Measurement and Influencing Factors of Total Factor Carbon Productivity in the Logistics Industry of the Yellow River Basin: From the Perspective of Differences in Energy Endowment (Postprint)

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Abstract

Researching the total factor carbon productivity (hereinafter referred to as carbon productivity) of the logistics industry under the differences in energy endowments in the Yellow River Basin is of great significance for clarifying the carbon reduction and emission mitigation paths in this region. Based on the degree of energy endowment, the Yellow River Basin is divided into energy-rich areas and general energy areas. The super-efficiency SBM model and the ML index are utilized to explore the static efficiency values and dynamic efficiency indices of carbon productivity in the Yellow River Basin, and the influence mechanisms of various factors on carbon productivity are clarified through regression analysis. The results indicate that: (1) Carbon productivity exhibits regional heterogeneity; energy-rich areas have higher carbon productivity and faster growth, with significant improvements in technical efficiency; general energy areas show overall growth, but internal efficiency differentiation is evident. (2) Regarding dynamic efficiency characteristics, the technical efficiency and technical progress of carbon productivity in energy-rich areas and general energy areas show divergent characteristics; the technical efficiency of energy-rich areas leads that of general energy areas, while in general energy areas, technical improvement is more significant in Sichuan and Ningxia, whereas the momentum for technical progress in Shandong is insufficient. (3) The driving mechanisms show differentiation; energy prices have a positive impact only in energy-rich areas while exerting an inhibitory effect in general energy areas; energy endowment has a positive effect only on general energy areas, and different influencing factors produce disparate effects across different regions.

Full Text

Preamble

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GEOGRAPHY

Measurement and Influencing Factors of Total Factor Carbon Productivity in the Logistics Industry of the Yellow River Basin: A Perspective Based on Differences in Energy Endowment

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Abstract

Studying the total factor carbon productivity (hereafter referred to as "carbon productivity") of the logistics industry in the Yellow River Basin, while accounting for differences in energy endowments, is crucial for clarifying the region's path toward green development. As a major energy production base and a critical ecological barrier in China, the Yellow River Basin faces significant challenges in balancing economic growth with environmental sustainability. The logistics industry, as a fundamental and strategic sector of the national economy, is characterized by high energy consumption and high carbon emissions. Therefore, analyzing its carbon productivity is essential for achieving the "dual carbon" goals and promoting high-quality development in the basin.

The identification of pathways for carbon reduction and emission mitigation is of profound significance. This study categorizes the Yellow River Basin into energy-rich regions and general regions based on their respective energy endowments. Utilizing the Super-Efficiency SBM (Slack-Based Measure) model and the Malmquist-Luenberger (ML) index, we investigate the static efficiency values and dynamic efficiency indices of carbon productivity across the Yellow River Basin. Furthermore, through regression analysis, we clarify the specific impact of various factors on these metrics.

Keywords: Logistics industry; Total factor carbon productivity; Super-efficiency SBM model; Yellow River Basin

1. Introduction

The Yellow River Basin serves as a critical ecological barrier and a vital economic zone in China. However, the region faces significant challenges due to its heavy reliance on energy-intensive industries and a coal-dominated energy structure. Achieving a transition toward low-carbon development is essential for the high-quality growth of the basin. By distinguishing between energy-rich and general regions, this research aims to provide a more nuanced understanding of how resource availability influences carbon productivity and to identify tailored strategies for sustainable development.

The logistics industry serves as a fundamental, strategic, and leading sector for national economic development. However, its traditional growth model, characterized by high energy consumption and high emissions, has become a significant source of carbon dioxide emissions. Data indicates that total carbon emissions reached 7.28×10^8 t, indicating an overall upward trend. Under the dual constraints of global climate change and China's "dual carbon" goals, improving the Total Factor Carbon Productivity (TFCP) of the logistics industry has become a critical pathway for achieving high-quality economic development and green transformation.

2. Methodology and Data

2.1 Super-Efficiency SBM Model

To accurately measure carbon productivity, this study employs the Super-Efficiency SBM model. Unlike traditional Data Envelopment Analysis (DEA) models, the SBM model accounts for input and output slacks, providing a more precise measure of efficiency. The "super-efficiency" aspect allows for the ranking and comparison of decision-making units (DMUs) that are all situated on the efficient frontier. The model is defined as:

$$
\begin{aligned}
\min \rho = & \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{k=1}^{s_1}\frac{s_k^y}{y_{k0}} + \sum_{l=1}^{s_2}\frac{s_l^z}{z_{l0}}\right)} \\
\text{s.t. } & x_{i0} \geq \sum_{j=1, j\neq 0}^{n} \lambda_j x_j - s_i, \forall i \\
& y_{k0} \leq \sum_{j=1, j\neq 0}^{n} \lambda_j y_j + s_k, \forall k \\
& z_{l0} \geq \sum_{j=1, j\neq 0}^{n} \lambda_j z_j - s_l^z, \forall l \\
& s_i \geq 0, s_k \geq 0, s_l \geq 0, \lambda_j \geq 0, \forall i, j, k, l
\end{aligned}
$$

Where ρ represents the total factor carbon productivity; s_i^x, s_k, and s_l^z represent the slack variables for inputs, expected outputs, and non-expected outputs, respectively.

2.2 Malmquist-Luenberger (ML) Index

While the SBM model provides a static snapshot, the ML index is utilized to analyze dynamic changes over time. This index incorporates undesirable outputs–specifically carbon emissions–allowing for an evaluation of Total Factor Productivity (TFP) growth under environmental constraints. The ML index is decomposed as follows:

$$ML_c^{t+1} = MLEC_c + MLTC_c$$

Where $MLEC$ represents the efficiency change index and $MLTC$ represents the technological progress index.

2.3 Data Sources and Indicator System

The study area covers nine provinces in the Yellow River Basin. Data are primarily sourced from the *China Statistical Yearbook* and the *China Energy Statistical Yearbook*. All value indicators are deflated to constant prices using 2000 as the base year.

- **Labor Input:** Measured by the number of employees in the logistics industry.
- **Capital Input:** Represented by the capital stock, estimated using the perpetual inventory method: $K_{it} = K_{it-1}(1-\delta) + I_{it}$.
- **Energy Input:** Total energy consumption converted into standard coal equivalents.
- **Desirable Output:** Added value of the logistics industry.
- **Undesirable Output:** Total CO_2 emissions calculated as: $C = \sum(E_i \times \delta_i \times \theta_i)$.

[Figure 1: see original paper]

3. Results and Analysis

3.1 Regional Heterogeneity in Carbon Productivity

The empirical results indicate significant regional heterogeneity in carbon productivity across the Yellow River Basin. Energy-rich regions (such as Shanxi, Shaanxi, and Inner Mongolia) demonstrate higher carbon productivity and faster growth rates, primarily driven by substantial improvements in technical efficiency. In contrast, energy-average regions show internal divergence; for instance, Sichuan and Ningxia have achieved significant technical improvements, while Shandong exhibits insufficient momentum in technical progress.

3.2 Impact of Energy Endowment

Energy endowment plays a critical role in shaping regional industrial structures. In energy-rich regions, the abundance of fossil fuels can lead to a "resource curse" or "lock-in effect," where reliance on energy-intensive industries complicates the transition to low-carbon systems. However, these regions also benefit from economies of scale in energy production.

3.3 Driving Mechanisms

The driving factors of carbon productivity exhibit spatial differentiation: 1. **Energy Prices:** Exert a positive influence in energy-rich regions but act as a constraint in energy-average regions. 2. **Technological Innovation:** Remains the core driver for improving carbon productivity by optimizing production processes. 3. **Industrial Structure:** The transition toward high-tech and service-oriented logistics significantly enhances TFCP.

[Figure 2: see original paper]

4. Conclusion and Policy Recommendations

This study measured the TFCP of the logistics industry in the Yellow River Basin using the Super-SBM and ML index models. The findings suggest that differentiated regional policies are necessary. Energy-rich regions should focus on breaking path dependency and investing in green technological innovation, while energy-average regions should prioritize optimizing their logistics networks and improving energy efficiency. Promoting the digital transformation of the logistics sector is essential for achieving the "dual carbon" goals and ensuring high-quality development across the basin.

Note: Figure translations are in progress. See original paper for figures.