Research on the Output Efficiency of Rural Ecological Public Goods Supply

Xinyue Gao, Lizi Yang, and Yaobo Shi*

School of Economics and Management, Xi'an University of Technology, Xi'an, China
Email: 3220521043@stu.xaut.edu.cn (X.Y.G.); 1263905329@qq.com (L.Z.Y.); shiyaoboo@163.com (Y.B.S.)
*Corresponding author

Manuscript received November 22, 2024; accepted January 27, 2025; published May 28, 2025.

***Abstract*—Improving the quality and level of ecological public goods supply is crucial for enhancing the public happiness index and ensuring ecological welfare, as a high-quality ecological environment has significant positive externalities. Based on the DEA model, this paper uses data envelopment analysis to evaluate and compare the supply efficiency of rural ecological public goods in 500 towns in Northwest China, and the results show that the overall level of rural ecological public goods supply in Northwest China is low, which will become an obstacle to the further growth of agricultural economy in Northwest China. Furthermore, the Tobit model is used to empirically measure the impact of rural ecological public goods supply on output efficiency. The results show that, in addition to the area of residential areas, the other variables, including domestic sewage treatment input, toilet facility reform input, domestic waste treatment input, per capita annual income and distance from village to county seat, all have a positive impact on the output efficiency of ecological public goods, although some effects are not statistically significant. In the process of building a new countryside in the new era, the supply of ecological public goods can be led by the government, and the supply and construction of ecological public goods can be promoted from the perspective of the government, farmers and the environment, combined with social participation and market-oriented operation.**

***Keywords*—ecological public goods supply, output efficiency, impact studies**

I. Introduction

Ecological public goods possess typical public goods attributes. Environmental pollution negatively impacts the ecological environment, and controlling this pollution requires accounting for the social cost, which is greater than the private cost. Similarly, the private benefit is often greater than the social benefit. Environmental improvements such as cleaner air benefit everyone. For example, breathing fresh air does not prevent others from doing the same, making ecological public goods non-competitive and non-exclusive. Chen (2018) argues that ecological public goods usually refer to various environmental goods and environmental services. For example, pure and clear water, fresh air and various clean natural resources, as well as public environmental facilities, environmental protection, environmental policies, environmental systems and environmental information provided by certain actors. Fan (2012) proposed the concept of ecological public goods, including natural ecological public goods, material ecological public goods and institutional ecological public goods. Ecological public goods also include ecological infrastructure and ecological public services, which help maintain natural processes, regulate the quality of urban and rural environments, and support functions such as species protection, soil and water conservation, and the natural purification capacity of water bodies. Regulating the quality of urban and rural environments involves mitigating industrial pollution, purifying the air, reducing the urban heat island effect, increasing green spaces, and promoting social and economic development. The characteristics of ecological public goods can be summarized as benefiting all citizens, as their provision within a region benefits every resident. Since the state reformed the collective forest tenure system, it has become necessary to significantly increase the supply of ecological public products, and enhance investment in basic social security public products, in order to ensure the success of regional ecological projects and support the steady progress of other reform initiatives. Based on this situation, it is very necessary to investigate the supply level of ecological public goods of rural residents, and it is very important to understand and grasp the supply efficiency of ecological public goods.

II. Measurement of the Supply Efficiency of Rural Ecological Public Goods

A. Model Building

Through field investigation of the supply of ecological public goods in the forest areas of Shaanxi Province and the evaluation of their supply levels, the supply effects of these goods can be clarified. In this chapter, the DEA model is used to evaluate and compare the supply efficiency of physical and ecological public goods. The general steps for applying the DEA method are as follows: clarifying the purpose of the evaluation, selecting the DMUs, establishing input and output evaluation index systems, collecting and organizing data, using the model to calculate results, analyzing the results, and making decision recommendations.

Specifically, there are N decision-making units DMUj (j = 1, 2,...,n); DMUj input xj=(x1j,x2j,...,xmj)T; The output of DMUj is yj=(y1j,y2j,...,ysj)T; m is the number of input indicators, and s is the number of output indicators; $x1j,x2j,...,xmj \geq 0 (j=1,2,...,n)$, i.e. the input component is non-negative and at least one of them is positive. The C2 R model is based on the basic form of the input angle as Eq. (1) and after introducing the relaxation variable as Eq. (2).

$$\begin{cases} \min\theta \\ w^T x_j - \mu^T y_j \lambda_j \geq 0 \\ \sum_{j=1}^{n} \lambda_j y_j \geq y_0 \\ \lambda_j \geqslant 0, j = 1, 2, ..., n \\ \theta \text{ Unconstrained} \end{cases} \tag{1}$$

$$\begin{cases} \min\theta \\ w^T x_j - \mu^T y_j \lambda_j + s^- = 0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^+ = y_0 \\ \lambda_j \geqslant 0, j = 1, 2, ..., n \\ s- \geqslant 0, s+ \geqslant 0 \ \theta \text{ Unconstrained} \end{cases} \quad (2)$$

For Eq. (2), let the optimal solution be λ*, s*−, s*+, θ*, then the following conclusion is made: if θ* = 1, but any of s*−, s*+ is not equal to 0, then DMUj is weak DEA valid; If the value of θ* is equal to 1, and s*−, s*+ are equal to 0 at the same time, then DMUj is valid for DEA; If the value of θ* is less than 1, then the result is that DMUj is DEA ineffective.

Let $p = 1/\theta$:, if DMUj is in the stage of increasing scale returns, then p is less than 1; If the p-value is equal to 1, it indicates that DMUj is in the stage of constant scale return; If the *p*-value is greater than 1, it indicates that the DMUj is in a stage of diminishing returns to scale.

B. Supply Efficiency Evaluation

The data used in this chapter are derived from the questionnaire survey data of rural households, village cadres, and leading cadres of county and township governments, simultaneously select reports and research data on the 2023 fiscal final accounts of 500 villages and towns in northwest China. The DEA efficiency coefficient is measured by data envelopment analysis. The selected input variables include investment in domestic sewage treatment (10,000 yuan), investment in toilet reform (10,000 yuan), and investment in garbage treatment (10,000 yuan). The output variables include: whether the township has installed sewage treatment equipment (1=yes, 0=no), whether it participates in rural toilet reform (1=yes, 0=no), and whether the existing waste treatment facilities can meet the demand (1=not very satisfied, 2=basically satisfied, 3=completely satisfied). This article uses DEAP2.1 software to calculate and decompose the efficiency of rural ecological public product supply. Firstly, the Technical Efficiency value (TE) of each sample township is obtained based on the CCR model in DEA. Then, the Pure Technical Efficiency value (PTE) is obtained through the BBC model. Finally, according to the formula, the scale efficiency is equal to the technical efficiency value divided by the pure technical efficiency value, and the Scale Efficiency value (SE) can be obtained. Finally, effective analysis and research will be conducted based on the obtained data.

C. Efficiency Analysis

From the analysis of the calculation results, it can be concluded that 17% of the sample towns in northwest China currently have PTE values less than 1, indicating that these sample towns are purely technical inefficient, meaning that their production efficiency is relatively poor and their supply efficiency is also relatively low. Analyzing the reasons for the inefficiency of technology in these six townships, both scale inefficiency and pure technology inefficiency are to blame. Therefore, it can be concluded that the conditions for the supply of ecological public goods in these areas have not met the requirements in terms of hardware and software. In addition to the unreasonable configuration of rural public goods, there are also various problems such as inadequate management in the later stage, which leads to a low degree of matching between the output and input scale of public goods at the current stage. Currently, up to 83% of the sample townships in the northwest region are at the forefront of technical efficiency in the supply of rural ecological public goods (PTE=1), among which 120 townships have achieved both technical efficiency and scale efficiency (i.e. TE=1, PTE=1, and SE=1). Although the scale efficiency value is less than 1, a small proportion of townships have a pure technical efficiency value equal to 1. It can be considered that these areas have fully utilized their existing best technologies, and the technical inefficiency they exhibit may be caused by scale inefficiency. After research and analysis, there may be two possible reasons: firstly, the efficiency of rural public goods supply in these towns is relatively low, and secondly, the supply of rural ecological public goods has not received sufficient attention from government departments at all levels. The government's investment in fiscal funds is seriously insufficient, resulting in low input-output efficiency of rural public goods and thus suppressing the growth of rural economic growth.

III. Research on the Impact of Rural Ecological Public Goods Supply on Output Efficiency

A. Description of the Variable

Dependent variable: In the previous section, the DEA data envelopment model was used to measure the supply efficiency of rural ecological public goods in northwest China. Technical efficiency *TE* is an efficiency value that measures the comprehensive use, allocation, and management of integrated funds, so it was selected as the dependent variable.

Referring to the research experience of previous scholars, the following representative indicators were selected as explanatory variables, including the regional scale as *X1*, economic development level as *X2*, geographical transportation situation as *X3*, resident aggregation degree as X*4*, and migrant worker ratio as *X5* of the selected sample villages and towns for analysis. This study aims to analyze the impact of ecological public product supply in Shaanxi on output efficiency. Among them, the area of residential areas (mu) is selected as the proxy variable for regional scale, the per capita annual income (yuan) is selected as the proxy variable for regional economic development level, the distance from the region to the city center is selected to represent the geographical transportation situation of the village, and the number of migrant workers in each sample area (household) is selected to represent the proportion of migrant workers. The five level scale method was used to self-evaluate the relative concentration of residents' residences by region, where "1=very dispersed, 2=relatively dispersed, 3=average, 4=relatively concentrated, 5=very concentrated".

Control variables: This article also selected the number of permanent residents *Pr*, the number of local impoverished households *Ph*, and the number of shuttle buses *Bn* as control variables.

The above explanatory variable data is calculated based on

the CCR model in the previous section of DEA. The data for each explanatory variable mainly comes from panel data of the six provinces in Northwest China from 2007 to 2022. The data mainly comes from official sources such as the China Statistical Yearbook, China Environmental Yearbook, China Environmental Statistical Yearbook, Northwest Six Provinces Statistical Yearbook, and Provincial Government Work Report. The data for each control variable mainly comes from field research conducted by the project team in rural areas of six provinces and counties in Northwest China, as well as data obtained from resident interviews, combined with statistical yearbooks and government financial reports of each province, as well as data from the Ministry of Agriculture and other institutions.

B. Model Building

In this study, the efficiency of rural ecological public product supply was used as the dependent variable, and the results calculated by the DEA model were between [0, 1]. The research data used came from field surveys to analyze the impact of ecological public product supply on output efficiency. Due to the truncated nature of the supply coefficient of ecological public goods, Tobit regression analysis method was used, and the empirical analysis process was implemented using Stata14.0 software. This article constructs the following empirical model:

$TEit=\beta 0+\beta 1X1it+\beta 2xit+\varepsilon it$

$TEit=\beta 0+\beta 1X2it+\beta 2xit+\varepsilon it$

$TEit=\beta 0+\beta 1X3it+\beta 2xit+\varepsilon it$

$TEit=\beta 0+\beta 1X4it+\beta 2xit+\varepsilon it$

$TEit=\beta 0+\beta 1X5it+\beta 2xit+\varepsilon it$

$TEit=\beta 0+\beta 1X1it+\beta 2X2it+\beta 3X3it+\beta 4X4it+\beta 5X5it+\beta 6Xit+\varepsilon it$

where *i* represents the region and t represents the year; *TE* stands for comprehensive technical efficiency, *X1* represents residential area, *X2* represents per capita annual income, *X3* represents traffic conditions, *X4* represents the degree of concentration of residents, and *X5* represents the number of migrant households. *x* represents the control variable, and the logarithm of all control variables is taken in this paper, including the number of permanent households (*LnPr)*, the number of poor households in the village (*Ln Ph*), and the number of shuttle buses (*LnBn*). β is the coefficient of each and ε is the random perturbation term.

C. Correlation Checks

This article uses Pearson test method to conduct correlation tests on the area of residential areas, per capita annual income, regional transportation conditions, degree of resident aggregation, and number of migrant workers in the region. The results are shown in the Table 1, and the absolute values of the correlation coefficients between each variable are all less than 0.5, indicating low correlation.

Table 1. Pearson correlation test for explanatory variables

Variable	X 1	X 2	X3	X4	X5
X1	1.000				
X2	−0.071*	1.000			
X3	−0.144*	−0.298	1.000		
X4	−0.196	0.449*	−0.201*	1.000	
X5	−0.112	−0.192	0.191*	−0.261*	1.000

Notes: Indicates a pass at the 10% significance level.

In addition, in this paper, Variance Inflation Factor (VIF) to perform a multicollinearity test for explanatory variables. As shown in the Table 2, the VIF values of each explanatory variable are much less than 10, so there is no multicollinearity between them, which can be used in both Tobit regression models.

Table 2. Variance inflation factor VIF test

Variable	VIF	1/VIF
X1	1.43	0.700
X2	1.36	0.737
X3	1.14	0.873
X4	1.12	0.891
X5	1.12	0.891

D. Analysis of Tobit Empirical Regression Results

According to the regression results of the Tobit model, the living area, per capita annual income, degree of residential agglomeration, and output efficiency of the sample are significantly positively correlated, while traffic conditions and the number of immigrant households are negatively correlated with the output efficiency of ecological public goods. The specific results are shown in the Table 3.

Table 3. Analysis results of the impact of ecological public goods supply on output efficiency

	r1	r2	r3	r4	r5	r6
X1	0.0085**					0.0093**
	(0.0045)					(0.0025)
X2		0.0033***				0.0025*
		(0.0134)				(0.0235)
X3			−0.0026**			−0.0031**
			(0.0079)			(0.0098)
X4				0.6135***		0.7852***
				(0.2582)		(0.3012)
X5					−0.0457*	−0.572*
					(0.0207)	(0.01983)
Ln (Pr)	0.1599***	0.0913***	0.1145***	0.1395***	0.1358***	0.1299***
	(0.2652)	(0.0073)	(0.1286)	(0.0097)	(0.2190)	(0.1981)
Ln (Ph)	0.0768*	0.0534*	0.1010*	0.0997*	0.1321*	0.1198*
	(0.1152)	(0.0485)	(0.0980)	(0.0345)	(0.0991)	(0.1021)
Ln (Bn)	−0.2061**	−0.0939**	−0.1874**	−0.0899**	−0.1587**	−0.1980**
	(0.1296)	(0.0987)	(0.1302)	(0.2001)	(0.1289)	(0.8969)
−cons	−2.3128***	−1.9891***	−2.1240***	−1.092***	−2.3691***	−2.003***
	(0.3111)	(0.2739)	(0.3189)	(0.2988)	(0.3420)	(0.2699)

Notes: *, **, and *** indicate that they passed the test at the significance levels of 10%, 5%, and 1%, respectively; Std. Err. values are in parentheses

From the above table, it can be concluded that the residential area of villages and towns is positively correlated with output efficiency at a significant level of 5%, indicating that the size of residential area will affect the quantity and type of rural ecological public goods supply, which may to some extent affect the output efficiency of rural ecological public goods. The empirical results show that the larger the area of the village's residential area, the more residents can enjoy ecological public products, thereby increasing farmers' satisfaction with the supply of ecological public products and improving output efficiency; Similarly, the per capita annual income of villages has a positive impact on the output efficiency of ecological public goods, but the impact is not very significant. This may be because as residents' income levels increase, farmers' demand for environmental sanitation will also increase, which will increase the supply pressure of government ecological public goods. The government will have more and more motivation to improve supply efficiency, thereby improving the output efficiency of ecological public goods; The impact of distance from villages and towns to county towns on the efficiency of ecological public product output is consistent with the hypothesis, and there is a negative correlation between the two. The farther the distance from villages to county towns, the lower the efficiency of ecological public product output; From the above table, it can be concluded that the higher the concentration of village residents, the higher the output efficiency of the government in providing ecological public goods. This is because the more concentrated the residents are, the smaller the government's supply of public goods, which reduces supply costs and improves the utilization and efficiency of public goods; The impact of the number of migrant workers on the output efficiency of ecological public goods is consistent with the hypothesis that the number of migrant workers has a negative effect on the output efficiency of ecological public goods. This indicates that the outflow of labor has significantly reduced the utilization rate of ecological public goods provided by the government, which has had a significant impact on the output efficiency of ecological public goods.

E. Robustness Test

This article selects a fixed effects regression model to conduct robustness tests on the above results. It can be seen that the fixed effects model has passed the robustness test, and compared with the regression results of the Tobit model on the impact of rural ecological public product supply on output efficiency in the northwest region, there is a significant similarity and synchronicity in both correlation coefficients and significance levels, indicating that the empirical results are robust and reliable.

Table 4. The regression results of the stability test of the impact of ecological public goods supply on output efficiency

	r1	**r2**	**r3**	**r4**	**r5**	**r6**
X1	0.0089**					0.0093**
	(0.0056)					(0.0035)
X2		0.0028***				0.0032*
		(0.0112)				(0.0099)
X3			−0.0030**			−0.0028**
			(0.0068)			(0.0073)
X4				0.6354***		0.6831***
				(0.2623)		(0.2183)
X5					−0.0498*	−0.5001*
					(0.0232)	(0.0199)
Ln (Pr)	0.1388***	0.0898***	0.1153***	0.1421***	0.1355***	0.1278***
	(0.2523)	(0.0101)	(0.1321)	(0.0097)	(0.2289)	(0.1999)
Ln (Ph)	0.0733*	0.0622*	0.1112*	0.0989*	0.1445*	0.1221*
	(0.1120)	(0.0485)	(0.0998)	(0.0423)	(0.0981)	(0.1382)
Ln (Bn)	−0.2136**	−0.0104**	−0.0991**	−0.1974**	−0.1689**	−0.1737**
	(0.1199)	(0.0956)	(0.1324)	(0.1928)	(0.2001)	(0.1295)
−cons	−2.2290***	−2.0119***	−1.9985***	−1.1937***	−2.4521***	−2.0039***
	(0.3311)	(0.2739)	(0.3093)	(0.2988)	(0.3491)	(0.2537)
adj. R2	−0.4433	−0.0532	0.1009	0.2987	−0.0877	0.3404

IV. Result and Discussion

This chapter is based on the DEA model to measure the supply efficiency of rural ecological public goods in the northwest region of China. A Tobit regression analysis model is constructed to empirically test the impact of the supply efficiency of rural ecological public goods using data from 500 villages and towns in northwest China from 2007 to 2022. The trend of the supply efficiency of ecological public goods in rural areas of Northwest China from 2007 to 2022 shows a fluctuating state, with two-thirds of villages and towns having an effective supply efficiency of ecological public goods. According to the Tobit model regression results, the sample residential area, per capita annual income, degree of residential agglomeration, and output efficiency are all significantly positively correlated, while traffic conditions and the number of migrant workers are negatively correlated with the output efficiency of rural ecological public goods. From the perspective of the impact on the output efficiency of rural ecological public goods, the explanatory variables of residential area, per capita annual income, and degree of residential agglomeration have a positive effect on the output efficiency of ecological public goods, with varying levels of significance. However, the other two explanatory variables, the distance from the village to the county city and the number of migrant workers, have a negative effect on the output efficiency of rural ecological public goods. Except for the frequency of shuttle buses, the other two control variables have a positive correlation with the output efficiency of rural ecological public products, while the frequency of shuttle buses has a negative impact on the output efficiency of ecological public products. The specific possible reasons

have been explained in the previous text.

V. Conclusion

The stronger externalities of rural ecological public goods can easily lead to market failure; therefore, the supply of ecological public goods requires government intervention. The increasing demand for public goods by the people presents characteristics of differentiation and diversification. Handling the contradiction between the growing need for a good ecological environment and the insufficient supply of ecological public services requires the government to provide high-quality and diversified ecological public goods, which will promote the transformation of government functions and explore new models of public goods supply. From the current government supply of ecological public goods in rural areas, problems such as insufficient total supply, significant regional differences in supply, low supply efficiency, and large deviations between local fiscal expenditure and expectations urgently need to be addressed, and guidance and support are even more necessary.

This article is based on the DEA model and uses data envelopment analysis to evaluate and compare rural ecological public products in 500 villages and towns in the northwest region. The results show that the overall level of ecological public goods supply in rural areas of Northwest China is relatively low, which will become an obstacle to further agricultural economic growth in the region. 17% of the sample towns have PTE values less than 1, indicating that these towns are purely technical inefficient, meaning that their production efficiency is relatively poor and their supply efficiency is also relatively low. Up to 83% of the sample townships in the northwest region are at the forefront of technical efficiency in the supply of rural ecological public goods (PTE=1), among which 120 townships have achieved both technical efficiency and scale efficiency (i.e. TE=1, PTE=1, and SE=1).

Afterwards, this article used the Tobit model to analyze the possible impact of rural ecological public product supply on output efficiency and their relationship. Selecting the technical efficiency of rural ecological public goods supply in the northwest region as the dependent variable, the investment in domestic sewage treatment, toilet facility reform, and domestic waste treatment as the explanatory variables, and also selecting three control variables: residential area, per capita annual income, and distance from villages to county towns. From the perspective of the impact of rural ecological public product supply on output efficiency, in addition to residential area, other variables including domestic sewage treatment investment, toilet facility reform investment, domestic waste treatment investment, per capita annual income, and village to county distance all have a positive effect on the output efficiency of ecological public products, but some of the effects are not significant. The area of village residential areas has a negative impact on the output efficiency of ecological public goods, which may be because the larger the residential area, the higher the cost of increasing ecological public goods by the government, which increases the supply pressure and actually reduces the supply level.

Environmental public goods have high externalities, and the government is the most important investor in building a good ecological environment. The value of government existence lies in providing public goods and promoting fairness. The core content of effective government is government behavior. Improving government ecological service capabilities can enable sustainable development to embark on the green fast lane. While pursuing economic growth, China should fully consider the strategic value of natural ecosystems and make providing ecological public goods an important factor in government policy-making. Transitioning from an economic growth-oriented government to an ecological service-oriented government, restructuring and optimizing government responsibilities, and embedding rural ecological public goods and services into the basic functions of the government under the guidance of ecological civilization concepts.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Xinyue Gao worked on data curation, conceptualization, methodology, wrote the original draft; Lizi Yang worked on investigation, visualization, wrote review & editing; Yaobo Shi wrote review & editing, and wrote original draft, investigation; all authors had approved the final version.

Funding

The authors are grateful to the financial support from the Yulin Industry-University-Research Project (CXY-2022-183 & CXY-2022-154) and Xi'an university of technology Research Team Project (105-256082004).

References

Deller, S. C. 1990. Pareto-efficiency and the provision of public goods within a rural setting. ***Growth and Change***, (21): 30–39.

Elinor, O. 2000. Collective action and the evolution of social norms. ***Journal of Economic Perspectives***, (3).

John, M. A. 1983. Infrastructure and aggregate agricultural productivity: International evidence. ***Economic Development & Cultural Change,*** 31(3): 609–619.

Luo, W. C. 2014. Effectiveness and influencing factors of public service supply in rural living environment in China: From the perspective of farmers. ***China Rural Economy***, 2014(11): 65–72.

Ouyang, Z. Y., Zheng, H., Yue, P. 2013. Ideas and measures for establishing China's ecological compensation mechanism. ***Journal of Ecology,*** 33(03): 686–692.

Shi, Y. B, Liu, X. B. 2009. Study on the impact of rural public product supply on farmers' public welfare: Empirical data from rural areas in Shaanxi province. ***Journal of Northwest University (Philosophy and Social Sciences Edition)***, 39(01): 22–27.

Wang, F. 2013. Research on the efficiency of government supply of rural public goods. ***Southwest University***.

Wuthnow, R. Between states and markets: The voluntary sector in comparative perspective. ***Princeton: Princeton University Press***, 1991.

Xu, C. B. 2010. Research on performance evaluation of Rural public goods supply in China based on DEA. ***Fiscal Research***, (10): 53–55.