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Research article

Factor mismatch measurement of resource-based cities: Evidence from all-round optimization total factor productivity decomposition framework

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ABSTRACT

In-depth analysis of the factors affecting the transformation of resource-based cities can provide effective support for the transformation and development of resource-dependent regions. How to comprehensively identify the factors affecting the transformation of resource-based cities is a complex problem. This study starts from the total factor productivity model and focuses on the two core basic factors that affect the transformation process of cities reliant on resources. Economic benefits and energy efficiency, respectively, from the economic benefit analysis framework and energy efficiency analysis framework for reconstruction, the two frameworks are combined with the use of distorted prices of resource elements to solve the problem that the synergistic effect of economic benefits and energy efficiency can not be measured. In order to quantitatively analyze the factors that affect the development efficiency of cities reliant on resources under the single or synergistic effect of the comprehensive framework, this study optimizes the directional distance function from three perspectives: exogenous weight, direction vector endogeneity, and absolute distance transformation relative distance, thus achieving an accurate assessment transformation efficiency of cities reliant on resources. Considering the impact of the new coronavirus epidemic, this study only selected the data of resource-based cities from 2003 to 2018, and found through model calculation that the impact on the transformation of cities reliant on resources: (1) Labor mismatch is mainly achieved by affecting the structure about the production of resource-based enterprises and industrial human resources; (2) Capital mismatch is mainly realized by affecting the production of resource-based enterprises; (3) Energy mismatch is mainly achieved by affecting high energy consumption enterprises and low production technology level enterprises. Further research shows that the main objects of these factors are the four parts of production technology level, energy consumption, total factor productivity and industrial structure. Through these contents, they affect environmental efficiency and deeply affect the transformation process of resource-based cities.

1. Introduction

Resource-based cities did have made great contributions to the process of urban economic development [1]. However, the development of resource-based cities depends on limited and non-renewable natural resources, they often face the depletion of

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resources, and eventually have to face a series of problems that caused by the depletion of resources. At the same time, they are facing challenges related to limited industrialization, struggles with industrial transition, and an excessive dependence on a singular economic framework. This is generally called the " resource curse " [2] in the academic community. The main bottleneck of the development of cities reliant on resources has been transformed into unbalanced industrial structure, excess supply of low-end energy and low efficiency of factor utilization [3], and these effects revolve around " factor misallocation".

Due to the mismatch of factors in the cities reliant on resources, a series of negative effects have been produced. For example, with the gradual depletion of resources in resource-based cities, the economic role of major resource-based industries in cities has been greatly weakened, and urban economic development has stagnated or even become negative [4–6]. Urban resources are excessively concentrated in mining, which leads to a decline in the efficiency of resource-based enterprises, an increase in urban unemployment and a slowdown in economic growth [7,8]. Even due to the lack of attention to environmental factors in the development of cities reliant on resources, air pollution, water pollution, and land pollution in the environment have been further aggravated [9–12]. Additionally, environmental degradation further inhibits the inflow of population. It reduces the retention of talents and inhibits the development of resource-based cities again [13–15]. The overall can be summarized as three points, (1) high resource abundance. It will produce resource transfer effect, expenditure effect, relative price effect and so on, which will inhibit the development of industrial industry [16,17] and the growth of resource-based cities. (2) The weakening of the political system. Encourage corruption and rent-seeking, exacerbating the difficulty of resource-based city development [18,19]. (3) The squeezing effect of resource abundance. Abundant natural resources will crowd out investors' investment in human capital, high-tech and other factors, which will inhibit the gathering of human capital and curb the development of scientific and technological innovation capabilities in the industry [20,21]. As a country with a comprehensive variety in resource-based cities [22], China has rich resource reserves, and its import and export resources can be used in various production activities at home and abroad. Therefore, from China's perspective, it is great significance to study the misallocation of cities reliant on resources. Effectively assessing the impact of misallocation of cities reliant on resources and systematically measuring the role of factor allocation in the progression of resource-based cities can assist cities reliant on resources to achieve urban transformation and promote the development of the overall economy.

1.1. Literature review

For the research of cities reliant on resources, Auty [23] first proposed the ' resource curse ' hypothesis, which saids that from the perspective of regional economic development, resource abundance is not the gospel of urban development, but the curse. Since then, the impact of factor endowments brought about by the natural resources on regional economic development and its potential effects have aroused extensive discussion among scholars. Most research has been carried out on the more basic problems that cities reliant on resources faced ——how to achieve the sustainable economic transformation and get rid of the city's dependence on the resource-based industrial chain [24]. With the completion of industrialization, the main driving force for the progression of urban economy is industrial production. The sustainable development of economy mainly depends on the innovation and development of industrial technology [25], the redistribution of production factors and improvement of the use process [26]. Among them, industrial technology innovation belongs to the vertical development direction, the redistribution and use of production factors belongs to the horizontal integration direction. From a vertical perspective scholars believe that technological innovation can reduce the reliance of resource-based industries on resources [27–29]. From a horizontal perspective, scholars believe that the optimization of the use structure of factors can enhance the efficiency of production and promote the transformation of resource-based cities [30–32].

Although the economy of resource-based cities has basically achieved sustainable development, the stubborn problems of resource-based industries in the past still exist [33,34]. These problems mainly focus on ' ecological environment ' and ' social construction '. For these problems, the current general research direction revolves around the perspective of ' green transformation ' [35,36]. Scholars believe that the dilemma of cities reliant on resources can be solved through the green transformation of society, such as improving the ecological environment [37], resource utilization [38], and introducing relevant environmental regulations [39]. At present, strategic innovation in comprehensive social construction, economic sustainability and coordinated development of ecological environment has become a necessary condition for the transformation of cities reliant on resources. Under this condition [40], proposed that in order to realize the transformation of cities reliant on resources, a set of perfect system compensation mechanism should be established first. The main means of compensation is to increase the government 's financial transfer, in order to help the exhausted resource-dependent cities achieve independent development. Around this idea, scholars conducted in-depth research from the perspectives of environmental compensation [41], re-employment compensation [42], production value chain compensation [43], and using of renewable energy to compensate for the impact of fossil energy on production and industrial restructuring [44].

Generally speaking, for the application of the measurement method of the transformation level. One is the method of manually constructing the index system. Chen et al. [45] devised an extensive index framework that encompasses aspects of economic restructuring, societal advancement, and ecological enhancement to assess the degree of transformation in cities dependent on resources. Zhang et al. [46] utilize a tri-tiered SBM-DEA approach and the global Malmquist index, the variations in green total factor productivity (GTFP) within China's chemical subindustries were evaluated. Additionally, the difference-in-differences (DID) technique was employed to investigate the effects of the "Air Pollution Prevention and Control Action Plan" (APCP), initiated in 2013, on the GTFP of China's chemical sector. Zhao et al. [47] based on the " resource curse " theory, an econometric model is constructed. It is found that the reasons for Jiaozuo 's transformation from rise to success lie in the comprehensive resource endowment. Xie et al. [48] employed the dynamic panel generalized method of moments (GMM) as an estimation technique to examine the influence of technological innovation and transfer on the eco-friendly transition within industries reliant on natural resources, anchored in the framework of the production function. Dai et al. [49] uses Kolmogorov entropy to construct five index layers, selects 14 specific indicators, measuring the industrial structure and transformation level of cities reliant on resources by using Pierce coefficient and transfer entropy. Li et al. [50] under the multi-industry competition equilibrium model, by introducing the distortion tax of factor input friction, the factor price distortion index is defined to measure the mismatch of factors, and the optimal allocation conditions of each factor are obtained by constructing the standardization index.

The other is to use computer direct simulation to construct the model. Tan et al. [51] have crafted a system dynamics framework that integrates four key domains: economy, society, environment, and resources, which they apply in assessing the sustainability of urban development. Yao et al. [52] use the system dynamics method to establish an industrial innovation ecosystem model of regional commercial centers to measure the evolution of industrial innovation ecosystems in cities reliant on resources. From the perspective of ecology, Xing et al. [53] studied how to use the three types of mechanisms to promote the sustainable economic development of resource-based industries by using the Lotak-Waltera model combined with the system dynamics model. Zhao & Zhen [54] constructed a support vector machine (SVM) model for the categorization and prediction of the level of coordinated development within regional ecological-environmental systems. Guan et al. [55] constructed a dynamic system dynamics and geographic information system (SD-GIS) dynamic combination method, evaluating the urban development of Chongqing city in China suffering from resource depletion and environmental degradation.

According to the existing research, it can be found that from a macro perspective, the method of directly constructing the index system for measurement is highly subjective, which will greatly affect the results of the measurement, and the results of the measurement by direct calculation of the computer are agnostic within a certain range. Therefore, the construction of quantitative or semi-quantitative decision support system may help to select a set of appropriate indicators to help cities achieve effective assessment of sustainable development [56]. From the micro perspective, few scholars have integrated the economy, resources and ecology of urban transformation into a unified analytical framework for research. Most of them only use the system dynamics method or construct the index system to measure the influencing factors of the development of cities reliant on resources in order to simplify the calculation. The transformation of cities reliant on resources is not only to solve the problems left over by over-exploitation, but also to innovate and apply energy-saving and clean energy utilization [57]. Therefore, this study further constructs an optimized overall measurement framework.

The shift in cities reliant on resources aims to achieve a sustainable transition of their urban economies [58] and to foster a harmonious progression of the environmental [59,60]. Among them, the economic growth of cities reliant on natural resources is inseparable from the support of basic resources such as energy, and also requires the modernization and enhancement of associated industries and technologies [61,62]. Generally, the metamorphosis of cities founded on natural resources is to realize the reasonable input of production factors in relevant economies. However, there are still different economic growth performances among different economies. In addition to differences in factor input, many studies attribute this growth and per capita income differences to different total factor productivity (TFP) among economies. Solow 's neoclassical growth model, as a classical analytical framework, examines the link between total factor productivity and production output. At its core, economic growth is predicated on industrial advancement. The changes in total factor productivity and output brought by factor misallocation to specific industries will eventually be reflected in the overall performance of the economy.

However, the existing framework can only evaluate the impact of input on output in the positive direction, but cannot measure the performance of the theoretical structure through the perspective of application in the negative direction. So it is impossible to comprehensively evaluate the determinants influencing the transformation of the cities reliant on resources from a systematic perspective. Therefore, this study draws on Solow 's growth accounting framework, from the perspective of the industry, integrates into the original energy efficiency analysis framework, and proposes an analysis framework to explore how the misallocation of factors among industries affects total factor productivity and causes output losses. At the same time, based on the optimized Direction distance function (DDF) model, the transformation efficiency of resource-based cities is measured, and finally the system framework for measuring and analyzing the transformation efficiency of resource-based cities is realized.

Based on the previous research, this research takes capital, labor and energy as resource elements from the perspective of resource-based industries. Based on the optimized TPF decomposition theory, it integrates into the original energy efficiency analysis framework, and uses the TFP decomposition method. From the standpoint of factor mismatch, the overall research object and the impact effect between the decomposed industries are systematically constructed. At the same time, the DDF model is optimized by introducing exogenous weights and direction vectors. Finally, the urban transformation efficiency is calculated based on the optimized DDF model, and the robustness, endogeneity and heterogeneity test are carried out in conjunction with the analysis framework. The TPF decomposition part refers to the research of Syrquin [63], that is, the increase of factor input and the total change of total factor productivity (TFPG) lead to the increase of total economic output. At the same time, the improvement of TFPG is further decomposed: (1) arising from advancements in the total factor productivity within each industry, (2) the allocation effect brought by the efficiency improvement caused by the flow and reconfiguration of factors among industries.

Based on this decomposition method, this study further decomposes the allocation effect into two parts, (1) Only the change brought by the change of output share, its economic meaning is the impact of the reallocation of factors among industries on 'aggregation technology. (2) Changes caused by changes in the degree of factor price distortions in various industries. Distorted prices make factors not optimally allocated among industries, so as long as the degree of price distortion decreases, factors will re-flow to approach the optimal allocation, thereby increasing TFP and total economic output. In order to gauge the variance between the current factor prices and the ideal distribution, on the basis of this decomposition framework, this study also constructs a gap measurement model between actual output and output when resources are effectively allocated (without factor allocation distortion) from the direction of industry production. Using this measurement model, we can effectively find the impact of price distortions on production efficiency. Because the above framework can only analyze the impact of factor misallocation on production efficiency, and another dilemma faced by the transformation of cities reliant on resources is the optimization of energy efficiency. In order to delve deeper into the influence of factor misallocation on the energy efficiency of resource-centered citiescities reliant on resources, this research uses Cobb-Douglas function to construct an analysis framework of energy efficiency from the perspective of input factors under the condition of balanced market competition, and finally realizes the systematic measurement framework of the impact of factor misallocation on the transition of cities reliant on resources.

In the part of optimizing the DDF model to delve the transformation efficiency, this study further endeavors to enhance in three key areas:(1) Endogenizing the direction vector. The model dynamically determines decision variables, enhancing realism over predetermined settings. (2) Converting absolute distances to relative distances. Each relaxation amount is divided by the actual dimension value, yielding varying relative distances across dimensions. (3) Incorporating exogenous weights. Diverse weight combinations signify distinct constraints and objectives, highlighting the varying significance of each dimension.

There are four innovations in this study. (1) Optimize the TFPG decomposition framework, construct a more detailed calculation formula, and realize the calculation of factor price distortion and industrial output share. (2) From the perspective of the optimal allocation of elements in TFPG decomposition lines, the gap estimation formula of factor misallocation and rational allocation of elements is established. (3) A novel approach is devised to assess the energy efficiency crucial for the progress of cities reliant on resources. The above framework is systematically integrated by using the influence of the overall interaction of factors (price distortion). (4) The DDF model is optimized by introducing exogenous weights and direction vector endogeneity.

2. Materials and methods

2.1. Materials

In order to accurately measure the impact of various factors on the transformation of resource-based cities, considering the serious impact of the new coronavirus epidemic, this study only selected the data before the outbreak of the epidemic, that is, the data before 2019, and the final data obtained are the prefecture-level cities's data of China from 2005 to 2018. Among them, the data of the three most important factors affecting the transformation of cities reliant on resources are labor factor, capital factor and energy factor. At the same time, the two outputs closely related to output are expected output and undesired output. The targeted output is GDP, while the unintended outputs are a range of pollution emissions. The specific situation is as follows:

Labor input: In this study, the average employee count in each city is selected as labor input.

Capital input: In this research, fixed asset investment serves as the capital investment, with the perpetual inventory method employed to gauge the real capital stock. Energy input: Considering that there is a precise computer data collection system for power resource consumption, this study chooses power energy as energy input.

Expected output: In order to systematically measure the role of economic effects in the transition of cities reliant on resources, the actual GDP is selected as the expected output in this study.

Unexpected outputs: In the part of unexpected output, this research selects the discharge of industrial wastewater, sulfur dioxide, and dust from industrial activities is considered as unintended output. However, under the DEA framework, the convergence rate will be very low if many pollutants are included as unexpected outputs, which will affect the calculation and make it more difficult to delve the environmental efficiency in the environment-friendly direction. So in this research, the entropy method was used to deal with the non-dimensionality of the pollutant data, and the weight coefficient of each year of the pollutant was calculated, considering the numerical proportion of the three pollutants annually, the comparative comprehensive pollution emission index (based on 2003) was obtained.

Other additional auxiliary measurement data are as follows:

The sample of cities reliant on resources is derived from the roster of resource-based cities delineated in the "National Sustainable Development Plan for resource-based cities (2013–2020)" (hereafter referred to as the "Plan"), as issued by the Chinese government. Pu'er City, beset by significant data loss, is excluded from this list, resulting in a total of 114 resource-based cities. In the case of non-resource-based cities, this study excluded four centrally-administered municipalities—Beijing, Tianjin, Shanghai, and Chongqing—to mitigate discrepancies in city volumes., on the other hand, it eliminated Chaohu City, Bijie City, Tongren City, Sansha City, Haikou City, Sanya City, Lhasa City, 7 prefecture-level cities with revocation and upgrading, and serious lack of data. Therefore, this study finally selected 278 prefecture-level cities as the overall sample, including 114 cities reliant on resources and 164 cities not reliant on resourcescities reliant on resources. In addition, because the energy input index of the whole society 's electricity consumption is only the data at the municipal district level, in order to unify the caliber and maintain the accuracy of energy mismatch, this research uses the data at the municipal district level. According to the geographical location, 114 cities will be divided into four categories: eastern (20), central (37), western (36),northeastern (21). According to the division of resource-dependent cities in ' planning ', it will be divided into four categories: growth type (14), mature type (62), recession type (23), regeneration type (15).

Due to statistical bias and other reasons, the original data may have abnormal observations, which will affect the final findings from the regression analysis. In order to take into account the consistency of the analysis before and after, and to reduce the information loss as much as possible, this study has carried out the tail reduction processing on the data of the degree of factor misallocation. According to the calculation characteristics of the degree of factor misallocation, the outliers are selected at the 90 % quantile on the right side, and the values of the 90 % quantile are assigned to the numbers greater than the 90 % quantile, so as to avoid the interference of outliers on the basis of retaining the original data sample size. After dealing with extreme values, the main indicators of this study and the statistical descriptions of key variables are described in Table 1.

The majority of the data utilized in this study are sourced from various publications, including the "National Sustainable

Development Plan for resource-based cities (2013–2020)", "China city statistical yearbook", "China statistical yearbook", "China regional economic statistical yearbook", as well as statistical yearbooks of different provinces and cities. Additionally, statistical bulletins on national economic and social development from various cities contribute to the dataset. For more specific data referenced in this research, interested parties may request access from the corresponding author.

2.2. The model of factor misallocation affecting output efficiency

2.2.1. Model assumptions

Syrquin 's (1986) study first decomposed the growth of total factor productivity (TFP) into two parts, one part came from the growth of industry TFP, and the other came from the allocation effect of factors. Aoki (2012) [64] further examined the factor mismatch between industries, and used the complete competition model to describe capital misallocation in the form of labor and capital tax. Therefore, this study combines the analytical framework of Aoki and Syrquin and Chen Yongwei (2011) [65], and constructs it as a theoretical framework to explore how labor and capital mismatches affect industry and total economic output in multi-sectors of resource-dependent cities.

It is assumed that identical industries exhibit equivalent production functions, so that the production problem of the industry can be simplified to a production issue of a representative enterprise, while different industries are assumed to have different production functions. The three of capital (K), labor (L), and energy (E) constitutes the essential components for enterprise production., and all enterprises in the market are price recipients and accept the price given by the market. Referring to the practice of Hsieh and Klenow (2009) [66], a distorted price is given to the enterprises in industry *i*, and the distortion is embodied in the ad valorem tax: the price of capital is $(1+\tau_{K_i})p_K$, the price of labor force is $(1+\tau_{L_i})\,p_L$, and the price of energy is $(1+\tau_{E_i})\,p_E$, where p_K, p_L, p_E is the price corresponding to the capital, labor and energy elements when there is no distortion of factor allocation under perfect competition conditions, and $\tau_{K_i}, \tau_{L_i}, \tau_{E_i}$ respectively, represents the distortion ' tax ' of each factor faced by enterprises in industry *i*.

Assuming that the representative enterprise of industry *i* has a C-D production function, the production function of the representative enterprise of industry *i* is:

$$Y_i = F_i(A_i, K_i, L_i, E_i) = A_i K_i^{\beta_{Ki}} L_i^{\beta_{Li}} E_i^{\beta_{Ei}} \tag{1}$$

Here represents the output K_i、 L_i、 E_i respectively, the amount of capital, labor and energy input. The parameters β_{K_i}、 β_{L_i}、 β_{E_i} represent the ratio of contribution about the three categories of factors influencing output. Assume $\beta_{K_i} + \beta_{L_i} + \beta_{E_i} = 1$, that is, the production function demonstrates constant returns to scale.

The pursuit of profit maximization is the goal of all decisions and behaviors of representative enterprises. At the same time, because all firms within the industry operate under an identical production function, the aggregate production function retains the nature of constant returns to scale. At this time, assuming that the price of the product market is not distorted, and the total capital factor input (K), labor factor input (L), and energy factor input (E) in each period are externally predetermined, the profit function of the enterprise is:

$$\pi_i = p_{Yi} Y_i - (1+\tau_{Ki}) p_K K_i - (1+\tau_{Li}) p_L L_i - (1+\tau_{Ei}) p_E E_i \tag{2}$$

Among them p_{Y_i} represents the product price of the industry. *i*. Then the first-order condition of profit maximization is:

$$\beta_{K_i} p_{Y_i} A_i \bullet K_i^{\beta_{K_i}-1} L_i^{\beta_{L_i}} E_i^{\beta_{E_i}} = (1+\tau_{K_i}) p_K \tag{3}$$

$$\beta_{L_i} p_{Y_i} A_i \bullet K_i^{\beta_{K_i}} L_i^{\beta_{L_i}-1} E_i^{\beta_{E_i}} = (1+\tau_{L_i}) p_L \tag{4}$$

Table 1
Statistical descriptions of key variables.

Variable	Sign	Sample Size	Mean	Std.
Transformation Efficiency	tranf	1596	0.504	0.219
	trane	1596	0.466	0.238
Energy Efficiency	e	1596	0.627	0.247
Output Efficiency	y	1596	0.433	0.413
Environmental Efficiency	env	1596	0.337	0.264
Capital Mismatch Degree	misk	1596	1.333	1.443
Labor Mismatch Degree	misl	1596	2.123	2.321
Energy Mismatch Degree	mise	1596	5.749	7.864
Capital Mismatch Direction	dk	1596	1.787	0.410
Labor Mismatch Direction	dl	1596	1.312	0.463
Energy Mismatch Direction	de	1596	1.590	0.492
Government Interference	dis	1596	0.246	0.155
Trade Dependence	trade	1596	0.013	0.023
Car Wwnership (one hundred thousand)	car	1548	2.328	2.505
Industrial Structure	ind	1596	0.073	0.083
R&D investment	rd	1596	0.008	0.024

$$\beta_{E_i} p_{Y_i} A_i \bullet K_i^{\beta_{K_i}} L_i^{\beta_{L_i}} E_i^{\beta_{E_i}-1} = (1+\tau_{E_i}) p_E \tag{5}$$

2.2.2. *Aggregate production function*

Assuming that the output price produced by each industry is 1, it determines the total social and economic output Y that can be expressed by valuation. The expression is:

$$Y = F(Y_1, \cdots, Y_N) \tag{6}$$

According to the above assumptions, F (·) satisfies the constant returns to scale, so:

$$\partial Y / \partial Y_i = p_i \tag{7}$$

According to Euler 's theorem, the sum of the output values of individual industries within society directly corresponds to the total economic output value, that is:

$$Y = \sum_{i=1}^{N} p_i Y_i \tag{8}$$

2.2.3. *Resource constraints*

It is assumed that the input of capital(K), labor(L), energy(E) and other factors is fixed and exogenous in each investigation period, so the expression of resource constraints is as follows:

$$\sum_{i=1}^{N} K_i = K, \sum_{i=1}^{N} L_i = L, \sum_{i=1}^{N} E_i = E \tag{9}$$

2.2.4. *Competitive equilibrium*

When the competitive equilibrium is reached, the proportion of the total output value of any industry i to the overall output value of the whole society is expressed as its share, that is $s_i = p_i Y_i / Y$, the weighted factor contribution value is considered $\widetilde{\beta_K} = \sum_{i=1}^{N} s_i \beta_{K_i}$、 $\widetilde{\beta_L} = \sum_{i=1}^{N} s_i \beta_{L_i}$、 $\widetilde{\beta_E} = \sum_{i=1}^{N} s_i \beta_{E_i}$. The analysis shows that the industry-specific distortion coefficients for capital, labor, and energy under equilibrium conditions can be expressed as:

$$\widehat{\lambda}_{Ki} = \left(\frac{s_i \beta_{Ki}}{\widetilde{\beta}_K}\right)^{-1} \frac{K_i}{K} \tag{10}$$

$$\widehat{\lambda}_{Li} = \left(\frac{s_i \beta_{Li}}{\widetilde{\beta}_L}\right)^{-1} \frac{L_i}{L} \tag{11}$$

$$\widehat{\lambda}_{Ei} = \left(\frac{s_i \beta_{Ei}}{\widetilde{\beta}_E}\right)^{-1} \frac{E_i}{E} \tag{12}$$

This study shows the factor price distortion coefficient through equations (10)–(12), and links the factor use cost distortion with the factor mismatch.

2.2.5. *Factor price distortions and output*

After the competitive equilibrium is achieved, the relationship between output and factor price distortion is further constructed. From Equations (1) and (10-12), the output of industry i under competitive equilibrium can be expressed as:

$$Y_i = A_i \left[\frac{s_i \beta_{K_i}}{\widetilde{\beta}_K} \widehat{\lambda}_{K_i} K\right]^{\beta_{K_i}} \left[\frac{s_i \beta_{L_i}}{\widetilde{\beta}_L} \widehat{\lambda}_{L_i} L\right]^{\beta_{L_i}} \left[\frac{s_i \beta_{E_i}}{\widetilde{\beta}_E} \widehat{\lambda}_{E_i} E\right]^{\beta_{E_i}} \tag{13}$$

Take logarithmic deformation, there is:

$$\ln Y_i = \ln A_i + \ln\left[s_i \left(\frac{\beta_{K_i}}{\widetilde{\beta}_K}\right)^{\beta_{K_i}} \left(\frac{\beta_{L_i}}{\widetilde{\beta}_L}\right)^{\beta_{L_i}} \left(\frac{\beta_{E_i}}{\widetilde{\beta}_E}\right)^{\beta_{E_i}}\right] + \left[(\beta_{K_i} \ln \widehat{\lambda}_{K_i}) + (\beta_{L_i} \ln \widehat{\lambda}_{L_i}) + (\beta_{E_i} \ln \widehat{\lambda}_{E_i})\right] + (\beta_{K_i} \ln K + \beta_{L_i} \ln L + \beta_{E_i} \ln E) \tag{14}$$

From Equation (14), the output level of industry i relies not only on the quantity of factors use and industry productivity, but also on the distortion about the cost of factor use in the industry. Therefore, any change in the distortion of factor use cost will directly affect the output level when the number of factors and industry productivity are kept constant. On this basis, this study will further discuss the effect.

2.2.6. *Decomposition of output*

Syrquin promoted Solow's growth accounting framework. This study expands the decomposition of output changes based on its framework. In Syrquin 's initial study, the rise in factor inputs alongside the total factor productivity change (TFPG) contributed to an escalation in total economic output, and the increase in TFPG can be further decomposed: (1) It is caused by the improvement of the TFP of each industry itself, (2) It is the allocation effect caused by the efficiency improvement caused by the flow of factors between industries and the reconfiguration. Since the relative distortion of factor prices has been set and deduced above, the allocation effect can continue to be decomposed, that is, the allocation effect includes the contribution of only share changes and the contribution of factor price distortion changes.

In the specific derivation, assuming that the entire economy has achieved equilibrium in any period, the difference in the total output value of the economy from period t to t + 1 is $\Delta ln\ Y_t = ln\ Y_{t+1} - ln\ Y_t$, where, Δ is the difference operator, that is $\Delta x_t = x_{t+1} - x_t$, $\Delta \ln Y_t$ can be decomposed into:

$$\Delta \ln Y_t = \sum_{i=1}^{N} s_{it} \Delta \ln TFP_{it} + \sum_{i=1}^{N} S_{it} \ln\left[\left(\frac{S_{it+1}}{S_{it}}\right) \Big/ \left(\frac{(\widetilde{\beta}_{Kt+1})^{\beta_K} (\widetilde{\beta}_{Lt+1})^{\beta_L} (\widetilde{\beta}_{Et+1})^{\beta_E}}{(\widetilde{\beta}_{Kt})^{\beta_K} (\widetilde{\beta}_{Lt})^{\beta_L} (\widetilde{\beta}_{Et})^{\beta_E}}\right)\right] + \sum_{i=1}^{N} s_{it}\left(\beta_{K_i} \Delta \ln \widehat{\lambda}_{Kit} + \beta_{L_i} \Delta \ln \widehat{\lambda}_{Lit} + \beta_{E_i} \Delta \ln \widehat{\lambda}_{Eit}\right) + \sum_{i=1}^{N} s_{it}\left(\beta_{K_i} \Delta \ln K_t + \beta_{L_i} \Delta \ln L_t + \beta_{E_i} \Delta \ln E_t\right) \tag{15}$$

In formula (15), $\sum_{i=1}^{N} s_{it}\left(\beta_{K_i} \Delta \ln K_t + \beta_{L_i} \Delta \ln L_t + \beta_{E_i} \Delta \ln E_t\right)$ represents the change in output value resulting from the alteration of factors in the initial accounting framework of Syrquin, and the sum of the first three is the contribution of TFPG change. Then, we examine the change of TFPG, $\sum_{i=1}^{N} s_{it} \Delta \ln TFP_{it}$ means the change caused by the change of TFP in all industries, and the sum of the remaining two is the ' configuration effect '.

Different from Syrquin 's initial accounting framework, the allocation effect of factors can be decomposed into two parts: the second and third. Specifically, the second is the change caused by only the change of output share. Its economic meaning is the impact of the reallocation of factors among industries on ' total technology '. The third is the change caused by the change of factor price distortion in various industries. The distorted price makes the factors unable to be optimally allocated among industries. Therefore, as long as the degree of price distortion decreases, the factors will flow again to approach the optimal allocation, thereby increasing TFP and total economic output. In addition, since the production function has been set as the Cobb-Douglas total production function, another interpretation of the third term is the change of the output gap, which will be explained later.

2.2.7. *Estimate of output gap*

The output gap refers to the disparity between the actual output and the output when the resources are effectively allocated (there is no distortion of factor allocation). In this part, the difference between the actual output share $p_i Y_i / pY$ of the economy and the industry output share $p_i Y_{ei} / pY_{efficient}$ under the optimal allocation of resources (hereinafter referred to as the " industry output share difference ") Ω_i, which is expressed as a function of industry labor and capital distortions (τ_{L_i}、 τ_{K_i}) to analyze how the industry output is affected by the misallocation of labor and capital elements. Therefore, in this part, the situation of only two elements K and L is simplified. In order to make the industry can be compared with each other and remove the influence of the dimension, and show the gap between the scale of the industry, the industry output share index is used to describe the industry output. The output share difference Ω_i of industry i is:

$$\Omega_i = p_i Y_i \Big/ pY - p_i Y_{ei} \Big/ pY_{efficient} = \left[(1 + \tau_{L_i}) - (1 + \tau_{L_i})^{\frac{1}{\beta_{K_i}}}\right] L_i \Big/ L \tag{16}$$

$$\Omega_i = p_i Y_i \Big/ pY - p_i Y_{ei} \Big/ pY_{efficient} = \left[(1 + \tau_{K_i}) - (1 + \tau_{K_i})^{\frac{1}{\beta_{L_i}}}\right] K_i \Big/ K \tag{17}$$

Considering that the amount of capital and labor factors is certain during the specified period, it can be seen from Equations (16) and (17) that the distortion of labor and capital prices τ_{L_i}、 τ_{K_i}, the amount of labor L_i and the amount of capital K_i will affect the difference Ω_i in the output share of industry i. Among them, when τ_{L_i}、 $\tau_{K_i} < 0$ and $\Omega_i > 0$, the factor price faced by industry i is ' subsidized ', the industry will overproduce, and the actual output share will be higher than the industry output in the optimal state; on the contrary, the factor price faced by industry i is ' taxed ', and the actual output share of industry i is insufficient. The first derivative of capital K_i and labor L_i quantity is obtained:

$$\partial\Omega_i \Big/ \partial L_i = \left[(1 + \tau_{K_i}) - (1 + \tau_{K_i})^{\frac{1}{\beta_{K_i}}}\right] \Big/ K \tag{18}$$

$$\partial\Omega_i \Big/ \partial K_i = \left[(1 + \tau_{L_i}) - (1 + \tau_{L_i})^{\frac{1}{\beta_{L_i}}}\right] \Big/ L \tag{19}$$

According to the Cobb-Douglas production function, there is a positive relationship between industry output Y_i and actual labor, capital quantity L_i、 K_i. When τ_{L_i}、 $\tau_{K_i} < 0$, $\partial\Omega_i / \partial L_i$、 $\partial\Omega_i / \partial K_i > 0$, there is too much output at this time, and with the increase of factor input, the output will increase and the difference will become larger. On the contrary, the industry output share difference Ω_i is negative and gradually becomes smaller. Therefore, labor and capital price distortions will amplify the impact of industry size on industry output.

Further, using the aggregated C-D function, the output gap can be expressed as a function of the relative distortion coefficient of resources in various industries. At this time, the situation of three factors is still considered. Suppose that the summation function is a C-D function type, and its specific expression is as follows:

$$Y = F(Y_1, \cdots Y_N) = \prod_{i=1}^{N} Y_i^{s_i} \tag{20}$$

The ratio between actual output and effective output can be expressed as a function of the resource distortion coefficient of each industry, that is:

$$\left(Y/Y_{efficient}\right)_t = \prod_{i=1}^{N} \left[\frac{\left(\frac{s_{it}\beta_{K_i}}{\widetilde{\beta}_{K_t}}\widehat{\lambda}_{Kit}K_t\right)^{\beta_{K_i}} \left(\frac{s_{it}\beta_{L_i}}{\widetilde{\beta}_{L_t}}\widehat{\lambda}_{Lit}L_t\right)^{\beta_{L_i}} \left(\frac{s_{it}\beta_{E_i}}{\widetilde{\beta}_{E_t}}\widehat{\lambda}_{Eit}E_t\right)^{\beta_{E_i}}}{\left(\frac{s_{it}\beta_{K_i}}{\widetilde{\beta}_{K_t}}K_t\right)^{\beta_{K_i}} \left(\frac{s_{it}\beta_{L_i}}{\widetilde{\beta}_{L_t}}L_t\right)^{\beta_{L_i}} \left(\frac{s_{it}\beta_{E_i}}{\widetilde{\beta}_{E_t}}E_t\right)^{\beta_{E_i}}} \right]^{s_{it}} = \prod_{i=1}^{N} \left[(\widehat{\lambda}_{Kit})^{\beta_{K_i}} (\widehat{\lambda}_{Lit})^{\beta_{L_i}} (\widehat{\lambda}_{Eit})^{\beta_{E_i}} \right]^{s_{it}} \tag{21}$$

$Y_{efficient}$ represents the total economic output in the ideal state, $\left(Y/Y_{efficient}\right)_t$ represents the proportion of the actual economic output in the t period to the ideal output without factor distortion configuration. In combination with formula (21), if the summation function is a C-D function, this ratio depends only on the relative distortion $\widehat{\lambda}_{Kit}$、 $\widehat{\lambda}_{Lit}$、 $\widehat{\lambda}_{Eit}$ of factor prices in various industries, and the ratio of output value of a certain industry to total economic output value s_{it}.

Assuming that the relative output ratio of s_{it} in each industry in the whole industry remains unchanged, it can be similarly obtained in the t + 1 period:

$$\left(Y/Y_{efficient}\right)'_{t+1} = \prod_{i=1}^{N} \left[(\widehat{\lambda}_{Kit+1})^{\beta_{K_i}} (\widehat{\lambda}_{Lit+1})^{\beta_{L_i}} (\widehat{\lambda}_{Eit+1})^{\beta_{E_i}} \right]^{s_{it}} \tag{22}$$

Thus:

$$\ln \left(Y/Y_{efficient}\right)'_{t+1} - \ln \left(Y/Y_{efficient}\right)_t = \sum_{i=1}^{N} s_{it}(\beta_{Ki}\Delta\ln \widehat{\lambda}_{Kit} + \beta_{Li}\Delta\ln \widehat{\lambda}_{Lit} + \beta_{Ei}\Delta\ln \widehat{\lambda}_{Eit}) \tag{23}$$

The portion on the right side of the equation is the third item in (15). We can find that regardless of the distortion of other factors, the relative distortion of labor between industries, that is, $\Delta\ln \widehat{\lambda}_L > 0$, will lead to $\ln \left(Y/Y_{efficient}\right)'_{t+1} - \ln \left(Y/Y_{efficient}\right)_t > 0$, which can reflect that labor distortion will lead to the expansion of relative gap and the expansion of relative gap of effective output, that is, labor mismatch will lead to the loss of final production output by affecting the human resource structure within the industrial framework. In terms of the impact of capital on output, bank credit financing is the most important way for enterprises to obtain financing. Assuming that enterprises finance in the form of bank credit, the cost of obtaining financing from banks is inferior to that of other funding avenues. when the interest rate is not marketized. Enterprises in resource-based industries can obtain funds from banks at a lower financing cost, in other words, their capital distortion ' tax ' τ_K is reduced to negative. Enterprises in the industry will occupy more capital to expand investment, forming a financial crowding-out effect on other industries, making other industries underdeveloped; simultaneously, the decline of capital distortion ' tax ' τ_K also means that the relative distortion coefficient of capital in resource-based industries increases, that is, $\Delta ln \widehat{\lambda}_K > 0$. Considering that other conditions remain unchanged, the output gap is only related to the relative distortion $\widehat{\lambda}_{Kit}$ of the price of capital factors within the sector and the output proportion s_{it} of the output value of each industry in the whole economy. The resource-based industry $\Delta ln \widehat{\lambda}_K > 0$ will lead to a further expansion of the difference between the total social output and the effective output, that is, $ln \left(Y/Y_{efficient}\right)'_{t+1} - ln \left(Y/Y_{efficient}\right)_t > 0$, whilst the output ratio s_{it} of the resource-dependent industry in the city is often larger, which will worsen the output loss of the whole city. That is to say, the mismatch of capital factors will affect the manufacturing of resource-dependent companies, further expand the difference between the total social output and the effective output, and curb the further development of cities reliant on resources.

2.2.8. *The impact of capital factor allocation distortion on output in various industries*

This part takes the misallocation of capital elements as an example to illustrate its impact on output, and the impact of other factor allocation distortions can also be obtained. Assuming that only one industry i's capital distortion ' tax ' changes in an economy, the relative prices of factors in the remaining industries will not be changed by industry i. It can be considered that the distortion of other industries should be of the same magnitude due to the impact of capital distortion ' tax ' changes in industry i. On this basis, as long as the remaining conditions do not change, it can be deduced that the total output is affected by the capital price distortion of a single industry i.

$$AE_{Ki} = s_{it}\beta_{K_i}\left(1 - \frac{1}{\widetilde{\beta}_K}\right)\Delta\ln \widehat{\lambda}_{Ki} \tag{24}$$

According to Equation (19), we can get some intuitive explanations: consider keeping other conditions unchanged, only let the capital distortion ' tax ' τ_{K_i} of industry i decrease, then according to the definition, $\Delta ln \widehat{\lambda}_{Ki} > 0$. Due to the reduction of distortion tax, the cost of using capital in industry i decreases, and the reduction of cost will encourage the industry to increase the possession of capital to expand production. From Equation (15), the direct effect is about $s_{it}\beta_{K_i}\Delta\ln\widehat{\lambda}_{Ki}$. The reduction of distorting ' taxes ' will also produce ' externalities ', which will increase the cost of using capital in the remaining industries in disguise, forcing other industries to reduce capital use and reduce production. The size of this effect is $-\frac{s_i\beta_{K_i}\Delta ln\,\widehat{\lambda}_{Ki}}{\widetilde{\beta}_K}$. Therefore, in general, the total effect of capital distortion ' tax ' changes in industry i on output is shown in Equation (24).

2.3. The model of factor misallocation affecting energy efficiency

The economic development of resource-based cities is inseparable from the support of basic resources such as energy. Resource-based industries have fostered economic expansion in the course of developing resources such as energy, but also accompanied by unwanted outcomes like environmental contamination. Therefore, the efficiency of energy use or the output of unit energy is not only related to economic efficiency, but also significantly influences environmental concerns. Based on the existing research [67], this part attempts to propose an analytical framework to study how inter-industry factor misallocation affects energy efficiency and thus indirectly affects the environment.

2.3.1. Basic settings

This section considers the production problems of the two industries. The specific assumptions are as follows.

- Assume that there are only two industries, and any enterprise in the same industry has the same production function, thus, the production issue in the industry can be seen as a production problem within the representative enterprise.
- All enterprises use Cobb-Douglas production technology, and the production factors are: capital (K), labor (L), energy (E), but the production functions of the two industries are different. One industry has the production characteristics of high technology and low energy consumption, and the other has the production characteristics of low technology and high energy consumption. The enterprises in the industry are price recipients.
- It is assumed that in each period, the total amount of capital, labor, energy and other factors is exogenously given. This part of the hypothesis still follows the previous article, that is, the resource constraints of the two industries are: $\sum_{i=1}^{2}K_i = K$, $\sum_{i=1}^{2}L_i = L$, $\sum_{i=1}^{2}E_i = E$.

Define the production function of industry representative enterprises as:

$$Y_i = F_i(A_i, K_i, L_i, E_i) = A_iK_i^{1-\alpha-\beta}L_i^{\beta}E_i^{\alpha} \tag{25}$$

Here Y_i represents the output, K_i、 L_i、 E_i represent capital, labor and energy inputs. The parameters α、 β、 $1-\alpha-\beta$ represent the ratio of the contribution about each factor to the output, respectively. It is evident that the production function exhibits constant returns to scale.

The goal of the enterprise is to maximize profits. Under the assumption that the price of the product market is not distorted, the profit function of the enterprise is:

$$\pi = p_YY - rK - wL - pE \tag{26}$$

Among them, p_Y is the product price, p_Y is exogenously given, the market price of energy factor is p, the price of capital is r, and the price of labor is w. The first derivative of the profit function is used to obtain the energy factor demand function:

$$E^* = \left(\frac{\alpha p_Y AK^{1-\alpha-\beta}L^{\beta}}{P}\right)^{\frac{1}{1-\alpha}} \tag{27}$$

An energy efficiency function is constructed. In any period, the total amount of labor factor L, the total amount of capital factor K and the total amount of energy factor E are given exogenously. The energy allocation when the energy efficiency of the economy is optimal is as follows:

$$\max\frac{Y}{E} = \left(A_1E_1^{\alpha}K_1^{1-\alpha-\beta}L_1^{\beta} + A_2E_2^{\alpha}K_2^{1-\alpha-\beta}L_2^{\beta}\right) / (E_1 + E_2) \tag{28}$$

Combined with the constraints of E_1 and E_2, using the Lagrange multiplier method, we can get:

$$F(E_1, E_2, \lambda) = \left(A_1E_1^{\alpha}K_1^{1-\alpha-\beta}L_1^{\beta} + A_2E_2^{\alpha}K_2^{1-\alpha-\beta}L_2^{\beta}\right) / (E_1 + E_2) + \lambda(E_1 + E_2 - E) \tag{29}$$

By solving the partial derivatives of E_1 and E_2 in parallel, it can be obtained that:

$$\left(\frac{A_1}{A_2}\right)\left(\frac{K_1}{K_2}\right)^{1-\alpha-\beta}\left(\frac{L_1}{L_2}\right)^{\beta} = \left(\frac{E_1}{E_2}\right)^{1-\alpha} \tag{30}$$

2.3.2. Equilibrium of energy market

According to the demand function of energy elements, the total differential can be obtained:

$$\Delta E^* = \frac{1}{1-\alpha} K^{\frac{1-\alpha-\beta}{1-\alpha}} L^{\frac{\beta}{1-\alpha}} p^{\frac{1}{\alpha-1}} A^{\frac{\alpha}{1-\alpha}} \Delta A + \frac{1-\alpha-\beta}{1-\alpha} \left(\frac{A}{p}\right)^{\frac{1}{1-\alpha}} L^{\frac{\beta}{1-\alpha}} \Delta K + \frac{\beta}{1-\alpha} \left(\frac{A}{p}\right)^{\frac{1}{1-\alpha}} K^{\frac{1-\alpha-\beta}{1-\alpha}} L^{\frac{\alpha+\beta-1}{1-\alpha}} \Delta L + \frac{1}{\alpha-1} A^{\frac{1}{1-\alpha}} K^{\frac{1-\alpha-\beta}{1-\alpha}} L^{\frac{\beta}{1-\alpha}} p^{\frac{\alpha-2}{1-\alpha}} \Delta P \tag{31}$$

In the process of finding the total differential, $(\alpha p_Y)^{\frac{1}{1-\alpha}}$ does not affect the later analysis, so it is omitted for simplicity. formula (30) reflects how the energy elements are configured in the two industries. (31) It shows that when it reaches the ideal state, the change of energy demand ΔE^* comes from four parts, that is, the change of energy price ΔP, the change of labor stock ΔL, the change of capital stock ΔK and the change of technical level ΔA. In each period, the differences between different individuals in the corresponding part can be reflected by these four variables. When the energy factor is in a state of complete competition, there is only a unified energy price p in the market. At this time, the improvement of technical level A ($\Delta A > 0$) will increase the energy demand ($\Delta E^* > 0$), that is, under the condition of complete competition, the energy factor will be allocated to high-tech and low-energy enterprises; when there is price distortion in energy factors, there may be a mismatch of energy factors. Equation (31) describes how energy factors flow among industries in an equilibrium state. This part still analyzes the energy allocation under the assumption of the two industries, which does not affect the promotion of the research conclusions. According to the first-order conditions of market equilibrium:

$$E^* = \left(\frac{\alpha p_Y A K^{1-\alpha-\beta} L^{\beta}}{P}\right)^{\frac{1}{1-\alpha}} \tag{32}$$

From (32), the E_1^* and E_2^* model corresponding to the two industries can be obtained, and then:

$$\left(\frac{A_1 P_2}{A_2 P_1}\right)\left(\frac{K_1}{K_2}\right)^{1-\alpha-\beta}\left(\frac{L_1}{L_2}\right)^{\beta} = \left(\frac{E_1}{E_2}\right)^{1-\alpha} \tag{33}$$

The mismatch of energy factors is primarily due to the distortion of energy prices. If the energy market is assumed to be a perfectly competitive market, the two industries will face the same market price (i.e. $P_1 = P_2$), so that formula (33) will become (30), that is, the allocation of energy factors under the market mechanism is efficient and meets the optimal conditions of energy effectiveness in the economy. The technological level is proportional to the level of energy factor possession, that is, enterprises with low energy consumption and high technology should occupy more energy factors. However, when there is a distortion within the price of energy factors, in other words, when the two industries face different market prices ($P_1 \neq P_2$), the (33) and (30) will not be the same, that is, when both industries reach equilibrium, the allocation of factors will be different from the allocation under the optimal efficiency conditions. Taking the case of $P_1 > P_2$ as an example, that is, high energy consumption enterprises occupy low-cost energy factors, so that the case of $E_1 \leq E_2$ is realized, which is contrary to the optimal state of efficiency in Equation (30), resulting in overall energy effectiveness loss. In order to illustrate the decline of energy efficiency, an optimal value function $V(E_1, E_2, K_1, K_2, L_1, L_2)$ of formula (25) is defined. In t_0 period, when the market is in a completely competitive state, the energy factor allocation in this state is the most efficient. If there is no factor price distortion (i.e., $P_1 = P_2$), the energy factor will continue to flow to enterprises that focus on technology improvement in period t_1. At this time, $E_1^1 > E_1^0, E_2^1 < E_2^0$, and the allocation state of E_1^1、E_2^1 not only conforms to the market equilibrium but also satisfies the optimal overall efficiency. The new allocation improves energy efficiency marginally, thus increasing the overall energy efficiency, that is, $V_{t_1} > V_{t_0}$. If there is a factor price distortion, such as $P_1 > P_2$, the equilibrium allocation (E_1'、E_1') determined by the market mechanism (33) does not meet the global efficiency condition (30). Hence, the energy factor price distortion will result to the mismatch of energy factors and further reduce energy efficiency. That is, due to the distortion of energy prices, the allocation of factors is different from the allocation under the optimal efficiency conditions, which makes high-energy-consuming enterprises occupy low-cost energy factors, squeeze out technology-based enterprises, and reduce energy efficiency.

2.4. *Optimized DDF model for measuring transformation efficiency*

2.4.1. *Calculation model of transformation efficiency*

This research employs the DDF approach to evaluate the efficiency of transition in cities reliant on resources. The methodology considers each city as an independent production unit, with labor, capital, and energy as inputs, and expected and undesired outputs. Consequently, the production possibility set is defined as:cities reliant on resources

$$T = \{(k, l, e, y, b) : (k, l, e) \ \ output(y, b)\} \tag{34}$$

Within this framework, capital factor(K), labor factor(L), and energy factor(E) are categorized as input variables, while GDP (y) represents the desired output and pollution emissions (b) signify the undesired output. According to the existing suty of Färe et al. [68], The production technology must adhere to the following fundamental assumptions: (1) there is null-jointness between expected output and undesired output; (2) Both factor inputs and desired outputs exhibit strong disposability; (3) Undesirable outputs demonstrate weak disposability. For the DMUs of n cities, the directional distance function model can be formulated as:

$$\vec{D}(k, l, e, y, b; g) = max\ \beta \tag{35}$$

$$\text{s.t.} \sum_{n=1}^{N}\lambda_n k_n \le k(1-\beta), \sum_{n=1}^{N}\lambda_n l_n \le l(1-\beta), \sum_{n=1}^{N}\lambda_n e_n \le e(1-\beta), \sum_{n=1}^{N}\lambda_n y_n \ge y(1-\beta), \sum_{n=1}^{N}\lambda_n b_n = b(1-\beta), \sum_{n=1}^{N}\lambda_n = 1, \lambda_n \ge 0, \beta \in [0,1]$$

Among them, λ_n represents the weight assigned to each decision-making unit. The weight variable $\sum_{n=1}^{N}\lambda_n = 1$ ensures that the sum of weights equals 1, implying variable returns to scale (VRS) in the production technology. Should this condition not be enforced, the return to scale would be constant (CRS). The objective function is defined as, which represents inefficiency value, and $1-\beta$ represents the efficiency value.

While the direction distance function (DDF) has been extensively utilized in measuring productivity, its model hypothesis still has drawbacks in the transformation efficiency of cities reliant on resources. There will be restrictions on the increase in desired output, and the decrease in factor input and undesired output are in the same proportion. This situation is very easy to lead to ' slack bias '. To solve this problem, this research further strives to enhance from three perspectives: (1) The endogeneity of the direction vector. The direction vector $g = \left(g_k, g_l, g_e, g_y, g_b\right)$ represents a unit vector, let $\sum g = 1$ and g be greater than or equal to zero; by admitting the model to figure out the endogenous decision variables, rather than pre-setting them artificially, the vector of direction for each decision-making unit may vary, leading to different transition directions for each resource-dependent city, which reflects a more realistic scenario. (2) Absolute distances are transformed into relative distances. The relaxation amount in the direction of the target element is divided by the total value in the direction of the element, so as to transform it from absolute distance to relative distance. This results in varying relative distances in different directions.(3) Introducing an exogenous weight denoted as α_i ($\sum \alpha = 1$). Various combinations of weights represent research elements of the respective objectives and constraints, which reflects the importance of the dimensions of different elements. After the enhancement, the direction distance function for assessing transformation effectiveness is:

$$\overrightarrow{D}(k,l,e,y,b;g) = \max\left(\alpha_1 \cdot \frac{\beta g_k}{k} + \alpha_2 \cdot \frac{\beta g_l}{l} + \alpha_3 \cdot \frac{\beta g_e}{e} + \alpha_4 \cdot \frac{\beta g_y}{y} + \alpha_5 \cdot \frac{\beta g_b}{b}\right) \tag{36}$$

$$\text{s.t.} \sum_{n=1}^{N}\lambda_n k_n \le l - \beta g_k, \sum_{n=1}^{N}\lambda_n l_n \le k - \beta g_l, \sum_{n=1}^{N}\lambda_n e_n \le e - \beta g_e, \sum_{n=1}^{N}\lambda_n y_n \ge y + \beta g_y, \sum_{n=1}^{N}\lambda_n b_n = b - \beta g_b; \sum_{n=1}^{N}\lambda_n = 1, \lambda_n \ge 0;\ n = 1,\dots,N \text{ and } \frac{\beta g_k}{k}, \frac{\beta g_l}{l}, \frac{\beta g_e}{e}, \frac{\beta g_y}{y}, \frac{\beta g_b}{b} \in [0,1]$$

As the object function β and the vector of direction are variables that need to be solved for and are in a product form, equation (36) represents a nonlinear programming model. This may result in non-global optimal solutions or no solution. Based on the findings of Färe et al. [68,69], let $S_k = \beta g_k$, $S_l = \beta g_l$, $S_e = \beta g_e$, $S_y = \beta g_y$, $S_b = \beta g_b$ convert Model (36) into a linear programming formulation (37):

$$\overrightarrow{D}(k,l,e,y,b;g) = \max\left(\alpha_1 \cdot \frac{S_k}{k} + \alpha_2 \cdot \frac{S_l}{l} + \alpha_3 \cdot \frac{S_e}{e} + \alpha_4 \cdot \frac{S_y}{y} + \alpha_5 \cdot \frac{S_b}{b}\right) \tag{37}$$

$$\text{s.t.} \sum_{n=1}^{N}\lambda_n k_n \le l - S_k, \sum_{n=1}^{N}\lambda_n l_n \le k - S_l, \sum_{n=1}^{N}\lambda_n e_n \le e - S_e, \sum_{n=1}^{N}\lambda_n y_n \ge y + S_y, \sum_{n=1}^{N}\lambda_n b_n = b - S_b\ \sum_{n=1}^{N}\lambda_n = 1, \lambda_n \ge 0;\ n = 1,\dots,N \text{ and } \frac{S_k}{k}, \frac{S_l}{l}, \frac{S_e}{e}, \frac{S_y}{y}, \frac{S_b}{b} \in [0,1] \text{ and } 0 \le S_k \le k, 0 \le S_l \le l, 0 \le S_e \le e, 0 \le S_y \le y, 0 \le S_b \le b$$

By solving (4) through linear programming, the numerical values of S_k, S_l, S_e, S_y and S_b can be acquired. Let $\eta = S_k + S_l + S_e + S_y + S_b$, and $\sum g = 1$, then we get:

$$\eta = \beta\left(g_k + g_l + g_e + g_y + g_b\right) = \beta \tag{38}$$

Therefore, $g_k^* = S_k/\eta$、 $g_l^* = S_l/\eta$、 $g_e^* = S_e/\eta$、 $g_y^* = S_y/\eta$、 $g_b^* = S_b/\eta$ can be acquired. β represents the maximum distance from the decision point to the production frontier. The magnitude of the directional vector in each dimension varies, leading to different projections of distance in each dimension. By solving the model, the non-efficiency value of the object function is determined, and the transformation effectiveness is calculated by subtracting the target value from 1. When the target decision-making unit is situated on the production frontier, the target value at that point is 0, resulting in a transformation effectiveness value of 1.

To summarize, this research assesses and contrasts the transition effectiveness of China's prefecture-level cities, encompassing both resource-dependent and non-cities reliant on resources, utilizing model (38). The study employs exogenous weight differentiation to determine the transition effectiveness of cities reliant on resources.

2.4.2. Decomposing the efficiency of transformation

Model (37) evaluates the efficiency of transformation for each prefecture-level city across five dimensions: labor input, capital input, energy input, expected output, and undesired output. As per the defined connotation of cities reliant on resources transition in this research, the transformation of such cities primarily focuses on resource conservation, environmental protection, and economic progression. Utilizing the transition efficiency measurement framework, and assuming fixed factors input of labor and capital factors as the foundational premise, the efficiency of transformation for cities reliant on resources in these three aspects (energy efficiency, environmental efficiency, and output efficiency) is assessed through the dimensions of energy factor input, undesired factor output, and expected factor output. In the enhanced measurement model, the reduction in energy factor input, the increase in expected factor output, and the decrease in undesired factor output represent the three dimensions of transformation effectiveness for cities reliant on resources. Therefore, if the fixed capital factor and labor factor input remain constant, the calculation model for measuring the transition of cities reliant on resources effectiveness can be derived as follows:

$$\vec{D}(k,l,e,y,b;g)=\max\left(\alpha_1\cdot\frac{S_e}{e}+\alpha_2\cdot\frac{S_y}{y}+\alpha_3\cdot\frac{S_b}{b}\right) \tag{39}$$

$$\text{s.t.}\ \sum_{n=1}^{N}\lambda_n k_n\le k,\sum_{n=1}^{N}\lambda_n l_n\le l,\sum_{n=1}^{N}\lambda_n e_n\le e-S_e,\sum_{n=1}^{N}\lambda_n y_n\ge y+S_y,\sum_{n=1}^{N}\lambda_n b_n=b-S_b\ \sum_{n=1}^{N}\lambda_n=1,\lambda_n\ge 0;\ n=1,\dots,N \text{ and } 0\le S_e \le e,0\le S_y\le y,0\le S_b\le b$$

Through the resolution of model (38), energy utilization S_e that a resource-dependent city can save, the increased Gross Domestic Product(GDP) is S_y, and the decrease inenvironmental pollution emissions are S_b. Let $\eta = S_e+S_y+S_b$, and $\sum g = 1$, get:

$$P_e=\frac{S_e}{e},P_e=\frac{S_e}{e},P_e=\frac{S_e}{e} \tag{40}$$

The efficiencies related to energy, production, and the environment in cities reliant on resources are determined by deducting the quotient of the distance value over the true value from 1 in three separate dimensions. It can be expressed as (Taking TFEE as an example):

$$TFEE=1\text{-}\frac{S_e}{e}=1\text{-}P_e \tag{41}$$

Among these efficiencies, *TFEE* represents energy effectiveness, *TFYE* represents output effectiveness, and *TFBE* represents environmental effectiveness.

2.5. Establishment of econometric model

2.5.1. Construction of regression model

Derived from the preceding examination, the basic mathematical model about regression of this part is set as follows:

$$tranf_{it}=\beta+\alpha_1 DisK_{it}+\alpha_2 DisL_{it}+\alpha_3 DisE_{it}+\alpha_4 X_{it}+\mu_i+\nu_t+\varepsilon_{it} \tag{42}$$

$$tranf_{it}=\beta+\alpha_1 Disc_{it}*Dircet_{it}+\alpha_4 X_{it}+\mu_i+\nu_t+\varepsilon_{it} \tag{43}$$

$$tranf_{it}=\beta+\alpha_1 DisK_{it}+\alpha_2 DisL_{it}+\alpha_3 DisE_{it}+\gamma_1 tranf_{it-1}+\gamma_2 tranf_{it-2}+\alpha_4 X_{it}+\mu_i+\nu_t+\varepsilon_{it} \tag{44}$$

In Equation (42), $tranf_{it}$ represents the transformation effectiveness of resource-dependent cities(The tranf and trane used in the test, representing the urban transformation efficiency under two different measurement weights, respectively. See 2.5.2 for details.); $DisK_{it}$, $DisL_{it}$, $DisE_{it}$ represent the level of factor misallocation, which are the level of misallocation of capital, labor and energy in the resource-dependent city i in the t year; X_{it} is a set of control variables, including the city 's opening to the outside world, car ownership, government intervention, industrial structure and R & D investment level; μ_i and ν_t represent urban and year fixed effects, respectively; The symbol "i" represents the city, while "t" represents the year. α_1、 α_2、 α_3 are the focus of this study, which describes the impact of factor mismatch on the transformation efficiency of cities reliant on resources. If it exhibits a significant negative trend, it shows that the increase in the degree of factor mismatch hinders the transition of cities reliant on resources; on the contrary, it indicates that improving the degree of factor mismatch facilitates the transition of cities reliant on resources. cities reliant on resources In order to further investigate the impact of the direction of factor misallocation on the efficiency of transforming cities reliant on resources, the interaction term between the level of factor mismatch and the direction of factor misallocation is introduced in the regression equation (43), where $Dircet_{it}$ represents the misallocation direction of a certain factor in resource-dependent city i in year t, and $Disc_{it}$ represents the degree of misallocation of a certain factor. The explanatory variables in the regression equation (44) include the lagged one-period term and the lagged two-period term of urban transformation efficiency. The dynamic panel model, which is different from the regression method of equation (42) and equation (43), is used for regression estimation to alleviate endogenous problems.

2.5.2. Setting of variables

The explained variable of this research is the transition of cities reliant on resources. The specific values are calculated according to the improved DDF method. Two kinds of transformation efficiency tranf and trane are obtained under the two weights (1/ 9 , 1/ 9 , 1/ 9 , 1/3 , 1/3) and (0 , 0 , 1/3 , 1/3 , 1/3). On the basis of measuring the transformation efficiency (tranf and trane), this study further decomposes it, that is, examining how cities reliant on resources are affected by factor misallocation in terms of energy effectiveness(e), output effectiveness(y) and environmental effectiveness(env).

The core explanatory variable of this research is the degree of factor mismatch in resource-dependent cities, specifically three indicators: Disk, Disl, and Dise, which represent the degree of capital factor mismatch, labor factor mismatch, and energy factor mismatch, respectively. This part is based on Formula (10), Formula (11), Formula (12), and combined with Aoki 's measurement framework to calculate the factor misallocation coefficient. The degree of factor mismatch can be obtained by subtracting 1 and taking the absolute value. The factor mismatch direction is a dummy variable, and the indicators corresponding to the three factor mismatch directions are dk, dl and de. The mismatch coefficient is compared with 1 to obtain the specific factor mismatch direction: the coefficient is below 1 for the factor configuration is insufficient, recorded as dk1, dl1 and de1; if the coefficient is exceeds 1, the factor allocation is excessive, which is recorded as dk2, dl2 and de2, respectively.

In order to control the impact of other variables affecting efficiency of urban transformation, drawing on existing research [70–79], the main control variables are set as follows:

Government intervention (dis) [70,71]: local governments can affect the supply of public goods such as environmental conservation, and can affect the change of urban economic structure to a certain extent through financial means. This research uses the proportion of fiscal spending as a percentage of GDP excluding education and science expenditure to measure the degree of government intervention.

Trade dependence (trade) [72,73]: Foreign trade helps to promote the economic growth of the city, so the proportion of the total import and export trade to the city 's regional GDP is used as a proxy variable.

Car ownership (car) [74,75]: The increasing number of cars in the city will produce a significant volume of emissions, which becomes one of the crucial sources of air pollution. At the same time, it also consumes a large amount of oil resources, which directly influences on urban environmental protection and energy consumption. This research directly uses the number of civilian car ownership in each city to characterize this variable.

Industrial structure (ind) [76,77]: In the three industrial structures, the industry of cities reliant on resources, especially the mining industry, is often given priority to development, which brings economic growth to resource-dependent cities and inevitably consumes a lot of energy and produces a lot of pollution. Therefore, the transformation of resource-dependent cities is indivisible from the adjustment and upgrading of industrial structure. Therefore, this research uses the ratio of mining industry to labor employment as the proxy variable of industrial framework.

R & D investment (rd) [78,79]: Cities with high R & D investment tend to have stronger innovation capabilities, and the resulting scientific and technological progress can bring more efficient and environmentally friendly technologies, thus promoting the smooth transformation and upgrading of cities reliant on resources. This study measures R & D investment by the ratio of scientific research, technical assistance, and geological exploration to labor employment.

3. Empirical analysis

3.1. Preliminary analysis results

In this part, this study conducts regression based on the data of the 14 years from 2005 to 2018, and Table 2 gives the estimation

Table 2
Benchmark regression outcomes.

	(1)	(2)	(3)	(4)	(5)	(6)
	tranf	tranf	tranf	trane	trane	trane
misk	−0.031***	−0.036***	−0.038***	−0.036***	−0.034***	−0.033**
	(0.010)	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)
misl	−0.069***	−0.066***	−0.067***	−0.072***	−0.068***	−0.069***
	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)
mise	−0.022***	−0.025***	−0.025***	−0.028***	−0.031***	−0.032***
	(0.005)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)
dis		0.007	−0.052		−0.030	−0.040
		(0.086)	(0.102)		(0.086)	(0.095)
car		−0.000	−0.002		−0.004*	−0.004
		(0.002)	(0.003)		(0.002)	(0.003)
trade		0.184	0.141		0.243	0.160
		(0.571)	(0.550)		(0.728)	(0.714)
ind		−0.025	0.026		0.019	0.050
		(0.158)	(0.158)		(0.174)	(0.171)
rd		−0.034	−0.079		−0.044	−0.095
		(0.054)	(0.056)		(0.059)	(0.058)
_cons	0.820***	0.834***	0.807***	0.826***	0.846***	0.821***
	(0.037)	(0.041)	(0.043)	(0.039)	(0.043)	(0.044)
city	Yes	Yes	Yes	Yes	Yes	Yes
year	No	No	Yes	No	No	Yes
N	1596	1548	1548	1596	1548	1548
R^2	0.219	0.257	0.284	0.255	0.303	0.327

Note: The robust standard error is within square brackets below the estimated coefficient. City represents the fixed effect of the city, year represents the fixed effect of the year, Yes and No represent the controlled and uncontrolled effects, respectively, N represents the sample size, *, * *, * * * represents significant at the levels of 0.1,0.05 and 0.01, respectively, the same below.

results of the regression outcomesof the two transformation efficiencies. Table 2 shows the regression results of the fixed effect model of the degree of factor mismatch on the two transformation effectiveness of cities reliant on resources. All columns control the urban fixed effect. The regression of (2), (3), (5) and (6) columns adds control variables at the city degree. (3) and (6) control the fixed effect of the year and adopt a two-way fixed-effect approach. Considering that all indicators are at the city level, the city clustering effect is used in the regression model to correct the standard error. The empirical results show that irrespective of whether the control variables are added, the coefficient of the level of factor mismatch is significantly negative in the six regressions, passing the statistical significance assessment of 1 % and 5 % respectively. This exhibit that without considering the endogeneity of the model, the level of factor mismatch in cities reliant on resources is significantly negatively correlated with their transformation efficiency, that is, the greater the level of factor mismatch, the lower the efficiency of urban transformation, and the factor misallocation substantially impedes the transition of cities reliant on resources. In other words, by alleviating the level of factor mismatch and optimizing the allocation of factors, the transition of cities reliant on resources can be effectively promoted.

Under the two exogenous weight settings, the degree of labor factor misallocation has the greatest impact on the transformation efficiency. It can be seen from Column (3) that the effects of the inefficient allocation of capital on transformation efficiency is higher than that of energy misallocation when considering the transformation efficiency of capital, labor and energy input, simultaneously. Column (6) shows that in terms of the transformation efficiency of only considering energy input, the impact of energy mismatch on the transition of cities reliant on resources is significantly improved, which is very close to the coefficient of capital mismatch, and the labor mismatch variable's coefficient is also improved, while the influence coefficient of capital mismatch is slightly reduced.

In the economic sense, taking (3) as an example, for every unit increase in the transformation effectiveness of cities reliant on resources, the labor mismatch decreases by 0.067, the capital misallocation decreases by 0.038, and the energy misallocation decreases by 0.025. ' The labor factor assumes a more significant function in the transformation of resource-dependent cities. This could be due to: the energy factor is more important to the resource-based industry and has less impact on other industries. Therefore, the energy factor has less impact on the output of the whole society and more is to produce unexpected output to affect the environment. The impact on the transformation efficiency is more focused on the environment; the industrial structure of cities reliant on resources is unreasonable, and other manufacturing industries that also require a large amount of fixed investment are congenitally underdeveloped, and the internal structure of the industry is single. Therefore, although there is an over-allocation of capital in resource-dependent industries, due to the small size of other manufacturing industries, the service industry has little demand for capital factors. Overall, the crowding out of other industries is relatively limited, but the over-allocation of capital in resource-based industries does exerts a notable influence on the environment. The labor factor has a more pronounced influence on various industries. The service industry naturally demands a large amount of labor, and the resource-based industry is no exception. For example, the early mining industry in China 's resource-dependent cities has a low level of automation, and still needs to hire a large number of manual excavation and mining. The allocation of labor factors will have a direct and obvious impact on the output of the entire city.

Table 3
The regression outcomes of factor misallocation direction and economic transformation efficiency.

	(1)	(2)	(3)	(4)	(5)	(6)
	tranf	tranf	tranf	trane	trane	trane
dk1	−0.104			−0.130		
	(0.144)			(0.164)		
dk2	−0.049***			−0.045***		
	(0.014)			(0.015)		
dl1		−0.061**			−0.065***	
		(0.024)			(0.024)	
dl2		−0.099***			−0.105***	
		(0.013)			(0.015)	
de1			−0.023***			−0.029***
			(0.004)			(0.004)
de2			−0.029***			−0.036***
			(0.005)			(0.005)
dis	−0.061	−0.143	−0.201*	−0.020	−0.100	−0.174
	(0.154)	(0.154)	(0.119)	(0.161)	(0.157)	(0.110)
car	−0.001	0.000	−0.003	−0.002	−0.001	−0.004
	(0.005)	(0.004)	(0.005)	(0.006)	(0.005)	(0.005)
trade	−0.147	−0.308	0.156	−0.308	−0.483	0.069
	(1.302)	(1.238)	(1.145)	(1.626)	(1.559)	(1.420)
ind	−0.093	−0.030	−0.006	−0.086	−0.023	0.014
	(0.231)	(0.216)	(0.200)	(0.264)	(0.253)	(0.215)
rd	−2.887	−2.729	−1.209	−3.449	−3.271	−1.462
	(2.682)	(2.532)	(1.890)	(2.898)	(2.746)	(1.906)
_cons	0.554***	0.662***	0.648***	0.535***	0.649***	0.659***
	(0.036)	(0.045)	(0.035)	(0.040)	(0.046)	(0.036)
city	Yes	Yes	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes	Yes	Yes
N	1548	1548	1548	1548	1548	1548
r2	0.064	0.097	0.218	0.066	0.103	0.276

Simultaneously, the gathering of human capital will also affect the enhancement of technical level, indirectly affect energy efficiency and output efficiency, and ultimately affect the city 's output and environment. Therefore, the mismatch of labor factors has the most significant inhibitory effect on urban transformation. The policy ramifications of this regression result are as follows: in the long run, the most effective measures for resource-dependent cities to seek transformation and development are to alleviate the misallocation of labor factors and increase the accumulation of human capital. The introduction of any policy should focus on retaining people and attracting people, so as to realize the transformation smoothly.

In order to study the impact of different directions of factor misallocation on urban transformation efficiency, Table 3 also shows the estimation outcomes of the cross-terms of the dummy variables between the level of factor mismatch and the direction of factor mismatch. It can be seen that the introduction of the heterogeneity of factor mismatch direction does not change the basic results of the regression. The direction and significance of the factor mismatch estimation coefficient are basically consistent, and the impact on the transformation effectiveness of resource-dependent cities is still basically negative. Only when the capital allocation is insufficient, the calculated factor misallocation coefficient is not significant. It may be that in this case, the sample size of insufficient capital factor allocation is quite different from that of excessive allocation, and the number of insufficient allocation is small. It can be seen from Table 1 that the mean value of capital allocation direction is 1.787, and most cities are in the state of excessive allocation of capital factors most of the time. From the columns (2), (3), (5) and (6), it is evident that in the case of transformation efficiency with two different weight settings, whether it is labor factor or energy factor, the absolute value of the overestimation coefficient about allocation is greater than that of insufficient allocation, that is, the impact of excessive allocation of factors on urban transformation efficiency is greater than that of insufficient allocation of factors on transformation efficiency. In general, the influence of factor allocation direction on urban transformation efficiency is consistent with the theoretical expectations and the previous empirical analysis results. The estimation outcomes regarding the inhibitory impact of factor misallocation on the transformation of cities reliant on resources are robust and trustworthy.

3.2. Discussion and solution of endogenous problems

In cities reliant on resources, there could exist a reciprocal causal connection between factor mismatch and efficiency of transformation. Specifically, cities reliant on resources with low transformation efficiency may intensify their reliance on a specific factor to foster development, consequently exacerbating the extent of factor mismatch. ; at the same time, although this study controls a set of control variables, the model may still have the problem of missing variables or measurement errors in the degree of factor mismatch. Therefore, the presence of endogeneity issues in the benchmark model makes the above conclusions may be biased. In view of the endogenous problem of the model, this part will use the instrumental variable method to carry on the regression to maintain the strength of the conclusion: (1) In this research, the factor mismatch degree of each factor is lagged by one period as the instrumental factor, and then the two-stage least squares method (2SLS) is used for regression estimation. The instrumental variables constructed in this study conform to the two basic pertinent principles and exclusivity: on the one hand, it is obvious that there is a high correlation between the level of factor misallocation in the previous period of cities reliant on resources and the degree of misallocation in the current period; on the other hand, the current transformation efficiency of resource-dependent cities cannot affect the degree of factor

Table 4
Full sample 2SLS regression estimation outcomes.

	(1)	(2)	(3)	(4)	(5)	(6)
	tranf	tranf	tranf	trane	trane	trane
misk	−0.026***			−0.018**		
	(0.008)			(0.009)		
misl		−0.097***			−0.107***	
		(0.015)			(0.017)	
mise			−0.027***			−0.033***
			(0.002)			(0.002)
dis	−0.041	−0.034	−0.105**	−0.021	−0.006	−0.089*
	(0.049)	(0.047)	(0.044)	(0.054)	(0.052)	(0.047)
car	−0.002	−0.000	−0.004	−0.004	−0.002	−0.006**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
trade	−0.175	−0.144	0.329	−0.243	−0.242	0.334
	(0.273)	(0.266)	(0.250)	(0.301)	(0.293)	(0.265)
ind	−0.113	−0.035	−0.018	−0.113	−0.028	0.003
	(0.129)	(0.127)	(0.117)	(0.142)	(0.139)	(0.125)
rd	0.002	−0.120	0.029	−0.014	−0.152	0.014
	(0.133)	(0.132)	(0.121)	(0.147)	(0.146)	(0.129)
_cons	0.525***	0.703***	0.650***	0.498***	0.701***	0.662***
	(0.018)	(0.035)	(0.019)	(0.020)	(0.039)	(0.020)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
F	283.93	32.20	61.56	283.93	32.20	61.56
city	Yes	Yes	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes	Yes	Yes
N	1548	1548	1548	1548	1548	1548

mismatch in the past, so the lag value of the degree of factor mismatch is not related to the error term, and also meets the requirements of exogenous. Secondly, building upon using the lag value of factor misallocation degree as the instrumental variable, this study constructs a dynamic panel model by incorporating the lag 1–2 period of the explained variable urban transformation efficiency into the explanatory variable, and then uses the lag 1–2 period of factor misallocation degree as the instrumental factor to estimate by using the system GMM model. The variables and samples employed in the instrumental factor regression utilizing the two-stage least squares (2SLS) approach align with the configurations in the benchmark regression.

3.2.1. Instrumental variable method

Table 4 presents the two-stage least squares (2SLS) regression results with one-period lag of factor misallocation serving as the instrumental variable. The regression outcomes of the first stage show that the F statistics under different weight transformation efficiency are much larger than the empirical value 10, and the degree of factor mismatch lags one period to fulfill the fundamental conditions of instrumental variables. Moreover, the outcomes of the regression analysis in the second stage show that except that the regression coefficient of the mismatch degree of capital factors in Column (4) satisfies the test at a 5 % significance level, the coefficient is negative, and the regression coefficients of the mismatch degree of other factors are all negative at the significant level of 1 %. This indicates that after considering the endogeneity of the model, the higher the mismatch level of each factor, the lower the effectiveness of urban transformation, and alleviating the mismatch degree of each factor will contribute to the transition of cities reliant on resources. Simultaneously, the absolute value of the regression coefficient of the mismatch degree of the labor factor is still the largest, while the coefficient estimated from regression of the mismatch degree of the capital factor and the energy factor is relatively close, which is close to the results in the benchmark regression. The regression outcomes are more robust and reliable.

In short, after considering the possible endogenous problems between factor misallocation and resource-based city transformation, the analysis conclusion of two-stage least squares regression using instrumental variable method is consistent with the previous article. Factor misallocation will significantly hinder the transition of cities reliant on resources.

3.2.2. Dynamic panel regression

When using the system GMM method for estimation, it is required that the disturbance term in the model does not have autocorrelation, but there is usually a first-order autocorrelation after the discrepancy in the disturbance term. Therefore, to accept the assumption of no autocorrelation in the error term, it is necessary to ensure that the disturbance term after the difference does not have second-order autocorrelation, and by comparing the size of the AR2 statistic P value in Table 5 to determine whether there is second-order autocorrelation; the dynamic panel model not only needs to test the autocorrelation at a lag of two in the error term, but also needs to test the rationality of the selection of instrumental variables. Therefore, Table 5 also shows the p-value of the Sargan test, which can be used to judge whether the selection of instrumental variables in the dynamic panel model is reasonable. Through the regression of the system GMM model, the specific outcomes are shown in Table 5. Whether considering the transformation efficiency of capital, labor and energy input at the same time or only considering the transformation efficiency of energy input, the p-value of AR2 statistic exceeds 0.1, which can significantly reject the hypothesis that there is second-order autocorrelation in the discrepancy in the disturbance term, while the p-value of Sargan statistic is greater than 0.2, showing that the instrumental variables selected by the model are not over-identified, and we can accept the hypothesis that all instrumental variables are valid, so the estimation of system GMM is effective.

Table 5 demonstrates that when controlling for city-level characteristic variables, the regression coefficients of the degree of misallocation of each factor are negative and significant at the degree of 1 %, indicating that after considering the endogenous problem of the model, the factor mismatch still has a significant negative influence on the efficiency of urban transformation, which is in line with the research conclusion obtained from the benchmark regression that the factor mismatch has a significant inhibitory effect on the

Table 5
Dynamic panel regression estimation results.

	(1)		(2)	
	tranf		trane	
L.tranf	0.622***	(0.007)		
L2.tranf	0.110***	(0.006)		
L.trane			0.650***	(0.007)
L2.trane			0.084***	(0.003)
misk	−0.028***	(0.002)	−0.022***	(0.002)
misl	−0.018***	(0.001)	−0.010***	(0.001)
mise	−0.009***	(0.000)	−0.009***	(0.000)
_cons	0.229***	(0.010)	0.191***	(0.012)
Control variables	Yes		Yes	
N	1322		1322	
AR2 (p-value)	0.1371		0.1031	
Sargan (p-value)	0.2094		0.2743	

Note: 1) The instrumental variables of the system GMM are the first-order and second-order lag values of the factor mismatch degree, and the regression equation includes the lag 1–2 period of the transformation efficiency. 2) The P value of AR2 represents the P value calculated by testing the second-order autocorrelation; the P value of Sargan is the corresponding P value of the Sargan statistic calculated by the instrumental variable over-identification test.

transformation of cities reliant on resources. Further comparison with the results of the benchmark regression, it can be seen that after considering endogeneity, the influence of the degree of misallocation of the influence of various factors on the transformation efficiency of cities reliant on resources has shifted. In the system GMM model, after the lag term of transformation efficiency is included in the explanatory variables, the regression coefficients of the mismatch degree of each factor are significantly smaller, especially the regression coefficients of the mismatch degree of labor and energy factors change greatly. Taking the transformation efficiency (tranf) of capital, labor and energy input in Table 5 as an example, the regression coefficient of capital factor mismatch changes from −0.038 to − 0.028, the absolute value of the regression coefficient of labor factor misallocation decline from 0.067 to 0.018, and the absolute value of the regression coefficient of energy factor misallocation decline from 0.025 to 0.009, which also leads to the greatest negative impact of capital factor mismatch on urban transformation.

In general, although the explanatory power of the mismatch degree of the original elements has decreased after adding new explanatory variables, the research findings derived from the analysis of the regression results of the model still remain robust after considering endogeneity.

3.3. Robustness test

3.3.1. Elimination of regenerative city samples

The subject of investigation in this study is resource-dependent cities, and the characteristics of cities reliant on resources are characterized by the mining and processing industries of natural resources like minerals and forests in the area. Among the four types of resource-dependent cities, regenerative resource-dependent cities have basically got rid of resource dependence. The leading industry and economic framework of the city have changed. The economic decision-making and urban planning of the city may be quite different from those of similar cities. The progress model and development direction of the city are also significantly different from those of traditional cities reliant on resources. Therefore, the inclusion of regenerative cities in the sample may affect the regression results of this study. In order to eliminate the interference caused by the sample of regenerative cities, this study removes all relevant cities during the sample period according to the regenerative cities listed in the ' National Sustainable Development Plan for Resource-based Cities (2013–2020) ', so as to further strengthen the robustness of the regression results of this study. The cities specifically eliminated include: Suqian City, Zibo City, Tangshan City, Lijiang City, Huludao City, Ma 'anshan City, Xuzhou City, Nanyang City, Linyi City, Anshan City, Luoyang City, Panjin City, Zhangye City, Baotou City, Tonghua City, a total of 15 cities, and the remaining 99 sample cities after elimination. Based on the panel data of the remaining 99 resource-based cities from 2005 to 2018, the two-way fixed effect regression is re-performed, and the regression outcomes are reported in Table 6 (1) and (2). After comparing the benchmark results, it is found that except that the level of capital factor mismatch in Column (2) passes the test at the 5 % confidence level, the regression coefficients of the degree of misallocation of other factors are significantly negative at the statistical level of 1 %. According to the magnitude of the regression coefficient, the degree of misallocation of labor factors, the degree of misallocation of capital factors and the degree of misallocation of energy factors are in turn. This is consistent with the outcomes of the previous benchmark regression, and the empirical results are relatively robust. This shows that factor misallocation will significantly restrict the transformation and development of resource-dependent cities, and all kinds of resource-dependent cities should pay attention to the mitigation of labor factor misallocation.

3.3.2. Replace the explained variable

In this research, when using the DDF method to delve the transformation efficiency of cities reliant on resources, the actual regional GDP is selected as the expected output. The regional GDP equals the sum of the value added by each industry, which is the final result of the production activities of all permanent units in a certain period of time. Taking it as the expected output can reflect the production situation of cities reliant on resources more comprehensively. However, the industrial development of resource-dependent cities has certain particularity. These cities are usually highly dependent on the extraction and processing of resources. Resource-based in-

Table 6
Results from regression testing for robustness.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	tranf	trane	trg	treg	tranf	trane	tranfp	tranep
misk	−0.036***	−0.031**	−0.003***	−0.002***	−0.045***	−0.041***	−0.112***	−0.139***
	(0.012)	(0.012)	(0.001)	(0.000)	(0.006)	(0.007)	(0.029)	(0.038)
misl	−0.051***	−0.054***	−0.003***	−0.003***	−0.053***	−0.058***	−0.107***	−0.109***
	(0.010)	(0.010)	(0.001)	(0.001)	(0.007)	(0.007)	(0.021)	(0.024)
mise	−0.012***	−0.015***	−0.003*	−0.004**	−0.023***	−0.029***	−0.052***	−0.073***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.005)	(0.007)
_cons	0.741***	0.747***	0.516***	0.446***	0.781***	0.798***	4.868***	4.469***
	(0.042)	(0.045)	(0.035)	(0.040)	(0.033)	(0.037)	(0.314)	(0.250)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
city	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1338	1338	1336	1336	1548	1548	1548	1548

Note: The negative binomial regression brackets in columns (7) and (8) are clustered self-help standard errors.

dustries belonging to industrial categories are often the leading industries of cities. Therefore, the industrial development of resource-dependent cities determines the economic development of cities. In previous studies on urban total factor productivity, some scholars have also selected aggregate value of industrial production as an indicator of expected output. The total value of industrial production is the total amount of industrial products sold or available for sale in monetary form by industrial enterprises over a certain period of time, mirroring the aggregate scope and collective intensity of industrial production within a set time frame. In order to reflect the influence of factor misallocation on urban transformation from different perspectives, and to reduce the bias caused by the selection of indicators, this research selects aggregate value of industrial production to replace the regional GDP as the expected output, and re-estimates the transformation effectiveness of resource-dependent cities. Since the relevant yearbooks have no longer counted the total industrial output value of the Chinese government since 2017, the data time span of aggregate value of industrial production of each city is from 2005 to 2016. In the absence of the city 's index of industrial producer ex-factory prices, the provincial industrial producer ex-factory price index is used as an alternative to reduce the total industrial output value of resource-dependent cities. Under the setting of two weights (1/9 , 1/9 , 1/9 , 1/3 , 1/3) and (0 , 0 , 1/3 , 1/3 , 1/3), the transformation efficiency trg and treg are recalculated respectively.

Based on the panel data of 114 resource-based cities from 2005 to 2016 of China, the two-way fixed effect regression is carried out again. Columns (3) and (4) of Table 6 reports the regression results using trg and treg as the explained variables. It can be seen that the regression coefficient of the mismatch degree of each factor still displays a markedly negative association when evaluated at the threshold 1 %, except that the mismatch degree of energy factors in columns (3) and (4) passed the test at the confidence levels of 10 % and 5 %, respectively. It verifies the inhibitory effect of urban factor mismatch on urban transformation, that is, increasing the degree of urban factor mismatch will reduce the efficiency of urban transformation, pointing to the fact that the main conclusions of this study are robust. After comparing the columns (3) and (6) of the benchmark regression in Table 2 and the columns (3) and (4) of Table 6 and it can also be found that the magnitude of the regression coefficient replacing the explanatory variable is much smaller than that of the original benchmark regression, which indicates that the factor mismatch has a greater effect on the overall output of the city, while the related industrial industries represented by resource-based industries are less affected by factor mismatch, and some industries may even become relative beneficiaries due to factor mismatch.

3.3.3. *Using different regression models*

Since the value range of transformation efficiency is 0–1, there are a large number of samples with urban transformation efficiency of 1, and the explained variables have the characteristics of merged data. Therefore, this research uses the Tobit model to further test the impact of factor misallocation on urban transformation. In addition, the level of transformation efficiency is only reflected by the size of the value of transformation efficiency. Therefore, expanding or reducing the number of times in the same proportion will not add or reduce information, and will not change the order of efficiency. Therefore, when the transformation efficiency is multiplied by 100 and rounded, the new explanatory variables tranfp and tranep are obtained. At this time, the value of transformation efficiency has the characteristics of counting variables. More counting means high efficiency, and the counting model can be used for regression. Table 7 reveals that the mean and standard deviation of tranf and trane are basically consistent with the average and standard deviation of tranf and trane after multiplying by 100. At the same time, because the variance and expectation of the explained variables are obviously inconsistent, this study uses negative binomial regression model to test the robustness. The panel data of 114 resource-based cities from 2005 to 2018 are used for Tobit regression and negative binomial regression respectively. The Findings of the two regression models are reported in columns (5) and (6) and columns (7) and (8) of Table 6 respectively. After using different models for regression, the estimated parameters of the regression of factor misallocation are significantly negative at the level of 1 %, and factor misallocation still significantly inhibits urban transformation, which is completely consistent with the benchmark regression results, further indicating the robustness of the findings of this research.

3.4. *Heterogeneity test*

3.4.1. *Decomposition of transformation efficiency*

According to the previous analysis, compared with the efficiency level of non-resource-dependent cities, the transformation efficiency of resource-dependent cities only considering energy input is more obvious, which can better reflect the attributes of low economic output of resource-dependent cities and more unexpected output. Therefore, this research breaks down the efficiency of transformation for 114 cities with resource-dependent economiescities reliant on resources only considering energy input, and further obtains the efficiency of each resource-dependent city in the three directions of output growth, consumption of energy and eco-friendliness from 2005 to 2018, namely output efficiency (y), energy efficiency (e) and environmental efficiency (env). Table 8 shows the regression results of each decomposition part of factor mismatch and transformation efficiency. It can be seen that whether

Table 7
Descriptive characteristics of the explained variable.

Variable	Sample Size	Mean	Std.
tranf	1596	0.5040	0.2188
tranfp	1596	50.4110	21.8752
trane	1596	0.4657	0.2379
tranep	1596	46.5789	23.7932

or not the significance test is passed, the regression coefficients of the degree of factor misallocation are negative, and only the regression coefficients of the level of capital factor misallocation in column (1) failed to meet the threshold for statistical significance. Therefore, we can deduce that the improper allocation of capital significantly impedes progress on energy efficiency (e) and environmental efficiency (env) of cities reliant on resources, and other types of misallocation have a significant inhibitory effect on output efficiency (y), energy efficiency (e) and environmental efficiency (env) of cities reliant on resources.

For output efficiency (y), capital misallocation has a negative correlation with it but not significant, while labor misallocation and energy misallocation pass the test at a confidence degree of 1 %, indicating that labor misallocation and energy misallocation will considerably hinder the enhancement of efficiency in urban productivity, and the inhibitory effect of labor misallocation is particularly obvious. This may be because: the impact of energy mismatch on output is more limited to resource-based industries, other industries rely less on energy, only need to ensure normal use to operate normally, and more energy possession will not significantly increase output; contrary to this energy factor, the misallocation of labor factors will affect the output of the whole society. On the one hand, resource-based industries cannot attract high-quality workers to accumulate human capital, the output efficiency of related industries cannot be effectively improved, and the marginal output of labor factors is less; on the other hand, related talents will flow into other industries, especially the financial industry and public service industry, resulting in excessive labor allocation and ultimately reducing the output efficiency of the whole society. For energy efficiency (e) and environmental efficiency (env), the regression coefficients of the degree of factor misallocation are significantly negative, indicating that factor misallocation will hinder the improvement of urban energy efficiency and environmental efficiency. Among all the factors, the magnitude of the regression coefficient of the degree of labor factor misallocation is still the largest, which indicates that the impact of labor factor misallocation on urban transformation is the largest, which is consistent with the findings of the standard regression analysis, and further emphasizes the importance of alleviating labor factor misallocation on urban transformation and development.

3.4.2. Different geographical regions

The phenomenon of unbalanced economic development among regions in China is very prominent. The degree of socio-economic development among the three regions of the eastern, central and western regions is very different. Therefore, cities that rely on natural resources in various regions have unique developmental histories and distinctive characteristics. In this study, 114 resource-based cities are divided into eastern, central, western and northeastern provinces according to their provinces to test the differential impact of factor misallocation on urban transformation efficiency. Tables 9 and 10 report the regression results of the two transformation efficiencies in the sub-regional context. It is evident that the influence coefficient of factor misallocation on urban transformation efficiency is negative in both eastern and central cities, northeast cities and western cities. Among them, only the energy mismatch in eastern cities significantly inhibits the improvement of transformation efficiency; the labor mismatch and energy mismatch of central cities will simultaneously restrict the transformation of cities; the misallocation of various factors in western cities will greatly adversely affect on the transformation of cities. For the transformation efficiency considering capital, labor and energy at the same time, only the mismatch of energy elements in the northeast cities will impede the efficiency of transformation of the cities. For the transformation effectiveness considering only energy input, the mismatch of capital elements will also have a significant inhibitory effect.

It is particularly important to note that in the western and northeastern regions, especially in the northeastern region, the inhibitory effect of capital factor misallocation on urban transformation efficiency is much greater than that in other regions, while the influence coefficient of labor factor misallocation is not significant. Here are some potential reasons: on the one hand, due to the fact that the number of cities in Northeast China is the least after division, the estimated coefficient is not significant due to the small sample size; on the other hand, the development of resource-dependent cities in Northeast China is relatively early. As an old industrial base, Northeast China has a high level of urbanization and industrialization. Industrialization is at a relatively high stage, and it does not rely solely on low-end industries such as mining resources to achieve urban development. Moreover, due to a significant amount of state-owned enterprises in the city, the internal flow of labor factors is not as frequent as that in the eastern region, which will not lead to

Table 8
Regression results of transformation efficiency decomposition.

	(1)	(2)	(3)
	y	e	env
misk	−0.035	−0.036**	−0.029**
	(0.027)	(0.015)	(0.014)
misl	−0.109***	−0.046***	−0.053***
	(0.025)	(0.017)	(0.018)
mise	−0.040***	−0.033***	−0.022***
	(0.007)	(0.003)	(0.006)
_cons	0.921***	0.959***	0.583***
	(0.091)	(0.054)	(0.059)
Control variables	Yes	Yes	Yes
city	Yes	Yes	Yes
year	Yes	Yes	Yes
N	1548	1548	1548
r2	0.201	0.194	0.126

Table 9
Regional regression results(1).

	Eastern	Central	Western	Northeastern
	tranf	tranf	tranf	tranf
misk	−0.018	−0.009	−0.060*	−0.073
	(0.022)	(0.014)	(0.030)	(0.047)
misl	−0.031	−0.075***	−0.074***	−0.040
	(0.022)	(0.025)	(0.016)	(0.040)
mise	−0.019***	−0.015***	−0.030***	−0.027***
	(0.003)	(0.004)	(0.005)	(0.007)
_cons	0.633***	0.640***	0.978***	0.861***
	(0.056)	(0.070)	(0.079)	(0.117)
Control variables	Yes	Yes	Yes	Yes
city	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes
N	272	518	495	263
r2	0.332	0.252	0.408	0.340

Table 10
Regional regression results(2).

	Eastern	Central	Western	Northeastern
	trane	trane	trane	trane
misk	−0.011	−0.003	−0.057*	−0.081*
	(0.022)	(0.016)	(0.029)	(0.047)
misl	−0.032	−0.072**	−0.072***	−0.042
	(0.023)	(0.027)	(0.016)	(0.044)
mise	−0.026***	−0.022***	−0.035***	−0.034***
	(0.003)	(0.006)	(0.005)	(0.008)
_cons	0.631***	0.625***	0.994***	0.875***
	(0.055)	(0.079)	(0.078)	(0.122)
Control variables	Yes	Yes	Yes	Yes
city	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes
N	272	518	495	263
r2	0.430	0.263	0.448	0.401

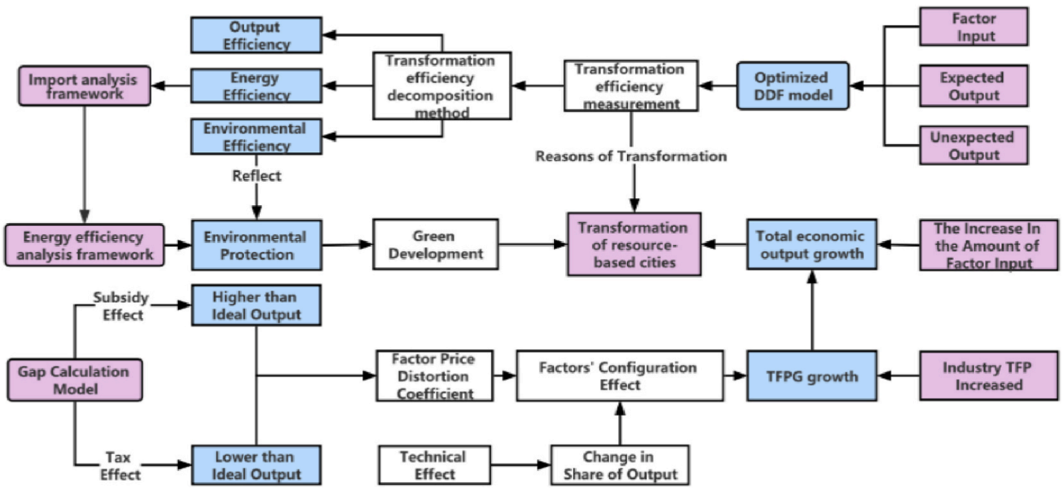

Fig. 1. Logical structure diagram of the measurement framework.

excessive changes in the output of various industries. Therefore, the influence coefficient of the degree of mismatch of labor factors is reduced.

4. Conclusion

This study first refers to the research of Syrquin [63], decomposes the total factor productivity change (TFPG) into the growth of industry TFP and the distribution effect of factors, and then further decomposes the allocation effect into two parts, (1) only the change brought by the change of output share. (2) Changes caused by changes in the degree of factor price distortions in various industries. The distorted price makes the factors unable to be optimally allocated among industries. Therefore, as long as the degree of price distortion decreases, the factors will flow again to approach the optimal allocation, thereby increasing TFP and total economic output. Simultaneously, combined with the research of Aoki (2012) [64], the gap estimation model is constructed by using the perfect competition model, and the distortion degree of capital allocation is described by using the form of labor and capital tax. Finally, the energy efficiency analysis model based on C-D function is integrated. At the same time, the DDF model is optimized by introducing exogenous weights and direction vectors. Based on the optimized DDF model, the corresponding urban transformation efficiency and the decomposed factor efficiency are dynamically measured. Combined with the analysis framework, a systematic resource-based factor misallocation measurement and analysis framework is realized (see Fig. 1). Through the test of endogeneity, robustness and heterogeneity, we find that the measurement framework can effectively measure the factor misallocation of resource-dependent cities. It can also effectively guide the transformation of resource-dependent cities through the calculation of factor efficiency.

On the whole, factor misallocation exerts a notable hindering influence on the transformation of cities reliant on resources. Therefore, by alleviating the degree of factor mismatch and improving the allocation of resources, the transformation of resource-dependent cities can be effectively promoted. Moreover, through further analysis, it has been observed that the final impact of the transformation efficiency of resource-dependent cities is concentrated on the environment of the city, and the environmental protection benefits can be used to evaluate the transformation of cities reliant on resources. Finally, the specific mechanism of factor mismatch affecting industrial transformation summarized in this study is as follows:

The factor mismatch will reduce the actual output by reducing the total factor productivity to affect the improvement of economic efficiency; factor misallocation affects the transformation of resource-dependent cities by inhibiting the refinement and advancement of industrial structure, and indirectly aggravates environmental problems while forming a lock-in development model. Factor misallocation will inhibit the R & D investment of enterprises to affect the improvement of energy efficiency, which will indirectly aggravate environmental pollution. Under the general theoretical framework, the mechanism of the impact of specific factor misallocation on the industrial transformation of resource-dependent cities is as follows: capital misallocation between industries reduces the output efficiency and environmental performance of resource-dependent cities by inhibiting the transformation and upgrading of industrial structure [5–7,33]; the labor mismatch between industries makes the actual output of the city deviate from the output under the optimal allocation, which reduces the transformation efficiency [14,26,32,80]; energy misallocation among enterprises reduces energy efficiency and environmental efficiency by encouraging enterprises to use energy to replace technology, while energy misallocation among industries will occupy the elements needed for enhancing alternative industries, inhibit the upgrading of urban industrial structure, cause the loss of energy efficiency and environmental efficiency [5,27,28], and hinder the overall industrial transformation of resource-dependent cities.

Simultaneously, through the operation and test of the model, this study has three findings.

(1) Labor misallocation and energy misallocation will significantly inhibit the improvement of urban output efficiency. Among them, energy factors are more important to resource-dependent industries and have less impact on other industries. Therefore, energy factors have less impact on the output of the whole society and are more likely to produce undesired output to affect the environment, and the impact on transformation efficiency is more concentrated in the environment. The inhibitory effect of labor mismatch is particularly obvious, which may be because: the impact of energy mismatch on output is more limited to resource-based industries, and other industries are less dependent on energy. They can operate normally only by ensuring normal use, and more energy possession will not significantly increase output; contrary to this energy factor, the misallocation of labor factors will affect the output of the whole society. On the one hand, resource-based industries cannot attract high-quality workers to accumulate human capital, the output efficiency of related industries cannot be effectively improved, and the marginal output of labor factors is less. On the other hand, related talents will flow into other industries, especially the financial industry and public service industry, resulting in excessive labor allocation and ultimately reducing the output efficiency of the whole society. For energy efficiency and environmental efficiency, factor mismatch will hinder the improvement of urban energy effectiveness and environmental effectiveness. Among all the factors, the mismatch of labor factors has the greatest impact on urban transformation.

(2) The industrial structure of resource-dependent cities is unreasonable, and other manufacturing industries that also require a substantial amount of fixed investment are congenitally underdeveloped, and the internal structure of the industry is single. Therefore, although there is an over-allocation of capital in resource-dependent industries, due to the small size of other manufacturing industries, the service industry has little demand for capital factors. Overall, the crowding out of other industries is relatively limited, but the over-allocation of capital in resource-based industries does have a substantial impact on the environment. The labor factor exerts a more significant impact on various industries. The service industry naturally need a large amount of labor, and the resource-based industry is no exception. For example, the early mining industry in China 's resource-dependent cities has a low level of automation, and still needs to hire a large number of manual excavation and mining. The

allocation of labor factors will have a direct and obvious impact on the output of the entire city. Simultaneously, the accumulation of human capital will also affect the improvement of technical level, indirectly affect energy efficiency and output efficiency, and ultimately affect the city 's output and environment. Therefore, the mismatch of labor factors has the most significant inhibitory effect on urban transformation.

(3) From the perspective of China 's resource-dependent cities, the phenomenon of unbalanced economic development among regions in China is very prominent. The degree of economic and social development among the three regions of the eastern, central and western regions is very different. Only energy mismatch in the eastern cities significantly inhibits the improvement of transformation efficiency. The labor mismatch and energy mismatch of central cities will simultaneously restrict the transformation of cities; the misallocation of various factors in western cities will have a substantial adverse impact on the transformation of cities. For the transformation efficiency, taking into account capital, labor, and energy simultaneously, only the mismatch of energy elements in the northeast cities will exhibit an inhibiting effect on the transformation efficiency of the cities. For the transformation effectiveness considering only energy input, the mismatch of capital elements will also have a significant inhibitory effect. It is particularly important to note that in the western and northeastern regions, especially in the northeastern region, the inhibitory effect of capital factor misallocation on urban transformation efficiency is substantially higher than that in other regions, while the influence coefficient of labor factor misallocation is not significant. Here are some potential reasons: on the one hand, due to the fact that the quantity of cities in Northeast China is the least after division, the estimated coefficient is not significant due to the small sample size; on the other hand, the development of cities reliant on resources in Northeast China is relatively early. As a former industrial base, Northeast China has a high level of urbanization and industrialization. Industrialization is at a relatively high stage, and it does not rely solely on low-end industries such as mining resources to achieve urban development. Moreover, due to the large quantity of state-owned enterprises in the city, the internal flow of labor factors is not as frequent as that in the eastern region, which will not lead to excessive changes in the output of various industries. Therefore, the influence coefficient of the mismatch degree of labor factors is reduced.

This study innovatively starts with the decomposition theory of total factor productivity change, carries out meticulous re-decomposition, and reaches the level of systematic interpretation of available formulas. Compared with previous studies, this study can systematically analyze the mechanism of resource-dependent city transformation from the perspective of the impact of factor composition units on the whole and the linkage effect between production factors. Simultaneously, it also uses the phenomenon of price distortion to link the impact of energy efficiency on the environment with the influence of energy on the input of production factors, and realizes the integration of the production side and the output side to further quantitatively study the impact of the interaction between the two ends. It can eliminate potential influencing factors such as endogeneity and heterogeneity, and offer scientific backing for the transformation of cities reliant on resources.

Further, this study also has certain defects, and the measurement of TFP in the industry is still not in place. In this study, it is only assumed that the allocation of factors has a greater impact on TFP, and further replaced with the rational allocation of factors. Future research can be further in-depth analysis. At the same time, this study only selects the necessary factors of production (labor, capital, energy) to construct the measurement model in the measurement of cities reliant on resources. In the calculation of factor misallocation, only the overall misallocation degree of labor, capital and energy is measured. Due to the limitation of city-level data, different types of factors are not further refined. For example, labor factor misallocation does not distinguish between high-skilled and low-skilled labor. In the empirical test of the efficiency of transformation in cities reliant on resources, there is a lack of further

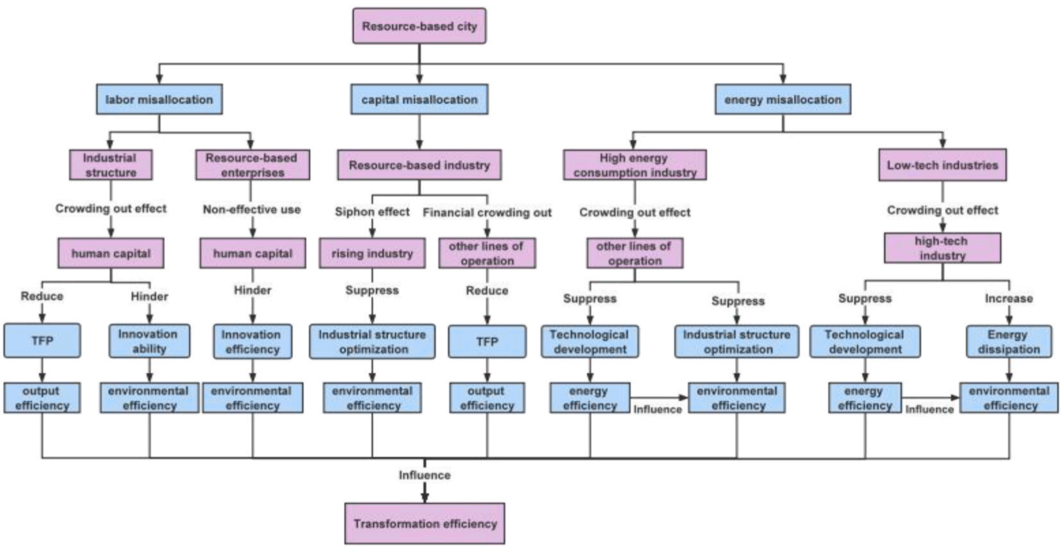

Fig. 2. The influence mechanism of factor misallocation in resource-based cities.

mechanism analysis, and the heterogeneity analysis needs to be further expanded. Finally, future research can further optimize the flexibility of model calculation and improve the connectivity between various combination models.

5. Policy recommendations

Simultaneously, according to the measurement framework, this study also analyzes from several aspects such as different regions, different industries and different factors, and summarizes the action system that affects the redevelopment of cities reliant on resources (see Fig. 2), which can provide a clear reference for the transformation of most resource-based cities.

According to the summary of the mechanism of factor misallocation affecting the transition of resource-dependent cities, and the various situations of factor misallocation affecting the transformation of cities reliant on resources abstracted from the Chinese perspective, this study finally puts forward three auxiliary suggestions for the transition of cities reliant on resources around the world.

(1) Guiding the flow of factors to stimulate the endogenous power of industrial development. In order to successfully achieve the transformation and eliminate the dependence on resources and energy, cities reliant on resources must build a diversified industrial system and rely on alternative industries and emerging industries to empower urban development. On the one hand, the cities reliant on resources can transform and upgrade traditional resource industries and tap their development potential. After years of development, cities reliant on resources have certain technical advantages in resource exploitation and resource processing. Resource-dependent cities should not completely abandon their existing advantages, but should transform resource industries through high-tech technologies, and apply new technologies and new processes to the production of traditional industries to enhance the added value and technical content of products. On the other hand, cities reliant on resources can enhance the attractiveness of cities by improving the investment and business environment to complete investment attraction, and then develop non-resource-based industries, cultivate diversified replacement industries, and achieve the optimization and upgrading of industrial structure. In the face of investment enterprises, especially small and medium-sized enterprises, cities reliant on resources should take the initiative to contact and assist them to solve various problems that may be encountered when enterprises land.

(2) The input of labor factors is a prerequisite for economic growth, and the high-quality labor force in labor factors is indispensable for high-quality economic development. The empirical research in this paper has shown that the misallocation of labor factors has the greatest impact on urban transformation, so alleviating the mismatch of labor factors can significantly enhance the transformation efficiency of cities. Combined with the research on the mechanism of labor mismatch in urban transformation, cities reliant on resources especially lack high-quality talents. Therefore, resource-based cities should first boost investment in education, especially to build a diversified vocational training mechanism, organize professional and technical personnel to participate in training regularly and irregularly, improve their professional skills and comprehensive quality, and cultivate local talents. Secondly, actively introduce special talents and improve the public employment service system, improve the welfare treatment of core employees and introduced talents, provide preferential policies for housing and medical care, and improve the talent service system; finally, we will form a complete talent incentive system, encourage enterprises to invest in human capital, form a multi-level and multi-form incentive system for governments, enterprises and institutions, reward outstanding talents with outstanding contributions, and form a society-wide respect for talents.

(3) Build a complete industrial chain system. In the past, the products of resource-based enterprises were mainly raw materials and primary products, and the production performance was simple mining and processing, resulting in a generally low profit margin of products. The government should make use of green finance, use transformation support funds to support resource-based enterprises to introduce and develop new technologies, assist advanced enterprises to breakthrough the lack and bottleneck of key technologies and links, achieve the deep processing of resources, enhance the added value of products, and encourage enterprises to sell some of the profits of primary products for research and development to enhance the economic benefits of enterprises. Simultaneously, the local government should also rely on local resource endowments to support leading enterprises to establish industrial clusters, open up the upstream and downstream segments of the industrial chain, complete the vertical industrial chain docking, and ultimately achieve the transformation and development of traditional resource-based industries.

Data availability statement

Most of data can be found in China 'National Sustainable Development Plan for Resource-based Cities(2013–2020) '(https://www.gov.cn/gongbao/content/2013/content_2547140.htm), 'China City Statistical Yearbook ' (https://www.zgtjnj.org/navibooklist-n3020013291-1.html) and ' China Statistical Yearbook '(https://www.stats.gov.cn/sj/ndsj/). Detailed data can request from the corresponding author.

CRediT authorship contribution statement

Runqun Yu: Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Zhuoyang Luo:** Writing – review & editing, Writing – original draft, Visualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Runqun Yu reports financial support was provided by Liaoning Social Science Planning Fund Project. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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