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A Study on the Input-Output Efficiency and Influencing Factors of ESG Investment in Cross-border E-commerce Listed Companies: An Empirical Analysis based on the DEA-Tobit Two-stage Model

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Abstract

As global trade patterns be restructured and sustainability become institutionalized, Environmental, Social and Governance (ESG) performance has become one of the key performance indicator dimension for cross-border e-commerce companies (CBEC). This study examines Chinese CBEC firms listed on the A-share and Hong Kong stock exchanges during the post-pandemic period (2023 - 2025), which is also the period of ESG regulatory formalization. An in-put oriented CCR model is employed to measure ESG input-output efficiency, followed by a Tobit regression to identify the influencing factors of the ESG efficiency. The discovery showed that the overall ESG efficiency is relatively low, with only about 10% of decision-making units (DMUs) achieved full efficiency. This indicates most CBEC firms have long way to go in ESG efficiency. Regulation analysis indicates the positive effect of enterprise scale on the ESG allocation, whereas supply chain concentration played a negative role. The effects of overseas revenue percentage and ISO 14001 certification, however, are statistically insignificant. From the perspectives of economies of scale, supply chain governance, an compliance costs, this study undertakes an in-depth research in ESG allocation efficiency of CBEC firms, and provides insights for companies seeking to optimize ESG resource management.

Keywords

Cross-border E-commerce; ESG Allocative Efficiency; DEA Efficiency; Tobit Regression; Economies of Scale; Supply Chain Concentration.

1. Introduction

Cross-border e-commerce companies in China has experienced a phase of rapid expansion in the post-pandemic era. After that, this sector has transformed into a quality-driven development. According to the statistics of GACC, China CBEC exports exceeded RMB 2.6 trillion in 2024, representing a year-on-year increase of 15.6%. It has served as a critical engine for stabilizing export demand. Concurrently, capital markets have imposed strengthened ESG disclosure requirements on listed companies both in domestic and international markets. In June 2023, the International Sustainability Standards Board (ISSB) formally issued two International Financial Reporting Standards regarding sustainability disclosure (IFRS S1 and IFRS S2), marking the beginning of standardized ESG financial reporting. One year later, Shanghai, Shenzhen, and Beijing stock exchanges jointly released the Guidelines for Sustainability Reports of Listed Companies, establishing tiered mandatory disclosure requirements. In November, nine ministries including the Ministry of Finance jointly promulgated the Enterprise Sustainability Disclosure Standards. This standard established a unified domestic framework for sustainability reporting. Many regulations have also been enacted abroad. The European Union, the United Kingdom, and 14 other jurisdictions have

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enacted mandatory ESG related legislation. As a result, Chinese enterprises engaging in overseas commerce are facing an increasingly complex web of ESG compliance obligations.

CBEC firms, by virtue of their cross-border operations and extended supply chains, confront particularly high environmental, social, and governance compliance risks. On the one hand, the value chain including procurement, production, warehousing, sales, and logistics is quite long, so that an ESG compliance failure at any single node may disrupt operations and affect the entire supply chain. On the other hand, different operational segments face multiple regulatory jurisdictions and distinct legal requirements, thereby inflating compliance costs. Despite this, existing studies mainly focused on the linear relationship between ESG policies or ratings and financial performance in traditional industries. The existing literature gave little attention to how firms convert ESG resources into economic outputs, and even less to the CBEC sector specifically.

Under the restriction of resources, the key factor of sustainable development is how firms can maximize economic returns under a given level of ESG investment. Data envelopment analysis (DEA) is a non-parametric method for evaluating the relative efficiency of systems, especially for multi-input, multi-output. It can effectively avoid the subjectivity effect in deciding weight, and has been widely adopted in ESG efficiency evaluation across other industries. Based on the nature of DEA method and the operational characteristics of CBEC firms, this study further employs a Tobit model to identify the key factors of ESG economic conversion efficiency.

Rather than examining linear input-output relationships, this study re-evaluates the ESG contribution of CBEC enterprises from an efficiency perspective. Moreover, it takes more CBEC operation-specific factors into consideration, such as degree of supply chain concentration and internationalization. This further enhances the analytical framework of ESG efficiency. In doing so, the study not only enriches the empirical evidence of ESG efficiency in CBEC industry, but also provides efficiency-based support for CBEC regulators and enterprises seeking to improve ESG strategy.

2. Literature Review and Theoretical Analysis

2.1. ESG Investment and Enterprise Performance

Some scholars contend that ESG investment increases operating costs and displaces working capital, thereby having a negative impact on financial performance (Friede et al., 2015). However, as non-financial performance indicators receive increasing attention, more researchers suggest that ESG investment can enhance enterprise performance. Freeman (1984) demonstrated that effective ESG activities can improve reputation of brand, and consequently reduce the cost of capital. From the perspective of Qiu and Yin (2019), this finding is also proved in China ecological civilization construction. Furthermore, ESG can also stimulate innovation and promote value creation.It is supported by Li et al. (2021) and Sheng et al. (2022).

To be more specific, the relationship between ESG investment and company performance is not a simple linear one. A study of A-share listed companies found that the environmental dimension is negatively correlated with operational efficiency, while the social and governance dimensions are positively correlated (Sun et al., 2025). For CBEC firms, however, the cross-border nature of operation implies broader stakeholders and different ESG impacts. This study therefore adopts an efficiency perspective, focusing on the relative efficiency of ESG inputs and their key factors in CBEC firms.

2.2. Application of DEA in Efficiency Evaluation

DEA evaluates the relative efficiency of decision-making units (DMUs) by constructing a production frontier. The predominant models include the constant returns to scale (CRS) CCR model proposed by Charnes et al. (1978) and the variable returns to scale (VRS) BCC model

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introduced by Banker et al. (1984). In ESG efficiency related researches, firms are generally assumed to have control over their resource input levels. Also, enterprise scale constitutes an important factor. Therefore, the CCR model is more commonly employed in ESG efficiency evaluation.

DEA has been widely applied to ESG performance assessment in traditional industries, such as banking and manufacturing. Zhu, Liu et al. (2025) measured the ESG efficiency of listed commercial banks, finding it at a low level and is constrained by regional economic development. For manufacturing industry, both international (Fried et al., 2008) and domestic (Li Ling et al.) studies have employed DEA models to evaluate ESG performance. However, the application of DEA to the emerging field of cross-border e-commerce remains in its infancy. CBEC industry needs further measurement and investigation.

2.3. ESG Research on Cross-Border E-Commerce Enterprises

Domestic research on ESG in China CBEC sector has primarily focused on macro economic policies and regional case analyses. Xie et al. (2022) demonstrated a mutually positive relationship between CBEC outward investment and host-country institutional environments. He (2023) examined the effect of environmental management system certification on innovation efficiency. He found it had positive innovation effects. Supply chain concentration has been shown to suppress ESG ratings (Zhang et al., 2024).

From the supply chain perspective, existing research mainly focused on traditional industries and cross-industry samples. Wang et al. (2026), using a sample of A-share listed companies, found that corporate social responsibility significantly reduces supplier concentration. Supply chain concentration has also been shown to inhibit ESG performance (Zhang et al., 2024). Sun et al. (2025) further confirmed the impact of supplier concentration on environmental performance. Given the supply chain characteristics of the CBEC industry (Asset-light, R&D-intensive, and globally networked), its ESG investment structure and supply chain impact mechanisms differs from those of traditional industries, improving need of further in-depth empirical investigation.

2.4. Theoretical Analysis and Research Hyptheses

2.4.1. H1: Economies of Scale Exert a Significantly Positive Effect on ESG Input-output Efficiency in CBEC Firms.

Economies of scale and production capacity: Larger firms can amortize the fixed costs of compliance and reduce per-unit ESG expenditure. Economies of scale and learning-curve effects further diminish the expenses in ESG investment. Moreover, the benefits of reputation are much more pronounced for large-scale enterprises, which also have more financial reserves and managing experience to establish systematic ESG strategies.These all enhance the conversion efficiency of ESG inputs.

2.4.2. H2: The Degree of Internationalization Has a Significantly Positive Effect on ESG Input-output Efficiency in CBEC Firms.

Internationalization and resource allocation: Firms with higher degrees of internationalization are better acquainted with overseas compliance requirements and can therefore allocate resources more rationally across regions. However, since these firms need to comply with divergent regulatory standards across jurisdictions, the compliance cost might increase. It may inflate overall resource consumption and reduce economic conversion rates.

2.4.3. H3: Supply Chain Concentration Exerts a Significantly Negative Effect on ESG Input-output Efficiency in CBEC Firms.

Supply chain concentration and bargaining power: High supply chain concentration may expose CBEC firms to higher risk of disruption and lower bargaining power. This can increase

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the compliance, coordination and negotiation expenses. Moreover, powerful suppliers may pass through their own compliance costs, thereby negatively affect overall ESG efficiency.

2.4.4. H4: Environmental Compliance Investment Has a Significantly Positive Effect on ESG Input-output Efficiency in CBEC Firms.

Environmental certification and signaling theory: Environmental certifications and related disclosures give signals of environmental management to stakeholders, reducing information asymmetry in capital markets. This results in lower costs of financing. However, the actual transmission of such effects is subject to considerable uncertainty. It is therefore necessary to compare the resources actually conserved against those consumed, and calculate the net impact on ESG input-output efficiency.

3. Research Design

3.1. Sample Selection and Data Sources

Given that IFRS S1 and S2, which formalized ESG disclosure requirements, were issued in 2023, and that domestic listed companies have only begun disclosing sustainability reports within the past three years, the study selects CBEC firms listed on the A-share and Hong Kong stock exchanges during 2023-2025 as the initial sample. Following the industry classification guidelines of the China Securities Regulatory Commission, 20 listed CBEC companies are identified, which include brand-oriented exporting firms in electronics, tools, apparel, and imaging products, as well as platform operation and logistics enterprises. The study focuses on 60 observations across 9 industry-specific input and output indicators. Since the input-oriented DEA model computes the projection distance of each DMU to the efficiency frontier via linear programming, it does not require the dimensions of inputs and outputs to keep the same (Cooper et al., 2007). Also, this DEA model examines the relative efficiency which ESG input intensity is converted into economic output. As a result, input indicators adopt ratio forms to neutralize firm-size differences, while output indicators adopt absolute values to reflect actual economic returns. This setting also meets the efficiency concept of evaluating input intensity to economic output conversion.

According to DEA model requirements, the number of DMUs should be no fewer than twice of the total indicator amounts (Cooper et al., 2007). In the study, the observation-to-indicator ratio is approximately 10.4. It substantially exceeds the minimum threshold and satisfies the judgement requirements. Data are sourced from annual reports, sustainability reports (where available), the Wind financial database, and public news. To ensure the validity of input-output relationship and ESG efficiency measurement, the financial data are processed as follows: (1) observations with negative net profit are excluded; (2) continuous variables are processed according to Winsorize tail reduction method at the 1st and 99th percentiles, to mitigate the influence of extreme values; (3) monetary variables are log-transformed to reduce heteroscedasticity; and (4) a small number of missing observations for the proportion of top five suppliers are imputed using linear interpolation and multi-year average calculation.

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3.2. Variable Definitions

Table 1. DEA-Tobit Variable Settings and Explanations

Type	Name	Symbol	Measurement	Explanation
Input 1	Environmental Investment (E)	E	R&D expenses / operating revenue×100%	Proxy variable for green technology research and development investment
Input 2	Social investment (S)	S	Employee protection investment / operating revenue×100%	Spare tire variable method: substitution of total employee compensation
Input 3	Governance investment(G)	G	Administrative Expense Ratio (%)	Management expenses/operating income×100%
Output 1	Operating income	Y1	Operating income (RMB 10,000)	Market output indicator
Output 2	Net profit	Y2	Net profit (RMB 10,000)	Financial output indicator
Explanatory variable 1	Proportion of income from abroad	Overseas	Overseas income/total revenue×100%	Measuring the degree of internationalization
Explanatory variable 2	Supply chain concentration	Supplier	Proportion of procurement from the top five suppliers (%)	Filled in missing values with their own multi-year mean
Explanatory variable 3	Environmental certification	ISO14001	Dummy variable (0/1)	Obtained ISO14001 certification or not
Controlling variable 1	Enterprise scale	Size	ln(Total assets)	Reflects size of business

3.3. DEA Model Specification

The study employs the input-oriented CCR model (constant returns to scale) to evaluate the ESG input-output efficiency of CBEC enterprises. Given that ESG resource inputs (Energy conservation and emission reduction, employee welfare, and compliance governance) fall within the firm's controllable arrangement, while output efficiency is subject to external market disturbances, an input-oriented evaluation is more suitable and offers more meaningful managerial implications.

For each DMU_0, the setting of DEA model is to solve the following linear programming:

$$\min \theta$$

$$\text{subject to: } \Sigma(j=1 \text{ to } n)\ \lambda_j \times X_j \le \theta \times X_0 \text{ (input constraint)}$$

$$\Sigma(j=1 \text{ to } n)\ \lambda_j \times Y_j \ge Y_0 \text{ (output constraint)}$$

$$\lambda_j \ge 0$$

In this model, θ is the input contraction factor (representing the DEA efficiency value), X is the input vector (The study utilizes R&D expense ratio, employee protection investment ratio, and administrative expense ratio to represent the E, S, and G dimensions respectively), Y is the output vector (operating revenue and net profit), and λ represents the intensity variables. The DEA efficiency score ranges from 0 to 1. Values closer to 1 indicates higher ESG input efficiency. When θ = 1, the DMU lies on the efficiency frontier and is DEA-efficient; when θ < 1, input

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redundancy exists and the DMU can achieve efficiency improvement by proportionally reducing inputs to project onto the frontier.

3.4. Tobit Model Specification

Given that DEA efficiency scores (Eff) are bounded in the interval [0, 1] and is right-censored data, ordinary least squares (OLS) would yield biased and inconsistent estimates. The Tobit model (censored regression model), proposed by Tobin (1958), is designed to handle such censored dependent variables. It can provide consistent parameter estimates. Hence, the following Tobit model is specified:

$$Eff_i^* = \beta_0 + \beta_1 Overseas_i + \beta_2 Supplier_i + \beta_3 ISO14001_i + \beta_4 Size_i + \varepsilon_i$$

$$Eff_i = Eff_i, \text{ if } 0 < Eff_i < 1$$

$$Eff_i = 1, \text{ if } Eff_i^* \geq 1 \text{ (right-censored at 1)}$$

In this model, the dependent variable is the DEA efficiency value, and the core explanatory variables are overseas revenue share, proportion of the top five suppliers, ISO 14001 certification, and the firm scale, ln (total assets). The model is estimated by maximum likelihood estimation (MLE), with $\varepsilon_i \sim N(0, \sigma^2)$ denoting the normally distributed error term. Given the short time dimension (T = 3), a pooled Tobit specification is adopted; the OLS model is additionally estimated for comparative purposes.

4. Empirical Results and Analysis

4.1. Descriptive Statistics

During the sample period, the average value of ESG efficiency is 0.3969, and the median of ESG efficiency is 0.3064, indicating a right-skewed distribution. This suggests that more than half of the CBEC listed firms operate below the median efficiency level. The industry-wide ESG resource allocation has considerable room for improvement. The maximum efficiency score reaches 1.0000 (Achieved by Anker Innovations in 2025, Zhejiang China Commodities City Group in 2024 and 2025, and Sinotrans Huamao Logistics in 2024 and 2025), while the minimum is only 0.0110 (JAME Technology, 2024). The range of 0.9890 reflects obvious differences in ESG conversion efficiency among CBEC enterprises. The standard deviation of 0.3127 further proved the high dispersion across firms.

From a temporal perspective, the average ESG efficiency was 0.3512 in 2023, rising to 0.4023 in 2024 and further to 0.4385 in 2025, showing the performance has taken a big step forward. Faced with the international standards of sustainability disclosure and tightening global ESG regulation, Chinese CBEC enterprises are adapting to new compliance requirements and gradually enhancing their ESG input-output efficiency.

At the firm level, high-efficiency enterprises (efficiency ≥ 0.8) are concentrated among brand-oriented export firms (Anker Innovations, Zhejiang China Commodities City Group) and logistics enterprises (Sinotrans Huamao Logistics). These firms generally possess mature brand, reputation and global supply chain management systems. Apart from that, they also published sustainability reports in each of the past three years. It shows their sustained commitment to ESG accounting and disclosure.

4.2. DEA Efficiency Results

Table 2 presents the complete DEA efficiency results. A total of five DMUs reach the efficiency frontier (efficiency = 1) and achieve DEA effectiveness, representing 9.6% of the sample. The efficient DMUs are Anker Innovations (2025), Zhejiang China Commodities City Group (2024, 2025), and SSinotrans Huamao Logistics (2024, 2025).

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Table 2. DEA Efficiency Value Calculation Results (Partial)

Year	Company	Stock	DEA Efficiency Value	Efficiency Ranking	Category of Efficiency
2025	Anker Innovations	300866	1.0000	1	Efficient DMU
2025	Zhejiang China Commodities City	600415	1.0000	2	Efficient DMU
2024	Sinotrans Huamao Logistics	603128	1.0000	3	Efficient DMU
2025	Sinotrans Huamao Logistics	603128	1.0000	4	Efficient DMU
2024	Zhejiang China Commodities City	600415	1.0000	5	Efficient DMU
2024	Saiwei Times	301381	0.8759	6	Inefficient DMU
2025	Saiwei Times	301381	0.8734	7	Inefficient DMU
2024	Anker Innovations	300866	0.8375	8	Inefficient DMU
2023	Sinotrans Huamao Logistics	603128	0.6915	9	Inefficient DMU
2023	Saiwei Times	301381	0.6832	10	Inefficient DMU
…	…	…	…	…	…
2024	JAME Technology	300868	0.0110	52	Inefficient DMU

Summary statistics: Efficient DMUs: 5 (9.6%); Inefficient DMUs: 47 (90.4%); Mean efficiency: 0.3969; Median: 0.3064; Minimum: 0.0110; Maximum: 1.0000.

These five efficient enterprises all share mature brand recognition, established global supply chain management systems, and extensive ESG accounting and disclosure experience. Firms with lower efficiency value include SFC, Focus Technology, Sunhome Precision and JAME Technology. This suggests deficiencies in R&D conversion rates, employee incentive mechanisms, and managerial redundancy. The low-efficiency observations are predominantly concentrated in 2023, with improvements observed in 2024 and 2025. This trend shows that the IFRS standards and global ESG regulation have objectively prompted firms to optimize ESG management and improve resource allocation.

4.3. Regression Results

Table 3. Regression Results for the OLS and Tobit Models

Variable	OLS Coefficient	Standard Error	T value	P value	Tobit Coefficient	Standard Error	Z value	P>
Constant	-2.3823	0.4879	-4.8831	0.0001 ***	—	—	—	—
Proportion of income from abroad	0.0018	0.0011	1.6738	0.1011	0.0016	0.0011	1.5002	0.1336
Proportion of procurement from the top five suppliers (%)	-0.0045	0.0022	-2.0792	0.0433 *	-0.0043	0.0022	-1.9542	0.0507 *
ISO14001	-0.0510	0.0647	-0.7877	0.4350	-0.0480	0.0664	-0.7231	0.4696
ln Total Assets	0.2124	0.0351	6.0584	0.0001 ***	0.2306	0.0376	6.1293	0.0001 ***
R^2/log likelihood value	0.5262	—	—	—	-3.9909	—	—	—
Adjusted R^2/σ	0.4840	—	—	—	0.2312	—	—	—
F Statistic/Sample size	12.4924	—	—	—	50	—	—	—

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Table 3 reports the regression results for both the OLS and Tobit models.

4.3.1. Enterprise Scale (H1)

The natural logarithm of total assets is positive and significant at the 1% level in both models (OLS $\beta = 0.2124$, $p < 0.001$; Tobit $\beta = 0.2306$, $p < 0.001$), providing strong support for H1. This result confirms significant economies of scale in ESG investment among CBEC firms. From the aspect of governance and employee protection, larger firms have more sophisticated internal control systems, higher managing capabilities, and more abundant resources. All of these resources lead to more professional ESG management. From the side of protecting environment, larger scale production amortizes the fixed costs of environmental compliance. Also, economies of scale may stimulate learning-curve effects that further reduce unit costs. Moreover, larger firms benefit from stronger brand effects, and ESG engagement yields higher economic value-added.

4.3.2. Supply Chain Concentration (H3)

Top-five supplier concentration is significantly negative at the 5% level in the OLS model ($\beta = -0.0045$, $p = 0.043$) and marginally significant at the 10% level in the Tobit model ($\beta = -0.0043$, $p = 0.051$), supporting H3. Higher supply chain concentration may increase CBEC firms' dependence on upstream suppliers and weaken their bargaining power. It may elevate costs spent in negotiating and coordinating. Suppliers may also pass through their own compliance costs to CBEC firms. Besides, too much reliance on a limited number of suppliers heightens supply chain disruption risk, indirectly inflating ESG compliance costs.

4.3.3. Overseas Revenue Share (H2)

The coefficient is positive but insignificant in both models (OLS $p = 0.101$; Tobit $p = 0.134$), failing to provide statistical support for H2. Although the directional effect is consistent with the hypothesis, the lack of significance may result from several factors: firstly, the sample firms all exhibit high internationalization, resulting in limited variation; secondly, multi-regional compliance costs and cross-border operational uncertainty may offset potential efficiency gains.

4.3.4. ISO 14001 Certification (H4)

The coefficient is negative but insignificant in both models (OLS $p = 0.435$; Tobit $p = 0.470$), failing to support H4. The insignificant effect of environmental management certification suggests that it has not yet translated into measurable efficiency benefits. This may reflect the long-term nature of environmental protection practices, whose positive effects exhibit a temporal lag. Furthermore, the certification demands substantial compliance costs and resource inputs, which may reduce short-term efficiency.

4.4. Robustness Checks

To examine the robustness of the baseline results, the study added an alternative specification and employed both Tobit and OLS model. The Tobit results are highly consistent with the OLS estimates. The directions of all explanatory variable coefficients are identical: Overseas revenue share and ln (total assets) are positive; top-five supplier concentration and ISO 14001 are negative. Also, the significance levels of ln (total assets) and supplier concentration keep the same in both models. In Enterprise scale remains highly significant at the 1% level in both specifications (OLS $t = 6.0584$; Tobit $z = 6.1293$), and the negative effect of supply chain concentration is consistent in direction.

Additionally, to test the robustness of the benchmark, the study re-estimated DEA efficiency from three alternative perspectives: (i) using all absolute value indicators, (ii) using all ratio type indicators, and (iii) employing the input-oriented BCC model. Spearman rank correlation coefficients across the above alternative specifications are all statistically significant, indicating that the efficiency rankings of DMUs remain stable under different model assumptions. Furthermore, the study re-estimated the Tobit model with each of the three alternative

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measures,the signs and significance levels of all key explanatory variables keep consistent. It further confirms the robustness of the regression results.

4.5. Model Diagnostics

Multicollinearity: Variance inflation factor (VIF) tests are conducted for all explanatory variables, which is shown in Table 4.

Table 4. VIF Diagnostic Results for Collinearity

Variable	VIF
Constant	1.0000
Proportion of income from abroad	1.1068
Proportion of the top five suppliers	1.1161
ISO14001	1.0346
ln(Total assets)	1.0302

All VIF values are far below the conventional threshold of 10 (maximum: 1.1161), indicating that the model is free from serious multiple collinearity problem. The independence between variables is good.

Outlier diagnostics: Further analysis of regression residuals shows that studentized residuals, high-leverage observations, and Cook's distances all remain within acceptable bounds. The sample does not contain extreme outliers that have significant influence on the regression results. It also confirms quality of data and findings.

5. Conclusion and Implications

5.1. Key Findings

Drawing on panel data from CBEC listed companies over the past three years, the study employs the DEA-Tobit two-stage model to systematically examine ESG input-output efficiency and its determinants since the implementation of IFRS S1 and S2. The principal findings are as follows:

(1)The overall ESG input-output efficiency of Chinese CBEC listed companies is relatively low, but it exhibits a year-on-year improvement trend. Only 9.6% of DMUs achieve DEA efficient during the sample period, indicating that the ESG resource allocation efficiency of most sample firms needs to be improved. The efficiency value showed a progressive increase from 2023 to 2025. It indicates that the domestic CBEC industry is currently in the stage of an adaptive improvement, driven by the formalization of ESG disclosure requirements and tightening global regulation.

(2)Economies of scale constitute the key driver for enhancing ESG input-output efficiency. Enterprise scale shows a significantly positive effect at the 1% level, confirming the presence of substantial scale economies in CBEC ESG investment. This finding aligns with the resource-based view theory, whereby larger firms, equipped with mature management systems, adequate idle resources and strong brand premium, can implement more efficient management, amortize compliance costs, and achieve higher value conversion.

(3)Excessive supply chain concentration inhibits ESG efficiency in CBEC firms. Top-five supplier concentration exhibits a significantly negative effect at the 5% level, reflecting that supply chain governance complexity and weakened bargaining power played a constraining role. The effect is especially significant due to the long-chain nature of CBEC operations. This finding links supply chain concentration with non-financial performance, and highlights the importance of supply chain governance in ESG management.

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(4)The efficiency benefits from internationalization and environmental management certification have not emerged. In the model, effects of overseas revenue share and ISO environmental certification on ESG efficiency are statistically insignificant, potentially attributable to uniformly high cross-border nature, overseas operational risks, and long-term nature of environmental protection effects. This finding also underscores that ESG investment benefits require time and actual effort to obtain efficiency benefits.

5.2. Managerial Insights

Based on the empirical findings, the following managerial suggestions are proposed:

(1) Leverage synergies and create economies of scale through strategic alliances and innovation platforms. Small and medium-sized CBEC enterprises should actively seek cooperation. The methods include mergers, strategic alliances, and platform-based operations. Cooperation can facilitate resource integration and experience sharing, thereby improving ESG management capabilities and input-output efficiency. Scaling up operations also amortizes the fixed costs of ESG compliance and improves the effectiveness of ESG investment.

(2) Establish diversified supply chain selection systems and optimize governance. Given the long chain, cross-regional characteristics of CBEC, enterprises need to reduce over-reliance on individual suppliers, expand the supplier base, and establish diversified, digitized supply chain management platforms. Through constructing the platform, companies can enhance bargaining power and mitigate disruption risks.At the same time, ESG criteria should be incorporated into supplier selection and evaluation systems. This can help develop deep cooperation with highly compliant suppliers, and improve overall supply chain ESG allocative efficiency through supply chain collaboration.

(3) Implement differentiation strategies. The experience of high-efficiency firms (e.g., Anker Innovations, Zhejiang China Commodities City) demonstrates that branding amplifies the effect of ESG strategies to a broader stakeholder base, enabling higher ESG premiums and intangible asset appreciation. Therefore, enterprises should start from their resource superiority and strategic positioning, formulate differentiated product strategies as well as ESG strategies. The differentiation can lead to strengthened brand, which is able to enhance market attention and capture more significant positive marginal effects from ESG engagement.

(4) Strengthen ESG measurement and sustainability reporting disclosures. The DEA-efficient firms (Anker Innovations, Zhejiang China Commodities City, and Sinotrans Huamao Logistics) have all published standardized ESG reports over the past three years with the most comprehensive data. It suggests that ESG disclosures improve internal and external monitoring, evaluation, and improvement of ESG management, thereby enhancing ESG efficiency.

(5) Pay attention to substantive and long-term ESG operations. Given that the efficiency benefits of ISO environmental certification are not yet significant, enterprises should avoid labeling behavior. They should essentially integrate ESG principles into R&D, production, logistics, and other operational processes instead. Besides, patience is required for long-term development of ESG management, and environmental protection investment should not be curtailed due to short-term performance pressure.

5.3. Limitations and Prospects

The study has the following limitations: (1) The implementation period of the IFRS standards and domestic mandatory disclosure requirements is relatively short, so data availability and the temporal window are constrained. Although the sample size exceeds the minimum model requirement, there is considerable scope for expansion, and this study should be regarded as exploratory. Future research can extend the sample to a broader set of CBEC listed companies that disclose detailed ESG information , after the policy has been implemented for a longer period of time. (2) As mandatory disclosure expands, more CBEC firms will provide detailed

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ESG data, broadening data accessibility. ESG indicators can be further refined to include carbon emissions data, employee training investment, and board independence. This can enrich the environmental, social, and governance indicators. (3) Based on the efficiency evaluation of CBEC listed companies, future studies can select representative benchmark firms, compare with other companies and implement in-depth qualitative analysis. The comparative analysis can discover the deeper institutional and organizational reasons for efficiency differences.

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