment $\bar{P}$ = 42,223,000 people, total comprehensive energy consumption of non-manufacturing industries $\bar{M}$ = 156,064,000 tons of standard coal, and comprehensive energy consumption per unit of GDP $\bar{E}$ = 0.76 tons of standard coal 10,000 yuan.

In addition, according to the research needs, the classified automobile manufacturing industry and the classified railroad, ship, aerospace and other transportation equipment manufacturing industry in the economic industry of ethnic minority areas are collectively called the transportation equipment manufacturing industry. And the classifications that account for a very small proportion - other manufacturing industry, waste resources comprehensive utilization industry and metal products, machinery and equipment repair industry - are removed, and the original 31 subsectors of the manufacturing industry are consolidated into 27 industries.

II. C.Multi-objective genetic algorithm based on improved genetic manipulation

After the optimization model of industrial structure in minority regions is constructed, this section tries to propose the genetic algorithm NSGA-II to solve the model.

II. C. 1) Introduction to the NSGA-II Algorithm

1) NSGA-II algorithm concept and characteristics

The first generation of non-dominated sorting genetic algorithm NSGA algorithm evaluates the individual's superiority and inferiority through the method of non-dominated sorting, and evaluates the individual's similarity by the small habitat technique, and evaluates and filters the performance of the objectives with these two criteria, which has certain advantages in solving the multi-objective optimization problem.

NSGA-Ⅱ algorithm is proposed on the basis of NSGA algorithm, and it mainly makes improvements for the following three aspects:

(1) The fast non-dominated sorting algorithm is proposed, which not only reduces the computational complexity, but also merges the parent population with the offspring population, so that the next generation of the population can be selected from a larger space, and in this way, all the most outstanding individuals in the population are retained.

(2) Introducing an elite strategy to ensure that some of the best individuals are retained in the evolutionary process as a way to improve the accuracy of the algorithm.

(3) Adoption of crowding degree and crowding degree comparison operator, which not only solves the defect of needing to artificially specify the sharing parameter in NSGA, but also serves as a comparison criterion between individuals, which enables the individuals in the quasi-Pareto domain to be uniformly expanded throughout the entire Pareto domain, and improves the diversity of the population.

2) Main steps of NSGA-II algorithm

The overall idea of NSGA-II algorithm is shown in Fig. 1. In the NSGA-II algorithm, the parent population P_t (of size N) first generates the offspring population Q_t through selection, crossover and mutation operations, merges the parent population P_t with the offspring population Q_t to obtain the population R_t, and then performs a fast non-dominated sorting operation on the population R_t to combine the non-inferiority frontiers of each individual with the information of congestion distances to filter N individuals from R_t into the next round of iteration.

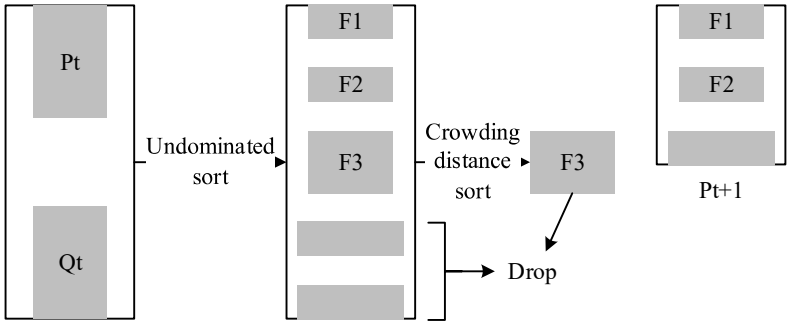

Figure 1: Idea of NSGA-II algorithm

The NSGA-II algorithm flow is shown in Figure 2.

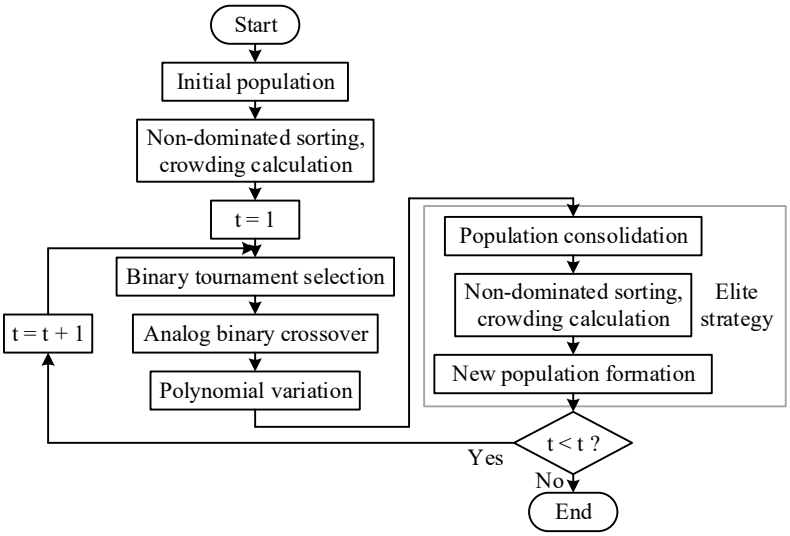

Figure 2: Flowchart of the NSGA-II algorithm

II. C. 2) The I-NSGA-II algorithm

NSGA-II algorithm has problems such as convergence and lack of distribution uniformity, in order to improve this problem, this paper proposes the I-NSGA-II algorithm with certain optimization of the crossover operator and mutation operator of genetic operation.

(1) Improvement of crossover operator

The traditional NSGA-II adopts the simulated binary crossover operator (SBX), which simulates the principle of single-point crossover for binary coding of chromosomal genes and acts on the real-coded chromosomal genes as in Eq. (17):

$$\begin{cases} x_{1i} = \dfrac{(1+\alpha)p_{1i} + (1-\alpha)p_{2i}}{2} \\ x_{2i} = \dfrac{(1-\alpha)p_{1i} + (1+\alpha)p_{2i}}{2} \end{cases} \tag{17}$$

where, x_{1i}, x_{2i} are the variables corresponding on the chromosomes of the two offspring, p_{1i}, p_{2i} are the variables corresponding on the two paternal chromosomes and α is the random variable with the following formula:

$$\alpha = \begin{cases} (2\beta)^{\frac{1}{\gamma}}, \beta \le 0.5 \\ [2(1-\beta)]^{\frac{1}{\gamma+1}}, \beta \ge 0.5 \end{cases} \tag{18}$$

where β is a random number uniformly distributed on (0, 1) and γ is a non-negative number defined by the decision maker.

However, in practice, the value of γ is subjective and random, which in turn leads to a weak search capability of the algorithm and fails to ensure the diversity of the population.

Normal distribution is the most frequently used random variable distribution in daily use, compared with SBX, the crossover operator (NDX) of normal distribution has a wider search range, is less likely to fall into local optimality, and is more likely to obtain a Pareto solution set with a more uniform distribution and better quality, as in Eq. (19):

$$\begin{cases} x_{1i} = \dfrac{p_{1i} + p_{2i}}{2} + \dfrac{1.481(p_{1i} - p_{2i}) \mid N(0,1) \mid}{2} \\ x_{2i} = \dfrac{p_{1i} + p_{2i}}{2} - \dfrac{1.481(p_{1i} - p_{2i}) \mid N(0,1) \mid}{2} \end{cases} \quad u \le 0.5$$

$$\begin{cases} x_{3i} = \dfrac{p_{1i} + p_{2i}}{2} - \dfrac{1.481(p_{1i} - p_{2i}) \mid N(0,1) \mid}{2} \\ x_{4i} = \dfrac{p_{1i} + p_{2i}}{2} + \dfrac{1.481(p_{1i} - p_{2i}) \mid N(0,1) \mid}{2} \end{cases} \quad u > 0.5 \tag{19}$$

where $\mid N(0,1) \mid$ is normally distributed random variable and u is random number on (0, 1).

(2) Improvement of the variational operator

The variation operator is a background operator proposed for the background advantages and disadvantages of the algorithm. The variation operator in the genetic algorithm not only improves the local random search performance of the algorithm itself but also improves the speed of convergence while ensuring the diversity of the population [29]. Therefore, the mutation link in the algorithm is very important, and the comprehensive ability of the mutation operator has a large impact on the performance of the algorithm.

The mutation process of the NSGA-II algorithm uses polynomial mutation, which is close to a random search algorithm if the mutation probability is large, and fails to maintain population diversity if the mutation probability is small. The mutation probability of the adaptive mutation operator changes with the size of the fitness, retains the better adapted individuals, has a better ability to search for the best, and improves the stability and diversity of the population, making the Pareto frontier distribution better. Then:

$$P_m = \begin{cases} P_{m\max} - \dfrac{(P_{m\max} - P_{m\min})(f^* - f_{avg})}{f_{\max} - f_{avg}}, f^* \ge f_{avg} \\ P_{m\max}, f^* < f_{avg} \end{cases} \tag{20}$$

where $f_{\max}$ is maximum fitness value in the population, f_{avg} is average fitness value in the population per generation and f^* is the fitness value of the individual to be mutated.

When the individual fitness is less than the average fitness, the probability of individual variation is $P_{m\max}$ [30]. When the individual fitness is greater than or equal to the average fitness, the individual variation probability decreases with the increase of fitness.

MATLAB comes with the gamultiobj function of the algorithm used, is based on NSGA-II improvement of a multi-objective optimization algorithm (a variant of NSGA-II), which provides a good way to solve the multi-objective optimization problem under the MATLAB platform, this study is the use of this analytical tool to complete the optimization model solution. The model has 3 objective functions, 12 endogenous variables and 8 submodules. The control parameters of the genetic algorithm are set as follows: population size 90, maximum evolutionary generations 200, crossover probability 0.8, and mutation probability 0.1.

III. Calculation of industrial structure model based on input-output analysis

In this section, the influence coefficient and inductance coefficient in the input-output technique are used to analyze the degree of influence of a sector on the forward and backward sectors in a certain industrial chain, and to analyze the impact of the incremental decomposition of the total output of each sector in the ethnic minority areas on the industrial structure through the SDA structural analysis model.

The source of the experimental data in this section is the input-output table of ethnic minority regions in 2019 and 2024 published by the Bureau of Statistics. The input-output table in 2019 includes 139 sectors and the input-output table in 2024 includes 149 sectors. The changes in the influence of coefficients (backward coefficients) for each sector in minority regions are shown in Table 1. Overall, the influence coefficients for each sector in the minority regions do not change much from 2019 to 2024 and are overall around 1. The influence of coefficient of computers, audiovisual equipment, communication equipment, and cultural and office supplies is larger, indicating that each additional unit of production has a larger pulling effect on each of the other sectors. Overall, the influence of coefficients of those sectors with high technological content, cumbersome processing steps, and located at the back end of the industrial chain are generally higher. It is worth noting, however, that light industries such as knitting or crocheting and its products, textile clothing and apparel, and textile manufactured goods, which seem to have a low technological content, also made the list in 2024. This may be because China's textile industry has been continuously upgrading its industry over the past few years, which has led to its production of more complex and diversified products, and to the use of more advanced processes, machines, and raw materials than in the past. In terms of the amount of change, basically the sectors that originally had a high coefficient of influence have further improved over the past five years, such as broadcasting, computers, audio-visual equipment, and so on. The sectors that have declined are also those that already had a low impact factor, such as transportation, steel rolled products, ferrous metal ores, chemical fibers, and so on. It is worth noting that the catering sector, which seems to be a low-tech sector, has seen a rapid increase in the coefficient of influence over the past five years, although the current coefficient of influence is only 0.92563, but with the continuous development of express delivery in minority areas in the future, it is possible that the pulling power of catering for other industries will be further enhanced.

Table 1: The influence coefficient of the influence coefficients of various parts

Ranking	2019		2024		Varying Quantity	
	Department	Backward Coefficient	Department	Backward Coefficient	Department	Variable Value
1	Computer	1.3451	Computer	1.38922	Broadcasting And Television Equipment And Radar And Supporting Equipment	0.10934
2	Culture, Office Machinery	1.31365	Audio-Visual Equipment	1.38544	Catering	0.06656
3	Audio-Visual Equipment	1.31352	Communication Equipment	1.37916	Knitting Or Crochet Knitting And Its Products	0.08799
4	Communication Equipment	1.29573	Broadcasting And Television Equipment And Radar And Supporting Equipment	1.36719	Textile Manufactured Goods	0.0553
5	Chemical Fiber Products	1.29677	Culture, Office Machinery	1.34322	Computer	0.05488
6	Household Appliance	1.24497	Knitting Or Crochet Knitting And Its Products	1.34421	Leather, Fur, Feathers And Their Products	0.05852
7	Other Transportation Equipment	1.2677	Electronic Components	1.28773	Audio-Visual Equipment	0.07407
8	Electronic Components	1.26986	Other Electrical Machinery And Equipment	1.25168	Shoe	0.07723
9	Transmission And Control Equipment	1.27682	Household Appliance	1.26895	Communication Equipment	0.04645
10	Electrical Wiring, Cable, Cable And Electrical Equipment	1.28246	Textile Clothing	1.22089	Textile Clothing	0.0752

11	Other Electrical Machinery And Equipment	1.26671	Transmission And Control Equipment	1.25257	Metal Products	-0.04302
12	Motor	1.17299	Textile Manufactured Goods	1.23571	Cement, Lime And Gypsum	-0.09254
13	Battery	1.23358	Other Transportation Equipment	1.2353	Synthetic Material	-0.08567
14	Pumps, Valves, Compressors And Similar Machinery	1.26886	Motor	1.2277	Water Transport	-0.07932
15	Plastic Products	1.2099	Battery	1.20644	Waste Resources And Material Recycling Products	-0.08938
16	Broadcasting And Television Equipment And Radar And Supporting Equipment	1.23931	Material Handling Equipment	1.22811	Chemical Fiber Products	-0.07634
17	Coatings, Ink, Pigments And Similar Products	1.23423	Railway Transport And Urban Rail Transit Equipment	1.23781	Black Metal Mining Products	-0.08886
18	Material Handling Equipment	1.21043	Other Electronic Equipment	1.1918	Air Transport	-0.07076
19	Knitting Or Crochet Knitting And Its Products	1.21658	Auto Parts And Accessories	1.22936	Steel Rolling Product	-0.12891
20	Car	1.2165	Farm, Forest, Grazing And Fishing	1.23531	Multi-Modal Combined Transport, Transportation, Handling And Warehousing	-0.1326

The changes in the coefficient of inductivity (forward coefficient) for each sector in minority regions are shown in Table 2. The distribution of the coefficient of inductance is a bit more uneven compared to the coefficient of influence. Among them, the sector of housing construction stands out, ranking first in both 2019 and 2024, with the forward coefficient reaching as much as 2.46407 and 2.84325 in the two years, respectively. In addition to this, there are two other categories of sectors with high inductance coefficients. One category is industrial manufactured goods, such as steel rolling products, metal products, electronic components, cotton and chemical fiber textile and dyeing and finishing products, and other sectors. This sector is characterized by the fact that the products it produces are needed by many other industries, most typically various steel and metal products. A large number of semi-finished products or raw materials for other industries to promote the role is very obvious. There is also another group of service sectors, such as business services, wholesale and retail trade, road transportation, money and other financial services. These sectors produce very little of their own directly, but are mainly used to serve other industries, facilitating the development of other sectors, and as the economy continues to grow, the development of these sectors can be crucial to the improvement of the economic structure.

Table 2: The change of the induction degree of the various doors

Ranking	2019		2024		Varying Quantity	
	Department	Forward coefficient	Department	Forward coefficient	Department	Variable Value
1	House building	2.46407	House building	2.84325	Business service	0.41011
2	Electricity, heat production and supply	1.92873	Civil engineering	1.75263	House building	0.35621
3	Steel rolling product	1.93893	Business service	1.75918	Wholesale and retail	0.30701
4	Metal products	1.61611	Wholesale and retail	1.65253	Civil engineering	0.2895
5	Civil engineering	1.47797	Electricity, heat production and supply	1.64953	Telecommunications and information technology series	0.24786
6	Refined petroleum and nuclear fuel processing products	1.42259	Electronic components	1.5392	hygiene	0.24547
7	car	1.39846	Metal products	1.49676	Electronic components	0.19067
8	Wholesale and retail	1.37772	Road transport	1.47484	Communication equipment	0.1769
9	Business service	1.34305	Steel rolling product	1.45416	Real estate	0.17194
10	Cotton, chemical fiber, printing and dyeing processing products	1.33453	Monetary and other financial services	1.45332	Monetary and other financial services	0.16632
11	Electronic components	1.33001	car	1.42563	Metal products	-0.06621

12	Auto parts and accessories	1.31311	Telecommunications and information technology series	1.40303	Coal picking products	-0.11503
13	Road transport	1.3063	Auto parts and accessories	1.3669	Synthetic material	-0.08117
14	Basic chemical raw material	1.26814	hygiene	1.30049	Basic chemical raw material	-0.12371
15	Nonferrous metal and its alloys	1.24629	Real estate	1.26941	Nonferrous metal and its alloys	-0.1737
16	Monetary and other financial services	1.28415	Communication equipment	1.24577	Cotton, chemical fiber, printing and dyeing processing products	-0.17251
17	computer	1.25066	Public administration and social organization	1.24312	Steel, iron, iron alloy and casting	-0.26769
18	Plastic products	1.21234	computer	1.19993	Refined petroleum and nuclear fuel processing products	-0.27091
19	produce	1.18183	Pharmaceutical products	1.19652	Electricity, heat production and supply	-0.26221
20	Non-ferrous metal rolling processing product	1.16612	Cotton, chemical fiber, printing and dyeing processing products	1.2107	Steel rolling product	-0.43596

Finally, the SDA structural analysis model was used to decompose aggregate output into the effects of changes in economic technology and changes in final demand. The sectoral SDA model decomposition is shown in Table 3. The sector with the largest share of economic and technological changes is the cotton, chemical fiber, printing and dyeing products sector, which accounts for 319,635.35% of the total output. This extreme situation may be mainly due to the fact that the final demand side of the industry has not grown vigorously in the past few years, and industrial upgrading and technological progress have been the main goals of the industry's development. There are many other industrial sectors that show the same trend, such as processed feedstuffs, oil and gas extraction products, coal mining and washing products, steel rolling products, refined petroleum and nuclear fuel processing products, woolen textiles and dyeing and finishing products, and so on, which are mainly industrial sectors, and in the process of production, some pollution inevitably occurs, which puts a burden on the environment and human beings. In general, the number of sectors with economic and technological utility of less than 50% is high, totaling 125 sectors, so in general most sectors are still expanding under the influence of the increasing final demand in ethnic minority areas, while the sectors that can progress by economic and technological utility are in the minority. This also shows that there is still a lot of room for future improvement in the minority areas in terms of economic and technological improvement.

Table 3: Department SDA model

Department	Economic and technological change		Final demand change	
	Change value: 10,000 yuan	Percentage (%)	Change value: 10,000 yuan	Percentage (%)
Refractory material	-12655.623	-2365.95	13665798	2426.65
Nonferrous metal and its alloys	-100692362	-1789.65	106592331	1963.54
Coal processing	-22639445	-1109.65	23200953	1263.22
Electrical wiring, cable, cable and electrical equipment	-47986993	-963.65	53962581	1065.95
Fertilizer	-18015632	-556.62	21963688	645.36
Synthetic material	-46263955	-396.85	58695452	499.62
……	……	……	……	……

IV. Analysis of optimization results based on NSGA-II genetic algorithm

In this section, based on the established optimization model of industrial restructuring of ethnic minorities, the effect of industrial restructuring in ethnic minority areas is measured and analyzed in detail with the help of I-NSGA-II algorithm.

IV. A. Algorithm Performance Testing

After several iterative operations using the I-NSGA-II genetic algorithm, the Pareto front surface is obtained, and the Pareto front surface is shown in Fig. 3, where each point corresponds to 1 Pareto optimal solution, the distribution of individuals is more uniform, and the populations converge to a smaller range, and the boundaries are

clearly visible. In order to further evaluate the performance advantages and disadvantages of this algorithm, the validity of the solution is verified from 2 aspects: diversity and convergence. The average distance between individuals in each generation is shown in Figure 4. As can be seen from the figure, the average distance between individuals in each generation during the running process began to exist a large spacing, but in the generations close to the stop, the decline slowed down, and finally maintained at a more reasonable level, which maintains the diversity of the population. The level of stopping conditions is shown in Figure 5 (the horizontal coordinate values in the figure correspond to the percentage of the number of evolutionary generations in which the algorithm stops as a percentage of the maximum number of evolutionary generations). The figure indicates that the algorithm converged faster, and did not reach the predetermined maximum evolutionary algebra 200 at convergence, and the actual algebra to maximum algebra ratio at the time of stopping evolution was about 55%, which shows that the operation stops because the fitness value did not improve after the stopping algebra 100, indicating that the optimization was carried out more successfully.

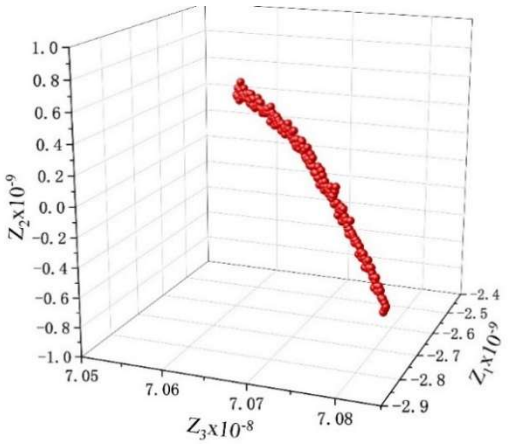

Figure 3: Pareto front side

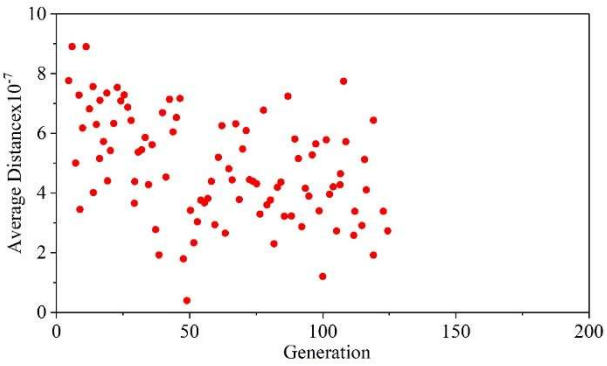

Figure 4: The average distance between individuals per generation

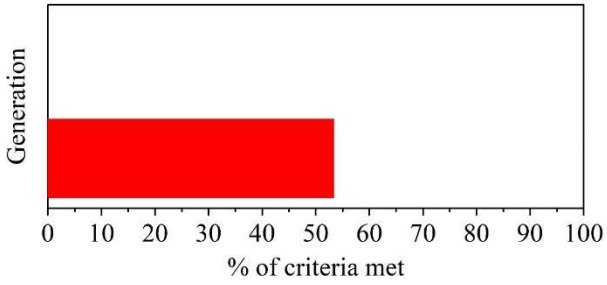

Figure 5: Stop condition

IV. B. Optimization scheme selection and comparison

In this paper, we do not differentiate the primary and secondary objective functions or assign weights, and we do not transform multi-objective into single-objective, but we directly find the Pareto optimal solution set of the multi-

objective optimization model based on the I-NSGA-II algorithm and obtain a series of corresponding objective function values. In order to eliminate the influence of the magnitude and order of magnitude of the objective values and to retain the information on the degree of difference, the homogenization method can be used first for the homogeneous treatment of the values, and then the rules can be set according to the needs, from which the scheme that meets the requirements can be selected. To examine the influence of different objectives on the optimization effect of industrial structure in minority areas, four optimization schemes are obtained:

(1) Growth-biased scheme, focusing on economic growth.

(2) Employment-biased scheme, focusing on employment promotion.

(3) Low-carbon biased scheme, which focuses on low-carbon development.

(4) Neutral program, which considers low carbon development, economic growth and employment promotion to be equally important.

It is undeniable that there are conflicts and contradictions between the multiple objectives of this optimization problem. Promoting growth will inevitably bring great pressure on emission reduction and consumption reduction at the same time, and industries with strong economic boost may not have the ability to absorb enough employment. Obviously, the adjustment of industrial structure is conducive to coordinating economic growth and full employment as much as possible, and how much this adjustment affects carbon emissions can be fully reflected in the simulation results of the model. 2024 actual data and the simulation results of the optimization scheme are shown in Table 4. Through overall comparison, in terms of the effect of industrial structure adjustment, the biased and neutral scenarios are the best and the growth-biased scenario is the weakest, and the direction of the adjustment of the proportion of the same industry in each scenario is basically the same, only the magnitude varies: among them, the changes in the proportion of the industrial and wholesale, retail, accommodation and catering industries are the most significant, with the former dropping by more than 10 percentage points and the latter rising by about 7 percentage points. The shares of agriculture, forestry, animal husbandry and fishery, construction, transportation, storage and postal services have increased somewhat, from the actual 5.96%, 7.65% and 3.86% to 7.06%, 10.65% and 6.95% respectively in the low-carbon biased scenario. Rationally compressing the scale of industry and expanding the wholesale, retail, accommodation and catering industry are effective ways to ensure low-carbon development. In addition, although the transportation, storage and postal services industry and the construction industry are characterized by high energy consumption and high emissions, they have not been downsized in order to ensure economic growth and employment stability but rather expanded to a certain extent within the scope permitted by the achievement of the basic low-carbon goal.

Table 4: Simulation result

	2024 actual data		Low carbon bias scheme		Growth bias scheme		Employment bias scheme		Neutral scheme	
	Output value/yuan	Percentage (%)	Output value/yuan	Percentage (%)	Output value/yuan	Percentage (%)	Output value/yuan	Percentage (%)	Output value/yuan	Percentage (%)
Fishery	488960000	5.96	579055361	7.06	567006085	6.95	562063892	6.98	570745692	6.95
Industry	5149539122	63.94	4095063052	50.26	4098465602	50.32	4112495822	50.22	4098399105	50.26
Construction industry	627322963	7.65	856992132	10.65	876632132	10.45	836469542	10.62	859802361	10.65
Transportation and warehousing	331509844	3.86	554095136	6.95	562098724	6.92	559902875	6.85	555185362	6.98
Wholesale retail accommodation	446251963	5.49	1006293715	12.36	1005675429	12.35	1002265985	12.26	1003125061	12.35
Other industries	1163052963	15.64	1098065591	13.65	1098523654	13.45	1115492232	13.65	1103625190	13.55
Total production / 10,000 yuan	8189592622		8189592622		8189592622		8189592622		8189592622	
Carbon emissions/tons	70792		70596		70795		70639		70785	
GDP/ 10,000 yuan	2495299412		2496299063		2563021849		2659482351		2658978443	
The number of employees/people	11532		12952		11936		11963		11942	

Obviously, compared with the actual value, the optimization results of the various programs can basically meet the requirements of maintaining growth and promoting employment, only the degree of goal achievement is not the

same, mainly depends on the different footholds and points of emphasis when choosing the program, choosing the lowest carbon emissions, it is difficult to stimulate the growth momentum of the most adequate, low-carbon biased optimization program so that the carbon emissions were reduced to 705,960,000t, a reduction of about 2 million tons, the total GDP, but basically unchanged. The total GDP remains largely unchanged. In conclusion, industrial restructuring will play a certain low-carbon role, but under the premise of economic growth and employment stability, the full play of this low-carbon effect is limited, because as the optimization model of the three objectives, control carbon emissions, economic growth and promote employment are interdependent and constraints on each other: economic growth requires energy and power, under the premise of a certain level of technology, low-carbon development and the requirement to compress the extraction and consumption of fossil energy, which restricts the use of fossil energy. Under a certain level of technology, low-carbon development requires the compression of fossil energy extraction and consumption, which limits the growth rate of the economy and puts pressure on employment. In order to alleviate and reconcile these contradictions, the trade-off between the three becomes inevitable, and the optimization of industrial structure can make it reach the Pareto optimal state.

V. Optimizing the path of upgrading the industrial structure of ethnic minority regions

From the above analysis, the industrial development of ethnic minority regions is relatively backward, so this section further explores the optimization path of industrial structure upgrading in ethnic minority regions.

V. A. Strengthening the foundations and vigorously developing efficient agriculture

(1) Promoting modernized agricultural development

With the changes in the market's consumption demand for agricultural products, ethnic minority regions should vigorously develop high-quality, branded agricultural products, reduce ineffective supply, and push forward the agricultural supply to realize the transformation from low-end to high-end.

(2) Promote regional agricultural cooperation

Minority regions should strengthen agricultural cooperation with midstream and downstream provinces and cities, drive the development of affiliated warehousing and logistics industries, promote the facilitation of regional trade and circulation of agricultural products, and form a virtuous cycle of regional agricultural production and supply.

V. B. Reforming traditional industries and laying out new industries

(1) Accelerating the transformation of traditional industries

Some ethnic minority regions are currently backward in industry, and the problems of “high investment, high pollution and low efficiency” brought by traditional industries need to be solved urgently. The construction and improvement of innovation centers should be strengthened, capital and talents between regions should be fully utilized, and technological transformation and upgrading of traditional technologies should be carried out by relying on the platforms of “industry-university-research” and scientific and technological innovation. We should strengthen the construction and improvement of innovation centers, make full use of capital and talents between regions, and carry out technological transformation and upgrading of traditional technologies by relying on the platform of “industry-university-research” and science and technology innovation.

(2) Undertake and introduce high-tech industries

Relying on the innovation platform, the introduction of high-tech industries can fundamentally change the production mode and optimize the structure of industries. Government departments should do a good job of strategic planning for the industry, give full play to the resource advantages of the industry, and realize the balanced development of the industry.

V. C. Accelerating the development of the service industry and promoting the upgrading of the consumption structure

(1) Improving the policy system and supporting the development of the industry

Coordinate the development of the service industry, actively implement national preferential and supportive policies, improve the supporting and service system, and guide social capital into the corresponding fields with pilot demonstrations. For the advantageous transformation category of industries, the productive service industry should be given financial subsidies, tax incentives and credit support and other incentives.

(2) Investing in the development of emerging service industries

Take the emerging service industry as a breakthrough, make up for the short board of the service industry development in the province that cannot meet the current demand of manufacturing industry development, and play the role of e-commerce, modern logistics, modern financial and scientific and technological services, and other productive service industry and high-end manufacturing industry to drive each other according to local conditions.

Optimize the existing productive service industry, give priority to the development of R&D and design, technology incubation, inspection and testing, business consulting and software outsourcing and other representative productive service industries, and accelerate the integration and development of modern service industry and high-end manufacturing industry.

VI. Conclusion

Under the background of digital economy driving, the problem of industrial structure upgrading in ethnic minority areas is receiving attention from many scholars. In this paper, multi-objective evolutionary algorithm optimization of industrial structure upgrading in minority regions is realized based on input-output analysis and multi-objective genetic algorithm with improved genetic operation. The article draws the following conclusions:

In the analysis of the change of the coefficient of inductance of each sector in ethnic minority areas, the house construction sector ranks first in both 2019 and 2024, with the forward coefficient reaching as much as 2.46407 and 2.84325 in the two years, respectively. In addition to this, the industrial manufactured goods and services sectors have high inductance coefficients. With the continuous development of the economy, the development of these sectors is crucial for the improvement of the economic structure of minority regions.

The optimization path for upgrading the industrial structure of ethnic minority regions can be carried out in several aspects, such as strengthening basic agriculture, vigorously developing efficient agriculture, laying out emerging agriculture and promoting the upgrading of consumption structure.

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