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Evaluation of Urban–Rural Total Factor Flow Efficiency Based on Multiple Symbiosis: Insights from 27 Provinces in China

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Abstract: The rational flow of production factors is crucial for promoting benign interactions between urban and rural areas. To unveil the intrinsic mechanisms of factor flow pathways promoting mutual symbiosis between urban and rural areas, this study, based on symbiosis theory, takes total factor flow including land, technology, capital, and labor as inputs and urban–rural symbiosis level as output. Utilizing the Super-Efficiency Slack-Based Measure (SBM) model, this study calculates the urban–rural total factor flow efficiency of 27 provinces in China from 2011 to 2021 and explores specific improvement directions of urban–rural factor flow based on projection analysis. This study revealed the following findings: (1) The overall efficiency of urban–rural total factor flow in China shows a fluctuating upward trend but has not yet reached an effective state. There are significant regional disparities, with 8 provinces such as Guangdong and Fujian reaching Pareto optimality, while the remaining 19 provinces exhibit varying degrees of inefficiency. (2) Provinces with insufficient symbiotic production are mainly concentrated in the central and western regions and the northeast region, with 14 provinces including Inner Mongolia showing the inadequate transformation of urban–rural symbiosis. However, except for Hainan, the situation is gradually improving in other regions annually. (3) There is input redundancy in total factor, where land, labor, and capital redundancy are the main reasons for the inefficiency of urban–rural total factor flow in China. However, trends show that the redundancy of land, labor, and capital elements is improving annually, while technology redundancy is worsening. (4) Through a comprehensive analysis of input redundancy, output deficiency, symbiosis coefficient, and efficiency, this study categorizes the impact of factor flow on urban–rural symbiosis level into basic matching, redundancy, and comprehensive scarcity types. The research provides scientific guidance for promoting sustainable development through the rational flow of total factors and offers valuable insights for similar countries.

Keywords: urban–rural symbiosis; total factor flow; super-efficient SBM model; redundancy analysis; China



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1. Introduction

Urban and rural areas are distinct spatial forms of human production and life, which interact and form a cohesive community. Countries have always prioritized the coordinated development of urban–rural relations. With the progress of global urbanization and industrialization, the issue of imbalanced urban–rural development and inadequate rural growth persists in the economic and social development of nations worldwide. China also confronts a similar challenge of unbalanced urban–rural development [1], with the primary obstacle being the uneven flow of production factors between urban and rural regions. Over an extended period, production factors such as labor, capital, and technology have predominantly exhibited a unidirectional flow from rural to urban areas, leading to the continuous concentration of resources in cities. This phenomenon further exacerbates the challenges associated with agricultural marginalization, rural population decline, and farmer aging [2]. The inability of urban and rural factors to flow smoothly and exchange

equally is not only a significant manifestation of the urban–rural dual structure but also an important reason for the lag in the transformation of the urban–rural dual structure [3]. To accelerate the dismantling of the urban–rural dual structure and achieve integrated urban–rural development, we must take the lead in making breakthroughs in the smooth flow of urban and rural factors [4]. With the continuous promotion of China’s rural revitalization strategy, the rational flow of factors between urban and rural areas plays a pivotal role in fostering symbiotic development. However, variations in economic foundations and policy implementation efforts across different regions result in disparities in the level of urban–rural symbiosis based on factor flow [5]. Therefore, it is imperative to scientifically measure the impact of factor flow on the level of urban–rural symbiosis and evaluate its efficiency along with regional discrepancies. The complexity, diversity, and dynamism of the urban–rural mega-system are highly consistent with the symbiosis theory [6]. Therefore, this paper applies the symbiosis theory to interpret the relationship between urban and rural areas, abstracting cities and villages as two mutual-influenced communities, to evaluate the efficiency of the two-way flow of urban and rural labor, technology, capital, and land factors in promoting the symbiotic development of urban and rural areas. Moreover, this study explores the redundancy of the input of factors to villages or cities and the insufficient output of symbiosis to provide a scientific basis for the institutional construction and practice promotion of common prosperity in urban and rural areas.

German biologist Anton de Bery first introduced the concept of “symbiosis” in 1897, pointing out that it represents a lasting material connection between diverse organisms, which can be employed to analyze the dynamic relationships among different units within a system [7]. The fundamental components of symbiotic theory encompass symbiotic units, symbiotic environments, and symbiotic models. As research progresses, the symbiotic theory has gradually extended its scope to encompass social and economic domains, offering a novel framework for contemplation and interpretation to investigate the survival, prosperity, and development of human society and its living space [8]. In the context of urban–rural integration, factor resources flow reciprocally between urban and rural areas, fostering an interdependent and mutually reinforcing relationship between cities and villages known as urban–rural symbiosis. In the process of achieving urban–rural integration and rural modernization in Western developed countries, numerous classic theories implicitly incorporate the concept of symbiosis [9]. For instance, Thomas More’s vision of “Utopia,” Saint-Simon’s viewpoint of “social equality between urban and rural areas,” Fourier’s ideal of a “harmonious society,” and the future development concept of “urban–rural integration” proposed by Marx and Engels, all reflect, to varying degrees, the ideal state of mutually beneficial symbiosis between urban and rural areas [10–12]. In recent years, scholars have conducted extensive research on the theoretical connotations, relationship evolution, influencing mechanisms, and improvement pathways of urban–rural symbiosis. They generally agree that the core of urban–rural symbiosis lies in strengthening exchanges between urban and rural areas in terms of material, information, and energy, thereby promoting interconnectedness, interaction, and coordinated development between urban and rural areas. This symbiotic relationship manifests as the city driving the countryside and the countryside promoting the city, with each serving as a resource and market for the other, mutually providing services and environments [13]. From a symbiotic perspective, the urban–rural relationship in China has undergone an evolutionary process from a “parasitic” to a “biased mutualism,” then to an “asymmetric reciprocal symbiosis,” and finally to a “symmetric reciprocal symbiosis” governance model, reflecting a developmental stage from differentiation, opposition, integration, to unification [14]. Regarding the influencing factors of urban–rural symbiosis, scholars have pointed out that due to long-standing barriers such as the land system and household registration system in China, the imbalance in urban–rural resource allocation remains severe [15]. They emphasized that the free flow of urban and rural factors plays an important role in the synergistic development of urban and rural areas [16]. In addition, factors such as marketization [17], transportation infrastructure [18], and spatial structure [19] also

have profound impacts on the urban–rural symbiotic relationship. To enhance the level of urban–rural symbiosis, scholars have proposed specific improvement pathways from multiple perspectives, including optimizing urban–rural spatial layout and governance [20], promoting educational integration [21], and improving the development mechanism of public services [22]. Meanwhile, they have also suggested optimization strategies focusing on urban–rural cultural integration [23], ecological construction [24], financial relationship development [25], and the interactive development of tourism resources [26], aiming to achieve a mutually beneficial, harmonious, and sustainable urban–rural symbiotic pattern. In summary, employing the theory of symbiosis to analyze the characteristics and evolutionary patterns of urban–rural relations has yielded substantial findings, and gradually formed an academic consensus that symbiotic relations are a scientific perspective for evaluating the development quality of urban–rural relations, which is identified as an important indicator for measuring the development quality of urban–rural relations in this paper.

Urban–rural factor flow has always been a topic of concern in the field of economics and sociology, and many mature theories and viewpoints have been formed in the study of urban–rural factor flow. Neoclassical economics emphasizes that if the flow of market factors is not blocked, the transfer of agricultural surplus labor will help achieve the convergence of labor productivity in agricultural and non-agricultural fields [27,28]. The new dual growth theory points out that the restriction of the flow of production factors between agricultural and non-agricultural sectors may hinder the elimination of the urban–rural dual structure [29]. In the study of economic growth and income disparity, Kuznets (1955) proposed the theory of an inverted U-curve, suggesting that the transition from isolated urban and rural factors to their free flow was responsible for this pattern. This theory offers a novel perspective in explaining the relationship between urban–rural disparities and economic growth rates [30,31]. Subsequently, Harris and Todaro (1970) employed an urban–rural labor migration model to investigate the connection between labor factor mobility and urban–rural gaps, providing valuable insights into comprehending the mechanisms and impacts of urban–rural factor flows [28,32]. In recent years, some scholars have conducted in-depth research on the influence mechanism and promotion path of urban–rural symbiosis by exploring the paths for developing countries to realize urban–rural symbiosis from the perspectives of labor transfer [33], government responsibility [34], urban pull [35] and industry promotion [36,37]. They concluded that the free flow of factors between urban and rural areas is crucial for rural development, and it is an effective way to crack the pattern of unbalanced urban–rural development [38]. The essence of urban–rural symbiosis lies in achieving the equitable sharing of social development benefits between urban and rural areas [39]. These studies provide theoretical guidance for enhancing urban–rural symbiosis, emphasizing that the removal of institutional and mechanistic barriers to the flow of factors between urban and rural areas, as well as the promotion of free flow and equitable exchange of factors, are crucial for advancing the level of urban–rural symbiosis. Other scholars have conducted research on the characteristics of urban–rural factor flow, positing that the type, direction, intensity, and degree of freedom of such flow [14] can significantly influence the relationship between urban and rural areas. The evolution of urban–rural factor flow has transitioned from a unidirectional to a bidirectional, circular network-based exchange [38]. Consequently, fostering bidirectional urban–rural factor flows emerges as a pivotal approach towards achieving symbiotic relations between urban and rural domains [40]. According to the distinct roles of government and market, factor flow has undergone various forms, including unrestricted, compulsory, and regulated. Moreover, the intensity of factor flow exhibits a positive correlation with the degree of urban–rural connectivity [14]. Furthermore, scholars have examined the impact of individual factors such as human capital [41], finance [42], and land [43] on the relationship between urban and rural areas from economic and geographical perspectives. They have also confirmed the non-linear association between single-factor flow and the income gap

between urban and rural regions, as well as the integrated development of the urban–rural economy [44].

The above literature has some explanatory power in the study of urban–rural symbiotic relationships and factor flow, but there are still several shortcomings. First of all, the measurement of the development level of urban–rural relations has focused on single economic and social indicators, such as the urban–rural income gap and the equalization of the urban–rural public service system, which is difficult to reflect the whole picture of the urban–rural complex system. Rural and urban areas should be a “five-in-one” symbiosis system covering politics, economy, culture, society, and ecology, and there is a complex relationship of multi-dimensional interactions and dynamics, but there is little literature that quantifies the level of urban–rural symbiosis from the perspective of multi-dimensional symbiosis. Secondly, most studies on the factors within the realm of urban–rural relationships primarily focus on individual indicators of factor flow such as labor, capital, and technology. However, they fail to systematically examine the overall effect of factor mobility on urban–rural diversified symbiosis from the comprehensive perspective of total factor flow. Thirdly, most of the empirical studies on the relationship between factor flow and urban–rural areas have been limited to the level of significant impact, reflecting the high explanatory power of factor flow on urban–rural development, but lacking attention to the efficiency of the flow of factors to urban or rural areas, which makes it impossible to accurately grasp and evaluate the effects of the “urban feeding the rural areas” policy over the past seven years since the implementation of the strategy for revitalization of the countryside. It is even more impossible to scientifically judge the differences in the level of symbiotic development of urban and rural areas based on the heterogeneity of regional development and to reveal the role played by the inputs of factors in the development of the urban–rural areas. Therefore, this study focuses on examining the efficiency of urban–rural factor flow, taking the level of total factor flow of labor, capital, technology, and land as the input indicator, and the level of urban–rural symbiosis of the “Five-in-One” as the output indicator. Moreover, the super-efficiency SBM model is applied to measure the efficiency of China’s urban–rural factor flow in order to provide theoretical guidance and a scientific basis for the further promotion of the level of urban–rural symbiosis.

The remainder of this paper is structured as follows. Section 2 describes the data and methodology used in this study and the efficiency evaluation index system is constructed. Section 3 presents and discusses the results of the efficiency evaluation and projection analysis, followed by the conclusions, recommendations, and discussion in Section 4.

2. Data Sources, Indicator Construction, and Research Methods

2.1. Data Sources

This study takes the provincial area as the research scale and measures the efficiency of total factor flow between urban and rural areas in China based on the multiple symbiosis perspective. Considering that Beijing, Tianjin, Shanghai, and Chongqing have an urbanization rate close to 90% with unclear urban–rural boundaries [45], using factor flow efficiency as a decision-making unit for evaluating urban–rural total factor flow efficiency becomes challenging. Therefore, this research focuses on 27 provinces in China from 2011 to 2021 as the subjects of analysis. The primary data sources include the *China Statistical Yearbook* (2011–2021), the *China Urban–Rural Construction Statistical Yearbook*, the *China Financial Yearbook*, the *China Agricultural Statistical Yearbook*, and regional statistical yearbooks. In cases where certain provinces had missing data for specific years, linear interpolation was used for supplementation.

2.2. Indicator Construction

This study abstracts the region of total factor flow into two major spaces, urban and rural, and argues that urban–rural total factor flow is characterized by the dichotomy of either/or in that the application scenarios of total factors are either urban or rural. To

accurately measure the level of total factor flow between urban and rural areas, and taking into account data availability, this study reflects the level of factor flow between urban and rural areas in terms of the ratio of factor presence in the countryside. Additionally, labor, technology, capital, and land are selected as input indicators for evaluating the efficiency of urban–rural total factor flow. The symbiotic relationship between urban and rural areas manifests itself as a dynamic organic system formed through the continuous flow of capital, technology, labor, and other factors between urban and rural areas in a certain symbiotic environment [46]. Based on the symbiosis theory, this study constructs a comprehensive index system of urban–rural symbiosis from the five-in-one level of politics, economy, society, culture, and ecology; calculates the weights by entropy method; and takes the coefficients of symbiosis in each province as the output indicators for the evaluation of the efficiency of urban–rural total factor flow. Based on this, the evaluation index system of China’s urban and rural total factor flow efficiency is constructed, as shown in Table 1. Among these, political sharing refers to the rational allocation of political resources between urban and rural areas, covering policy support, the construction of municipal public facilities, public financial investment, social welfare, and other aspects. This paper selects social security, per capita road area, urban–rural public financial investment, and urban–rural population ratio to measure the level of urban–rural political coordination [7]. Economic prosperity focuses on achieving a reasonable allocation and shared prosperity of economic resources between urban and rural areas through the equitable distribution of urban–rural land appreciation gains and the support and feedback from industry to agriculture. This paper selects the per capita income of urban and rural residents, local fiscal revenue, and per capita GDP to reflect the level of economic coordination between urban and rural areas. Social co-construction mainly refers to the coordinated development of urban and rural livelihoods, with a focus on ensuring access to healthcare, employment, and other issues related to people’s livelihood. Therefore, the ratio of urban–rural per capita medical institution beds and the ratio of urban–rural year-end employment population are selected as indicators. Furthermore, the development of socialism with Chinese characteristics is moving towards informatization and digitization, with the internet serving as the foundation for information construction. Thus, the urban–rural differences in internet broadband access are used to reflect the level of urban–rural information infrastructure construction. The level of cultural integration is primarily measured by differences in urban–rural educational resources, book resources, and cultural consumption. Additionally, ecological protection should be taken into consideration during urban–rural development. This paper measures the level of urban–rural ecological coordination based on per capita green area, per capita daily water consumption, and per capita carbon emissions.

Table 1. Evaluation indicator system of urban and rural total factor flow efficiency.

Indicator Classification	Primary Indicators	Secondary Indicators	Tertiary Indicators	Calculation Method	Weight
Input Indicators	Labor factor flow	-	-	Number of employees in the primary industry/total number of employees	-
	Capital factor flow	-	-	Balance of agriculture-related loans/balance of various loans	-
	Technology factor flow	-	-	Total power of agricultural machinery/number of employees in primary industry	-
	Land factor flow	-	-	Rural arable land area/total land area	-

Table 1. Cont.

Indicator Classification	Primary Indicators	Secondary Indicators	Tertiary Indicators	Calculation Method	Weight
Output indicators	Coefficient of symbiosis	Political sharing	Social security harmonization	Expenditure of basic medical insurance fund for urban workers/expenditure of basic medical insurance fund for rural residents	0.0484
			Road size harmonization	Per capita road area in urban areas/per capita road area in rural areas	0.1469
			Public expenditure ratio	Urban general public finance expenditure/rural general public finance expenditure	0.0183
			Urban/rural population ratio	Urban population/rural population	0.0960
		Economic co-prosperity	Income difference between urban and rural residents	Per capita disposable income of urban residents/per capita disposable income of rural residents	0.1255
			Local fiscal revenue difference	Urban general public finance revenue/rural general public finance revenue	0.0185
			GDP per capita differences	Per capita output value of secondary and tertiary industries/per capita output value of primary industries	0.0658
		Social co-construction	Differences in medical standards	Number of beds in medical and health institutions per 1000 urban population/number of beds in medical and health institutions per 1000 rural population	0.0117
			Harmonization of employment of the population	Number of employed persons at the end of the year in urban areas/number of employed persons at the end of the year in rural areas	0.0316
			Differences in information infrastructure	Urban broadband access users/rural broadband access users	0.0118
		Cultural integration	Differences in education levels	Amount of financial assistance for urban elementary middle school and high school/amount of financial assistance for rural elementary middle school and high school	0.0642
			Differences in library resources	Public library books per capita in urban areas/public library books per capita in rural areas	0.0230
			Differences in cultural consumption	Consumption expenditure on education, culture, and recreation of urban residents/consumption expenditure on education, culture, and recreation of rural residents	0.0118
		Ecological co-governance	Difference in green areas of parks	Green space per capita in urban areas/green space per capita in rural areas	0.0123
			Difference in water consumption	Urban per capita daily water consumption/rural per capita daily water consumption	0.1050
			Coordination degree of energy conservation and emission reduction	Urban per capita domestic carbon emissions/rural per capita domestic carbon emissions	0.2092

The urban–rural symbiosis output indicator in Table 1 is calculated using the symbiosis degree model. Firstly, the quality parameter Z of urban or rural needs to be computed to re-

flect their developmental level [47], and the calculation formula is presented in Equation (1) as follows:

$$Z = \sum_{i=1}^n W_i Q_i \quad (1)$$

where n represents the total number of provincial indicators, W_i represents the weight of indicator i , and Q_i represents the corresponding sample value.

Secondly, it is found that there is a linear relationship between urban and rural quality parameters through the scatter plot. β and μ are set as slopes and γ and δ as intercepts. Therefore, the linear relationship expression of urban and rural quality parameters is proposed, as shown in Equation (2) as follows:

$$\begin{cases} Z_{ui} = \beta Z_{ci} + \gamma \\ Z_{ci} = \mu Z_{ui} + \delta \end{cases} \quad (2)$$

Thirdly, the symbiosis degree is employed to quantify the extent of influence between urban quality parameters and rural quality parameters [48], specifically representing the impact of urban development on rural development (denoted as $\alpha_{\mu ci}$) or the impact of rural development on urban development (denoted as $\alpha_{\beta ui}$). The variables u and c represent urban and rural, respectively. According to the value of symbiosis degree, it can be judged whether the relationship between urban and rural is no relationship ($\alpha = 0$ or $\alpha < 0$), a parasitic relationship ($\alpha < 0$), biased symbiosis ($\alpha = 0$ and $\alpha > 0$), or reciprocal symbiosis ($\alpha > 0$). By combining Equations (1) and (2), the expression for symbiosis in this paper is formulated as follows:

$$\begin{cases} \alpha_{u_i c_i} = (dZ_{ui}/Z_{ui}) / (dZ_{ci}/Z_{ci}) = (dZ_{ui}/dZ_{ci}) \times (Z_{ci}/Z_{ui}) = \beta \frac{Z_{ci}}{\beta Z_{ci} + \gamma} \\ \alpha_{c_i u_i} = (dZ_{ci}/Z_{ci}) / (dZ_{ui}/Z_{ui}) = (dZ_{ci}/dZ_{ui}) \times (Z_{ui}/Z_{ci}) = \mu \frac{Z_{ui}}{\mu Z_{ui} + \delta} \end{cases} \quad (3)$$

Finally, considering the urban and rural areas as two parts of a system that influence and interact with each other, the interaction force between the urban and rural areas is expressed by the coefficient of symbiosis θ , which is given in the following expression:

$$\begin{cases} \theta_{u_i c_i} = \frac{|\alpha_{u_i c_i}|}{|\alpha_{u_i c_i}| + |\alpha_{c_i u_i}|} \\ \theta_{c_i u_i} = \frac{|\alpha_{c_i u_i}|}{|\alpha_{u_i c_i}| + |\alpha_{c_i u_i}|} \\ \theta_{u_i c_i} + \theta_{c_i u_i} = 1 \end{cases} \quad (4)$$

In the formula, $\theta_{u_i c_i}$ and $\theta_{c_i u_i}$, respectively, denote the symbiotic coefficients of urban areas to rural areas and rural areas to urban areas within the context of the urban–rural symbiosis system. According to the judgment method of interactive impact between urban and rural symbiosis [49], when $0 < \theta_{u_i c_i} < \theta_{c_i u_i}$, it indicates that the impact of rural development on the urban areas is smaller than the impact of urban development on the rural areas, and the spillover effect of the urban areas is greater; when $0 < \theta_{c_i u_i} < \theta_{u_i c_i}$, it indicates that the impact of urban development on the rural areas is smaller than the impact of rural development on the urban areas, and the spillover effect of the rural areas is greater; and when $\theta_{u_i c_i} = \theta_{c_i u_i} = 1/2$, the influence between the urban and rural areas is the same, and the more the value of the coefficient of symbiosis tends to 0.5, the more the level of mutual influence between the urban and rural areas is more balanced and the level of urban–rural symbiosis is higher. The sum of the coefficients $\theta_{u_i c_i}$ and $\theta_{c_i u_i}$ between urban and rural is 1. Both coefficients can represent the level of urban–rural symbiosis in this region, so the coefficient $\theta_{u_i c_i}$ of urban-to-rural symbiosis is uniformly chosen as the output indicator in this study. In the data envelopment approach, the idealized situation is to achieve the maximum output with the minimum input, thus allowing the DMU to reach an efficient state. Therefore, in this paper, symbiotic values $\theta_{u_i c_i}$ greater than 0.5 are

uniformly processed as $1 - \theta_{u_i c_i}$ as a way to satisfy the requirement that the outputs are positively varying in the super-efficient SMB model.

2.3. Research Methods

Efficiency analysis can be categorized into parametric and non-parametric methods. Data Envelopment Analysis (DEA) is a non-parametric estimation method that is widely used in empirical studies of various types of efficiency analysis and is becoming more mature due to its relatively loose assumptions [50]. Tone proposed the SBM (Slacks-Based Measure) model in 2001, which introduces slack variables into the objective function based on the traditional DEA efficiency measure, eliminating the effect of non-zero slacks in input–output variables on the efficiency value of the decision-making unit (DMU) [51]. The SBM model possesses advantages in problem-solving and enables measurement of total factor flow efficiency for both urban and rural areas while exploring input redundancy and output deficiencies.

According to Tone's approach, suppose there are n provinces, each province has m inputs $X = (x_{ij}) \in R^{m \times n}$, s outputs $Y = (y_{kj}) \in R^{s \times n}$, and $X > 0, Y > 0$, then the production possibility set is: $P = \{(x, y) | x \geq X\Lambda, y \leq Y\Lambda, \Lambda \geq 0\}$, where $\Lambda = [\lambda_1, \lambda_2, \dots, \lambda_n] \in R^n$ represents the weight coefficient vector, and two inequalities in the P function respectively indicate that the actual input level is greater than the level of the front plane, and the actual output is less than the level of the front plane. The constructed SBM model is shown in Equation (5) as follows:

$$\min \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^x}{x_{i0}}}{1 + \frac{1}{s} \sum_{k=1}^s \frac{s_k^y}{y_{k0}}} \quad (5)$$

$$s.t. \begin{cases} x_{i0} = \sum_{j=1}^n \lambda_j x_j + s_i^x, \forall i \\ y_{k0} = \sum_{j=1}^n \lambda_j y_j - s_k^y, \forall k \\ s_i^x, s_k^y, \lambda_j \geq 0, \forall i, j, k \\ \sum_{j=1}^n \lambda_j = 1 \end{cases}$$

In the formula, m and s , respectively, represent the number of variables of factor input and symbiotic output in the evaluation of urban–rural total factor flow efficiency; λ is a vector of weights for linear programming; and ρ denotes the value of the efficiency of total factor flow in urban and rural areas. When $\rho = 1$, that is $s^x = 0, s^y = 0$ represents that the DMU is efficient. When $\rho < 1$, it represents that the DMU is non-efficient and there is improvement space. s_i^x and s_k^y respectively represent the slack variables of factor input and symbiotic output (input redundancy and output deficiency). By subtracting input redundancy s^{x*} and adding output deficiency s^{y*} , the optimal input x_0^* and output y_0^* can be obtained as follows:

$$\begin{aligned} x_0^* &= x_0 - s^{x*} \\ y_0^* &= y_0 + s^{y*} \end{aligned} \quad (6)$$

The SBM model solves the problem of input–output slack variables, but the final computed efficiency can only take values in the $(0, 1)$ interval; DMU efficiency values less than 1 are considered invalid, and those equal to 1 are valid [52]. Therefore, it is not possible to continue the comparison of decision-making units with an efficiency value of 1 in the case of a large number of research subjects. In order to further solve the problem that effective DMU cannot be distinguished, Tone (2002) et al. constructed a super-efficient SBM model, which is characterized by the fact that the value of the efficiency of the unit being decided upon is calculated by reference to the production frontier constituted by the remaining decision-making units. Moreover, the efficiency value of the decision-making unit can be greater than 1 under the super-efficient SBM model, with a higher value indicating its

higher efficiency [53]. Based on the above analysis, the super-efficient SBM model with variable returns to scale (VRS) is constructed (7) as follows:

$$\rho = \min \frac{\frac{1}{m} \sum_{i=1}^m \frac{\bar{x}_i}{x_{io}}}{\frac{1}{s} \sum_{k=1}^s \frac{\bar{y}_k}{y_{ko}}} \quad (7)$$

$$s.t. \begin{cases} \sum_{j=1, \neq 0}^n \lambda_j x_j \leq \bar{x}_i, \forall i \\ \sum_{j=1, \neq 0}^n \lambda_j y_j \geq \bar{y}_k, \forall k \\ \bar{x}_i \geq x_{i0}, 0 \leq \bar{y}_k \leq y_{k0}, \lambda_j \geq 0, \sum_{j=1, \neq 0}^n \lambda_j = 1, \forall i, j, k \end{cases}$$

Note that the super-efficient SBM model calculates an efficiency value of $\rho \geq 1$. Moreover, $\bar{X}$ and $\bar{Y}$ are not slack variables in the traditional sense, and the slack variables calculated by the SBM model should still be used if non-efficient or optimal values of input and output variables need to be calculated.

3. Empirical Results

3.1. Analysis of Urban and Rural Total Factor Flow Efficiency

Using Dearun software V3.2.0.2, combined with the super-efficient SBM model, the total factor flow efficiency of urban and rural areas in China's 27 provinces and autonomous regions is measured from the perspective of variable returns to scale over the period 2011–2021. The specific results are shown in Table 2, while Figure 1 demonstrates the trend of China's urban–rural total factor flow efficiency during the examination period.

Table 2. Total factor flow efficiency of urban and rural areas in China based on pluralistic symbiosis.

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Mean	Rank
Tibet	1.040	1.043	1.047	0.949	1.003	0.883	1.009	1.000	1.002	1.004	1.016	1.000	1
Hubei	1.042	0.983	1.000	1.000	0.972	1.002	0.983	0.984	1.001	1.003	1.000	0.997	2
Qinghai	1.007	0.881	1.016	0.963	0.949	0.989	1.005	1.006	1.028	0.977	1.023	0.986	3
Guangdong	1.048	0.960	0.924	0.884	0.916	1.016	1.005	1.020	1.020	1.001	1.036	0.984	4
Fujian	1.021	1.001	0.928	0.900	0.892	1.002	1.002	1.007	1.040	1.002	1.028	0.984	5
Xinjiang	1.021	1.009	1.008	0.988	0.972	1.001	0.965	1.013	0.827	0.807	0.808	0.947	6
Jiangxi	0.790	0.763	1.017	0.990	0.974	1.002	0.956	0.945	0.956	1.007	1.002	0.946	7
Sichuan	1.037	0.968	0.945	0.915	0.877	0.909	0.898	0.876	1.003	0.952	1.002	0.944	8
Zhejiang	0.630	0.633	0.647	0.675	0.707	0.761	0.785	0.839	0.914	1.003	1.017	0.783	9
Hunan	0.777	0.747	0.741	0.747	0.747	0.748	0.736	0.746	0.781	0.751	0.793	0.756	10
Yunnan	1.025	0.688	0.678	0.668	0.656	0.653	0.627	0.743	0.787	0.768	0.751	0.731	11
Jiangsu	0.550	0.556	0.563	0.567	0.577	0.596	0.608	0.635	0.659	0.708	0.758	0.616	12
Gansu	0.578	0.558	0.545	0.527	0.512	0.653	0.625	0.613	0.610	0.563	0.557	0.576	13
Hainan	0.561	0.547	0.537	0.539	0.552	0.572	0.550	0.634	0.612	0.581	0.573	0.569	14
Shaanxi	0.506	0.495	0.484	0.484	0.478	0.567	0.567	0.572	0.650	0.573	0.572	0.541	15
Henan	0.500	0.500	0.503	0.494	0.491	0.532	0.539	0.550	0.572	0.579	0.579	0.531	16
Guizhou	0.657	0.487	0.489	0.464	0.454	0.532	0.500	0.471	0.461	0.415	0.420	0.486	17
Anhui	0.422	0.410	0.403	0.403	0.409	0.420	0.448	0.457	0.479	0.440	0.442	0.430	18
Guangxi	0.451	0.439	0.443	0.429	0.407	0.405	0.403	0.414	0.437	0.423	0.422	0.425	19
Liaoning	0.382	0.391	0.396	0.400	0.396	0.427	0.434	0.444	0.431	0.439	0.433	0.416	20
Hebei	0.266	0.267	0.268	0.269	1.090	0.321	0.321	0.323	0.333	0.341	0.329	0.375	21
Shandong	0.308	0.305	0.303	0.299	0.299	0.343	0.348	0.359	0.374	0.391	0.405	0.339	22
Ningxia	0.285	0.284	0.298	0.298	0.304	0.353	0.349	0.355	0.372	0.385	0.387	0.334	23
Shanxi	0.236	0.243	0.252	0.256	0.256	0.346	0.425	0.415	0.405	0.399	0.393	0.330	24
Jilin	0.343	0.336	0.324	0.314	0.301	0.302	0.294	0.295	0.291	0.298	0.296	0.308	25
Inner Mongolia	0.197	0.224	0.243	0.259	0.263	0.278	0.270	0.289	0.267	0.256	0.250	0.254	26
Heilongjiang	0.109	0.123	0.134	0.137	0.472	0.138	0.143	0.148	0.140	0.131	0.133	0.165	27
National	0.622	0.587	0.598	0.586	0.627	0.620	0.622	0.635	0.640	0.637	0.645	0.620	-

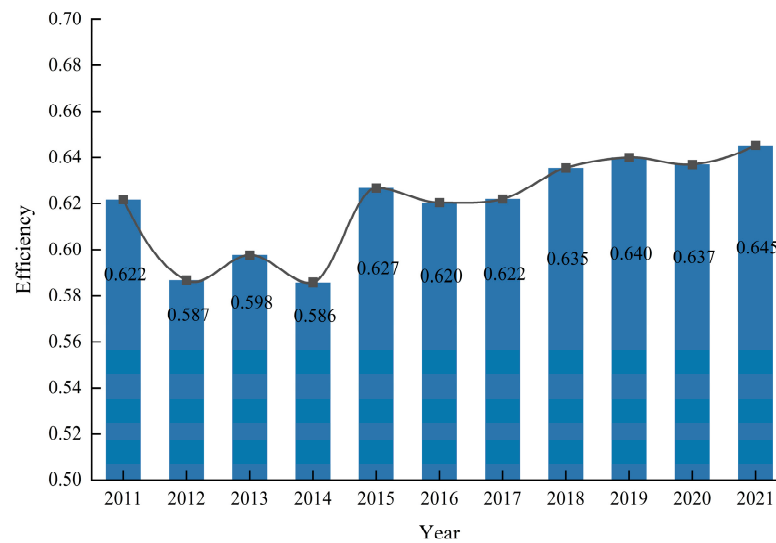


Figure 1. Average urban–rural total factor flow efficiency in China from 2011 to 2021.

From the perspective of the whole country, the average value of total factor flow efficiency between urban and rural areas in China was 0.620 during the study period, which is still far from the effective value of 1, and there is still a large space for improvement in urban–rural factor mobility efficiency. It can be further observed from Figure 1 that the national urban–rural total factor flow efficiency shows a small fluctuating increase between the minimum value and the maximum value during the examination period, with efficiency values of 0.587, 0.598, and 0.586 for three consecutive years in 2012, 2013, and 2014, respectively, forming a factor flow efficiency depression. This phenomenon may be because the Communist Party of China made integrated urban–rural development one of the priorities of the Party and the State in 2012. The Party carried out a new round of macro-adjustments and planning for the allocation of urban–rural factor flows, which led to a certain degree of instability in urban–rural total factor flows in the short term and a decline in the efficiency of factor flows. However, with the subsequent implementation and optimization of relevant policies, coupled with the improvement in factor marketization, the scale of urban–rural factor flows gradually gained momentum, and the urban–rural total factor flow efficiency began to steadily increase after 2015, with the value of urban–rural total factor efficiency reaching a peak of 0.645 in 2021.

In terms of provinces, there are notable regional disparities in the efficiency of total factor flows between urban and rural areas in China. Among them, the Tibet Autonomous Region exhibited the highest performance, with an average urban and rural total factor flow efficiency value of 1. This indicates that the overall urban and rural total factor flow efficiency in this region has reached an effective state during the investigation period. With the exception of non-effective values in 2014 (0.949) and 2016 (0.833), the urban and rural total factor flow efficiency in other years surpasses the effective threshold of 1, suggesting that a relatively optimal allocation ratio of various input factors for promoting urban–rural symbiosis has been achieved. The average efficiencies of Hubei, Qinghai, Guangdong, Fujian, Xinjiang, Jiangxi, and Sichuan all exceed 0.9, indicating a relatively high level of performance. Moreover, their input–output structures closely approach the optimal ratio. Among them, Hubei, Qinghai, Guangdong, and Fujian exhibited relatively strong performance, with efficiency values consistently exceeding 1 throughout the study period. Jiangxi province demonstrated rapid improvement, as its efficiency values increased from 0.790 in 2011 to 1.002 in 2021. The efficiency values of Sichuan province followed a U-shaped development trend and reached 1.002 in 2021. Conversely, Xinjiang performed comparatively poorly with declining efficiency values from 1.021 in 2011 to 0.808 in 2021; furthermore, the urban–rural total factor flow efficiency showed a continuous decrease over the years. It is worth noting that despite Zhejiang province’s average efficiency of 0.783,

which still falls short of the national high level, the implementation of the “Thousands of Villages Model and Ten Thousand Villages Rectification” strategy has led to a significant increase in urban–rural total factor flow efficiency in this region from 0.630 in 2011 to 1.017 in 2021. This indicates that by the end of the investigation period, the urban–rural total factor flow efficiency reached the effective level. The average efficiency values of Hunan, Jiangsu, and Yunnan provinces are 0.756, 0.731, and 0.616, respectively, which are higher than the national average level (0.620). Their input–output structures are relatively good, but to some extent, the direction and intensity of factor flows need to be improved in promoting the realization of urban–rural symbiosis. The total factor flow efficiency of the remaining 15 provinces, including Gansu and Hainan, in terms of urban–rural development, falls below the national average level, with Inner Mongolia and Heilongjiang exhibiting an average efficiency lower than 0.3. This indicates an imbalanced distribution of urban and rural factors as well as an unsound input–output structure in these regions. From the perspective of the changing trend observed in each province, with the exception of Xinjiang and Guizhou where efficiency values exhibit a year-by-year decrease, the efficiency trends in other provinces align with the overall changing trend of the country, displaying a fluctuating upward trajectory. In summary, the urban–rural total factor flow efficiency in China remains relatively low, leaving ample room for improvement. There are discernible provincial disparities in urban–rural total factor flow efficiency; however, it does not exhibit regional agglomeration as the efficiency is dispersed across space.

3.2. Projection Analysis of Urban–Rural Total Factor Flow Efficiency

The projection analysis model is employed to further elucidate the specific circumstances of redundant input and insufficient output, building upon the efficiency analysis conducted in the preceding section. This model enables a comprehensive examination of factors contributing to disparities in efficiency from both input and output perspectives, while also identifying corresponding improvement directions and precise adjustment ranges for decision-making units.

3.2.1. Input Redundancy Analysis

Based on the analysis of optimal efficiency frontier surface projection, the ratio of factor redundancy amount to the actual input amount is defined as the factor redundancy rate, which reflects the redundancy of the urban and rural total factor input. The specific results are shown in Table 3. Meanwhile, Figure 2 shows the changing trend of various factor input redundancy rates between urban and rural areas in various provinces from 2011 to 2021.

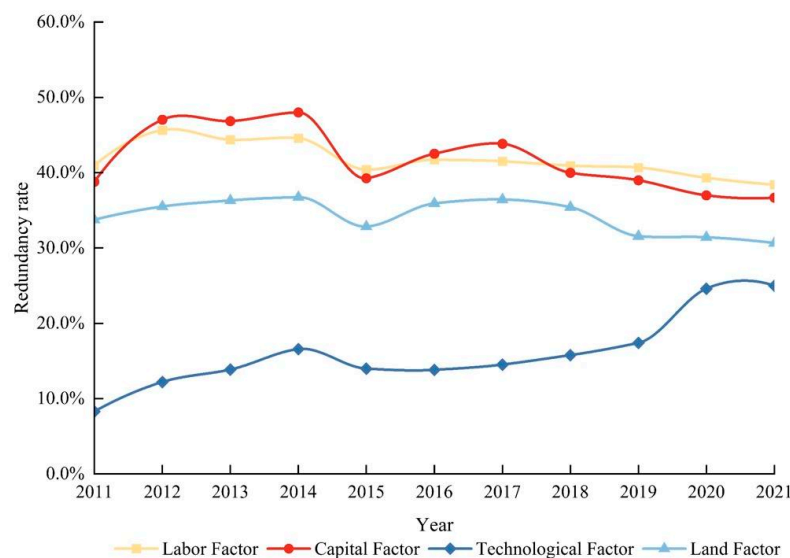


Figure 2. Variation trend of total factor input redundancy in urban and rural areas from 2011 to 2021.

Table 3. Input redundancy rates of urban–rural total factor mobility by province in China (unit: %).

Province	Labor			Capital			Technology			Land		
	2011	2021	Mean	2011	2021	Mean	2011	2021	Mean	2011	2021	Mean
Tibet	0.0	−0.5	−0.1	0.0	0.0	−0.2	−16.1	0.0	−1.4	0.0	0.0	0
Hubei	0.0	0.0	0.3	−6.4	0.0	0.7	−10.2	0.0	−0.4	0.0	0.0	0.7
Qinghai	0.0	−5.5	−0.3	0.0	−3.6	−0.1	−2.7	0.0	−2.1	0.0	0.0	0
Guangdong	0	−2.3	2.4	−7.3	−1.8	3.1	−11.5	0	−1.9	−0.5	0	−0.1
Fujian	0.0	0.0	0.8	0.0	0.0	5.4	−5.2	0.0	−2.3	−3.0	−8.1	3.0
Xinjiang	0.0	33.7	10.7	0.0	33.8	10.2	−8.3	9.2	0.7	0.0	0.0	0
Jiangxi	44.4	0	8.9	10.8	0	5.6	7.5	0	2.7	21.4	0	5.5
Sichuan	0.0	0.0	12.6	−3.5	0.0	8.9	−11.4	0.0	−1.0	0.0	0.0	2.3
Zhejiang	21.5	−2.0	5.1	55.9	0	36.0	16.0	−2.3	10.6	54.6	0	35.5
Hunan	45.4	23.5	46.9	9.0	0.0	7.2	0.0	43.2	7.7	34.8	16.0	36.0
Yunnan	0.0	49.8	49.9	0.0	30.9	42.0	−10.1	0.0	−0.9	0.0	18.8	16.4
Jiangsu	30.7	0	19.3	49.7	0	26.6	18.9	28.4	27.7	80.5	68.5	79.9
Gansu	73.2	75.8	75.9	73.3	72.4	71.8	0.0	18.5	3.2	0.0	7.9	7.9
Hainan	58.6	65.7	64.5	74.6	51.8	63.7	0.0	11.8	1.7	29.5	23.3	29.3
Shaanxi	65.3	63.6	66.8	71.1	60.1	67.6	0.0	15.7	2.5	29.4	26.6	33.4
Henan	50.9	71.1	50.0	38.4	16.3	29.7	32.9	10.0	30.7	77.9	71.1	77.2
Guizhou	16.3	67.5	64.6	12.1	80.9	76	0.0	31.4	6	39.9	45.1	45.8
Anhui	72.6	48.1	61.3	71.7	40.8	59.6	5.2	56.1	29.5	75.0	78.2	76.4
Guangxi	58.3	67.8	70.7	59.5	70.3	74.5	0.0	27.4	7	23.2	23.3	29.7
Liaoning	64.0	61.1	62.3	52.2	50.3	56.6	2.2	21.2	8.8	62.0	69.9	65.2
Hebei	70.7	50.1	56.8	78.4	75.2	66.3	51.9	67.8	52	69.6	66.6	62.4
Shandong	70.9	51.1	62.6	80.0	53.1	73.2	40.0	56.8	49	78.3	76.8	77.8
Ningxia	77.4	54.6	67.3	75.0	74.4	75.2	28.6	58.5	43.8	38.1	41.5	43.8
Shanxi	70.2	54.5	61.6	79.4	75.3	80	25.5	18.7	19.1	59.3	57.1	58.1
JiLin	75.1	71.2	73.2	70.8	64.0	72.2	7.2	63.3	39.8	71.8	73.4	72.3
Inner Mongolia	66.2	66.9	64.3	23.5	67.9	41.9	28.3	64.3	46.2	0.0	0.0	0.9
Heilongjiang	73.5	70.7	67	79.0	77.8	72.7	34.9	74.9	53.3	69.7	72.0	64.9
National	40.9	38.4	41.7	38.8	36.7	41.7	8.3	25.0	16	33.8	30.7	34.2

Combined with Table 3 and Figure 2, from the national average level, the redundancy scale and changing trend of labor and capital factors in urban and rural China during the investigation period is the same, with a total average redundancy of 41.7%; the total average redundancy of land factors is 34.2%; and the total average redundancy of technological factors is 16.0%. This means that factors such as labor, capital, land, and technology are redundant in the rural input. At the current level of urban–rural symbiosis, there is a surplus in the input of factors to the rural area, among which the redundancy of labor, capital, and land is the largest. These three factors are the main reasons for the low efficiency of urban–rural total factor flow. This should be paid attention to and optimized with emphasis. From the perspective of changing trends, the redundancy rates of labor, capital, and land factors showed a downward trend during the investigation period, with redundancy reduced and waste improved. However, the redundancy rate of technological factors showed a large upward trend, indicating an increase in the waste of technological input, which should be paid attention to.

In terms of provinces, most provinces in China have a certain degree of redundant factor input. Among them, Tibet, Hubei, Qinghai, Guangdong, Fujian, and Jiangxi performed the best. The average redundancy rate of each input factor during the investigation period was below 10%, with a small redundancy range. Moreover, the redundancy value of factors at the end of the investigation period was almost zero, indicating that these regions have basically achieved a reasonable flow of urban and rural factors and a scientific input–output structure under their existing symbiotic levels. It is noteworthy that the redundancy rates of some regions are negative, such as labor (−0.1), capital (−0.2), and technology (−1.4) in Tibet, which are all less than zero, indicating that the input of labor, capital, and technology into rural areas is slightly insufficient under the existing level of urban–rural symbiosis in the province. Therefore, the input of factors into rural areas should be appropriately increased to promote a higher level of urban–rural symbiosis. The average redundancy of input factors in Sichuan and Zhejiang is relatively high, but with the development of urban–rural integration, the redundancy rate of input factors in the

two provinces also reaches a non-redundant state at the end of the investigation period, showing a reasonable flow of urban and rural factors. Heilongjiang, Jilin, Hebei, Ningxia, and Shandong have poor overall performance, with redundancy rates of labor, capital, technology, and land all higher than the national average level. The flow of urban and rural factors is uneven, and the input–output structure of urban and rural factors is unreasonable. The other 14 provinces, such as Shaanxi and Henan, also exhibit varying degrees of factor redundancy and suboptimal resource utilization.

In terms of factors, the three provinces with the worst labor factor redundancy are Gansu (75.9), Jilin (73.2), and Guangxi (70.7). The three provinces with the worst capital factor redundancy are Ningxia (75.2), Guangxi (74.5), and Shandong (73.2). The three provinces with the worst technology factor redundancy are Heilongjiang (53.3), Inner Mongolia (46.2), and Ningxia (43.8). The three provinces with the worst land factor redundancy are Jiangsu (79.9), Shandong (77.8), and Henan (77.2). The above results indicate that there is a serious problem of unbalanced flow of urban and rural factors in the above areas. Given the current level of urban–rural symbiosis, there is an excessive investment of factors in rural areas. It is imperative to adopt context-specific measures and harmonize the flow of factors based on the requirements of both urban and rural development. In addition, the redundancy of labor, capital, and land factors in certain provinces contradicts the overall trend of improvement observed nationwide. The provinces with increased labor factor redundancy (range of increase) are Guizhou (51.2%), Yunnan (49.8%), Xinjiang (33.7%), Henan (20.2%), Guangxi (9.5%), Hainan (7.1%), Gansu (2.6%), and Inner Mongolia (0.7%), while the remaining provinces are either in the optimal state of factor input or in the state of reducing labor factor redundancy. The provinces experiencing an increase in capital factor redundancy (range of increase) include Guizhou (68.8%), Inner Mongolia (44.4%), Xinjiang (33.8%), Yunnan (30.9%), and Guangxi (10.8%); whereas the provinces witnessing a rise in land factor redundancy (range of increase) are Yunnan (18.8%), Gansu (7.9%), Liaoning (7.9%), Guizhou (3.4%), Ningxia (3.2%), Anhui (2.3%), Heilongjiang (1.6%) and Jilin (56.1%). In addition, throughout the investigation period, only the technical factor redundancy in Henan and Shanxi provinces exhibited a consistent year-on-year improvement, while the technical factor redundancy rate in other provinces demonstrated a persistent upward trend. Among all factors, the technical factor redundancy is the most severe. The provinces in China exhibiting subpar performance in the urban–rural factor flow are predominantly concentrated in the southwestern, northwestern, and northeastern regions. Over time, there has been a persistent increase in the redundancy of rural factors within these areas, and an optimal input–output effect remains elusive.

3.2.2. Analysis of Output Deficiency

In terms of output indicators, the insufficient level of urban–rural symbiosis is also a factor causing the inefficiency of urban–rural total factor flow efficiency. The insufficient output is due to the ineffective transformation of resource input into results, which is a waste of resource input into the countryside. The insufficient output of urban and rural total factor flow efficiency in various provinces in China is presented in Table 4 for the years 2011, 2016, and 2021.

As can be seen from Table 4, 11 provinces, including Hubei, Guangdong, Fujian, Xinjiang, Jiangxi, Sichuan, Zhejiang, Hunan, Yunnan, Jiangsu, and Henan, have achieved the optimal level of urban–rural symbiosis based on their existing factor input levels. The provinces of Tibet, Qinghai, Shandong, and Anhui experienced a slight output deficiency; however, they all achieved the optimal level of urban–rural symbiosis by the end of the investigation period. Twelve provinces, including Gansu, Hainan, Shaanxi, Guizhou, Guangxi, Liaoning, Hebei, Ningxia, Shanxi, Jilin, Inner Mongolia, and Heilongjiang are all experiencing varying degrees of insufficient output. Among them, Inner Mongolia and Heilongjiang have performed the worst with output deficits reaching as high as 163.6% and 114.6%, respectively. This reflects that these provinces' level of urban–rural symbiotic development is far from sufficient given the current level of factors flowing from urban

to rural areas. The aforementioned findings demonstrate that the implementation of the rural revitalization strategy has led to an increasingly effective allocation of resources in rural areas, thereby promoting a higher level of urban–rural symbiosis and enhancing the capacity for rural resource transformation. However, it is worth noting that there are still 12 provinces in China where the ability of rural areas to carry and transform factors remains insufficient, resulting in an inadequate level of urban–rural symbiosis that affects the realization of urban and rural common prosperity.

Table 4. Output insufficiency rate of each province in 2011, 2016, and 2021 (unit %).

Province	2011	2016	2021	Mean	Province	2011	2016	2021	Mean
Tibet	0	9.4	0	3.1	Shaanxi	15.7	1.5	2.3	6.5
Hubei	0	0	0	0	Henan	0	0	0	0
Qinghai	0	0.7	0	0.2	Guizhou	26.3	0	4.3	10.2
Guangdong	0	0	0	0	Anhui	4.1	0	0	0.6
Fujian	0	0	0	0	Guangxi	43.7	27.3	25.0	32
Xinjiang	0	0	0	0	Liaoning	43.8	23.2	14.0	27
Jiangxi	0	0	0	0	Hebei	21.7	10.8	6.7	13
Sichuan	0	0	0	0	Shandong	6.1	0	0	2
Zhejiang	0	0	0	0	Ningxia	58.6	26.4	10.5	31.8
Hunan	0	0	0	0	Shanxi	75.1	42.5	23.5	47
Yunnan	0	0	0	0	Jilin	27.8	13.2	8.1	16.4
Jiangsu	0	0	0	0	Inner Mongolia	257.2	132.4	101.3	163.6
Gansu	9.7	7.5	1.2	6.1	Heilongjiang	226.6	110.2	97	114.6
Hainan	5.8	3.0	7.9	5.6	-	-	-	-	-

3.2.3. Comprehensive Analysis

The comprehensive analysis of efficiency, input redundancy, output deficiency, and urban–rural symbiosis level was conducted to unveil the systematic factors contributing to the insufficient total factor flow efficiency in urban and rural areas. The results are illustrated in Figure 3.

The arrangement of Figure 3 is based on the descending order of urban–rural total factor flow efficiency values for each province, which are categorized as follows: The first type pertains to the fundamental alignment between input and output, exemplified by regions like Tibet and Qinghai. This category is characterized by a slight insufficiency in the flow of labor, capital, and technological factors toward rural areas in these regions, as well as a slightly deficient capacity for absorption and transformation of factors within rural areas. However, the movement of resource factors between urban and rural areas remains essentially rational. To further enhance the level of urban–rural symbiosis in Tibet and Qinghai provinces to an ideal state of 0.5, it is recommended to appropriately increase the allocation of rural factors while maintaining the current flow direction, structure, and mode of input factors in both urban and rural areas. This will effectively promote the common prosperity between urban and rural regions in these two locations. The second type is factor redundancy, which is characterized by the low level of urban–rural symbiosis caused by the redundancy of factors in rural areas. This category consists of 11 provinces, including Hubei, Guangdong, Fujian, Xinjiang, Jiangxi, Sichuan, Zhejiang, Hunan, Yunnan, Jiangsu, and Henan, and is characterized by varying degrees of redundancy of inputs to the rural areas for the four factors. Among them, Henan has the most serious redundancy of inputs in the countryside, while some provinces such as Fujian, Guangdong, Sichuan, and Hubei have slightly insufficient inputs of technical factors into the countryside. In addition, there are two types of urban–rural symbiosis observed in these provinces. One type is characterized by a non-equilibrium state of urban–rural symbiosis coefficient greater than 0.5, indicating a faster pace of urban development compared to rural development, as seen in the Guangdong, Jiangxi, Zhejiang, Jiangsu, and Henan provinces. Therefore, enhancing the urban–rural symbiosis in these regions should primarily focus on significantly improving the rural areas' capacity for resource transformation rather than solely increasing factor

inputs to rural areas. This approach will effectively promote comprehensive revitalization of the rural areas. Another situation is the non-equilibrium state of the symbiosis coefficient between cities and rural areas, where rural development is faster than that of cities, such as Hubei, Fujian, Xinjiang, Sichuan, Hunan, and Yunnan. The policy focus in such areas is to return factors to or retain them in cities, accelerate the speed of urban development, and enhance the ability of cities to drive rural development, thereby promoting regional common prosperity. The third is the overall scarcity type, meaning that the causes of inefficiencies in factor flows between urban and rural areas in such areas are both redundancy of factors to the countryside and insufficient symbiotic output, including other provinces in addition to the first and second scenarios, such as Gansu, Hainan, Shaanxi, Guizhou, Anhui, Guangxi, Liaoning, Hebei, Shandong, Ningxia, Shanxi, Jilin, Inner Mongolia, Heilongjiang, and the other fourteen provinces. Among them, the resource mismatch in Inner Mongolia and Heilongjiang is the most serious. At the same time, except for Anhui province, the urban–rural symbiosis coefficient of the other 13 provinces is less than 0.5, and the coefficient of Inner Mongolia and Heilongjiang is only 0.19, indicating that the rural development in most provinces of this type of area is faster than that of the urban, and the urban development is weak. Therefore, to achieve urban–rural coexistence and prosperity, on the one hand, it is necessary to retain factors in the urban areas or let redundant factors in the countryside return to the urban areas to promote urban development. On the other hand, it is necessary to improve the ability of rural areas to undertake and transform resources and promote the improvement in essential productivity in rural areas.

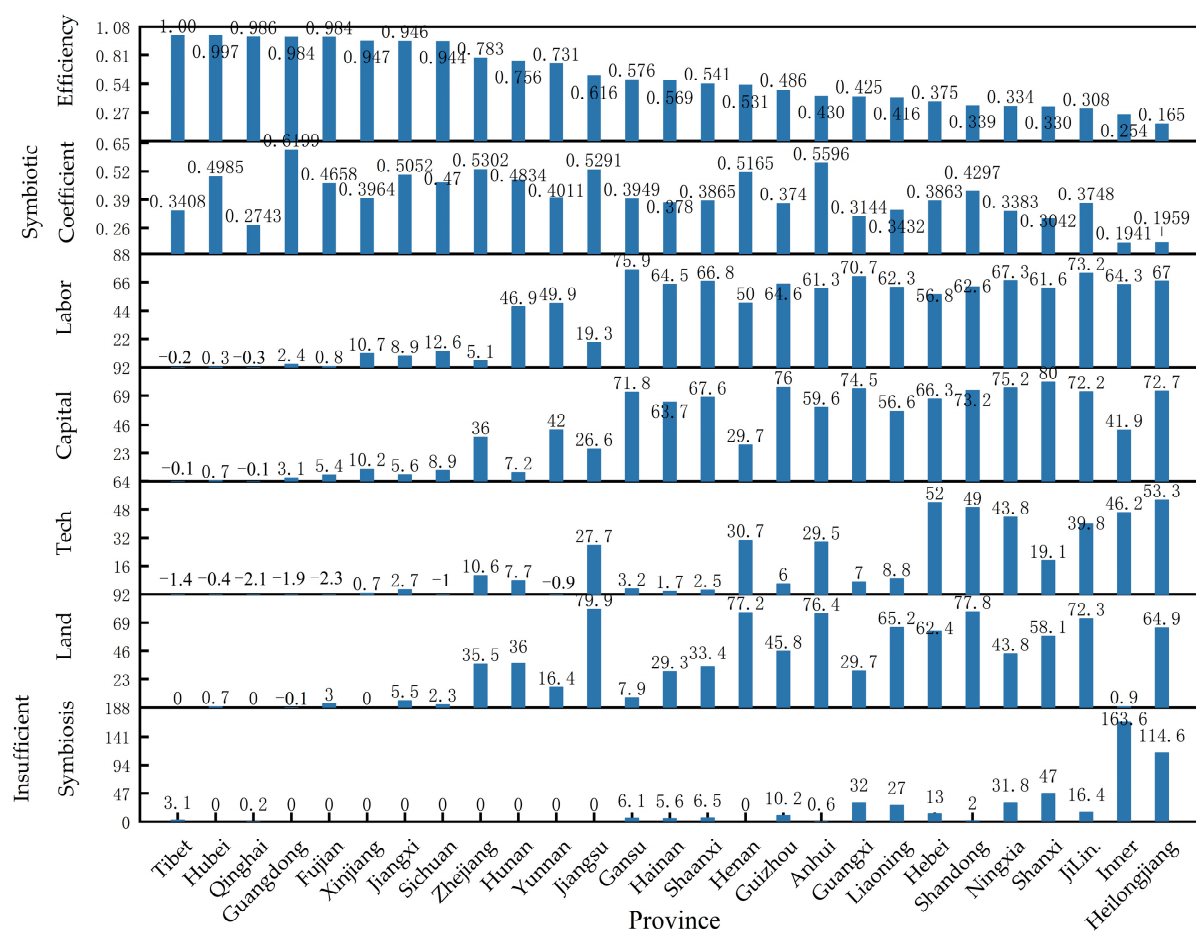


Figure 3. Comprehensive analysis of urban–rural total factor flow efficiency in 27 provinces.

4. Discussion, Conclusions, Recommendations

4.1. Discussion

With the continuous promotion of China's rural revitalization strategy, the rational flow of factors between urban and rural areas plays a pivotal role in fostering symbiotic development. However, variations in economic foundations and policy implementation efforts across different regions result in disparities in the level of urban–rural symbiosis based on factor flow [5]. Therefore, it is imperative to scientifically measure the impact of factor flow on the level of urban–rural symbiosis and evaluate its efficiency along with regional discrepancies. Compared with previous studies on coordinated urban–rural development, this research breaks through the conventional single-factor perspective [44] and comprehensively considers the impact of the flow of all factors, including labor, capital, technology, and land, between urban and rural areas on urban–rural development. The quality of integrated urban–rural development was quantified using an urban–rural coefficient of symbiosis. This study employed the super-efficiency SBM method to construct an input–output model for urban–rural total factor flow. The model calculates the evolutionary trend and regional differences in the efficiency of urban–rural total factor flow in China. Through analyzing input redundancy and output insufficiency, this research comprehensively grasps the direction and structure of urban–rural total factor flow in China, as well as the internal relationship between urban–rural symbiotic output, and explores the primary causes of the main contradictions in regional differences in urban–rural symbiotic development.

Our research suggests that it is reasonable to explore the systematic causes of the inefficiency in urban–rural total factor flow from four perspectives, including comprehensive urban–rural total factor flow efficiency, symbiotic coefficient, input redundancy, and output insufficiency. The findings of this study reveal that input–output basic matching provinces can aptly augment factor inputs to townships while maintaining an intact existing urban–rural factor flow direction, structure, and modality [48], thereby fostering urban–rural co-prosperity. Provinces exhibiting factor redundancy can enhance urban–rural relations through two principal strategies: Firstly, by significantly bolstering the countryside's resource transformation capacity, rather than merely elevating factor inputs, to catalyze comprehensive rural revitalization. Secondly, these provinces should prioritize policies that encourage factor reflux or retention in urban areas, expediting urban development and enhancing urban capabilities to spearhead rural progress [27], ultimately fostering regional co-enrichment. For provinces with comprehensive scarcity, the path to achieving urban–rural symbiotic prosperity entails two main aspects. On the one hand, it is essential to retain factors in urban areas or redirect redundant factors from rural areas back to urban centers to promote urban development. On the other hand, it is crucial to enhance the ability of rural regions to receive and transform resources, thereby fostering the improvement in their intrinsic productivity.

This study provides novel insights for evaluating the quality of urban–rural relations and promoting their development. These research findings contribute to the existing knowledge system of urban–rural relations. Central to this approach is a comprehensive consideration of the total factor flows between urban and rural areas, as well as the utilization of quantitative methods to measure their effects. This line of thinking is equally applicable in other countries, as urban–rural development is a common challenge faced globally, and factor flows serve as a significant driving force for urban–rural development. However, the limitations lie in the differences in national conditions, systems, policy environments, and economic development levels among various countries. Some countries may lack comprehensive statistical data and information, making it difficult to accurately measure various indicators of urban–rural development [54]. Therefore, when applying our methodology to other countries, adjustments and optimizations need to be made based on specific circumstances.

4.2. Conclusions

This study focused on 27 provinces in China and employed the super-efficiency SBM model to measure the urban–rural total factor flow efficiency in China from 2011 to 2021. Subsequently, the input redundancy and output insufficiency were quantified through the projection analysis model. This comprehensive approach sheds light on the internal mechanism of how factor flow pathways promote mutual benefit and symbiosis between urban and rural areas. The key findings are as follows: (1) The overall urban–rural factor flow efficiency has exhibited a positive development trajectory, yet significant differences exist among different provinces. The efficiency analysis indicates that during the study period, the urban–rural factor flow efficiency displayed a slight upward trend but did not reach its optimal level. Among these provinces, Guangdong, Fujian, Hubei, Zhejiang, Jiangxi, Sichuan, Tibet, and Qinghai have attained effective states of urban–rural total factor flow efficiency, while the remaining 19 provinces exhibit varying degrees of inefficiency. (2) Factors such as capital, labor, technology, and land between urban and rural areas exhibit a certain degree of redundancy in rural areas. Among these, the redundancy rates of labor, capital, and land factors have shown a consistent downward trend, whereas the redundancy rate of technological factors has gradually increased. (3) There is a deficiency in the symbiotic output of twelve provinces, including Gansu, Hainan, Shaanxi, Guizhou, Guangxi, Liaoning, Hebei, Ningxia, Shanxi, Jilin, Inner Mongolia, and Heilongjiang. This phenomenon is evident in the countryside's inadequate capacity to effectively carry and transform essential factors, coupled with a lackluster enhancement in the level of urban–rural symbiosis. Consequently, this hinders the pursuit of common prosperity across urban and rural regions. Notably, the output deficits in Inner Mongolia and Heilongjiang province surpass 100%, signifying a significant shortcoming in the countryside's endogenous development capacity. (4) Based on a comprehensive analysis of input redundancy, output insufficiency, symbiotic coefficients, and efficiency, the impact of factor flows on the urban–rural symbiotic level can be broadly classified into three types: basic input–output matching, factor redundancy, and comprehensive deficiency. For different types of regions, corresponding policy measures should be adopted to enhance the urban–rural symbiotic level and promote common prosperity in the region.

4.3. Recommendations

The overall development trend of urban–rural total factor flow efficiency in China is promising, yet the overall efficiency level remains suboptimal. In the context of rural revitalization, the rational flow and allocation of factors play a crucial role in adjusting urban–rural relations. To enhance the efficiency of total factor flow in China's urban and rural areas, it is imperative to dismantle the dual system and eliminate institutional barriers favoring urban areas. Simultaneously, addressing internal institutional constraints within rural regions becomes essential by optimizing the proportion of labor, capital, land, and technological factors. This optimization will stimulate rural vitality while unlocking resource potential [55], thereby improving resource transformation capabilities in rural areas and maximizing utilization of existing resources. Furthermore, it is worth noting that there exists a certain level of redundancy in factor inputs and insufficient symbiotic output across most provinces in China. However, distinct regional disparities can be observed when examining the underlying causes of inefficiencies in total factor mobility between urban and rural areas within these provinces. For regions such as Tibet and Qinghai, it is recommended to moderately enhance inputs into rural factors, particularly technology and capital inputs, while maintaining the current direction, structure, and mode of urban–rural factor flow in order to facilitate rural economic development and resource transformation capacity, thereby achieving urban–rural prosperity. In the case of Guangdong, Jiangxi, Zhejiang, Jiangsu, and Henan provinces, emphasis should be placed on enhancing resource transformation capacity and promoting comprehensive rural revitalization through industrial development in rural areas. In terms of specific policies, the structure of factor allocation can be adjusted to optimize resource utilization

efficiency and avoid redundant factors, thereby expediting rural development and fostering urban–rural coexistence and prosperity. For provinces such as Hubei, Fujian, Xinjiang, Sichuan, Hunan, and Yunnan, the policy focus lies in facilitating factor flows or retention within urban areas, expediting the pace of urban development, and bolstering its capacity to drive rural development. The primary task for Gansu, Hainan, Shaanxi, Guizhou, Anhui, Guangxi, Liaoning, Hebei, Shandong, Ningxia, Shanxi, Jilin, Inner Mongolia, and Heilongjiang is to address the issue of low factor flow efficiency. It is recommended to enhance policy-level support for these regions and optimize resource allocation to improve the efficiency of urban and rural factor flow. This can be achieved through measures such as strengthening technology transfer and talent introduction. At the same time, it is necessary to strengthen rural infrastructure construction, promote technological innovation and talent training, and improve the level of industrial development in rural areas in order to achieve the goal of urban and rural coexistence and prosperity.

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