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Original Article

CAN STANDARDIZATION ENHANCE THE GREEN TOTAL FACTOR PRODUCTIVITY OF EXPORTING ENTERPRISES?

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Abstract: *Standardization plays a crucial guiding role in the green transformation of export enterprises by unifying technical specifications and optimizing institutional provisions. Based on data from A-share listed export companies from 2012 to 2023, this study utilizes the National Comprehensive Standardization Reform Pilot Program and employs a multi-period DID model to examine the impact of standardization on the green total factor productivity (GTFP) of export enterprises.The results indicate that: (1) standardization significantly promotes the improvement of GTFP in export enterprises; (2) the mechanism lies in reducing institutional transaction costs and stimulating green innovation; (3) heterogeneity analysis shows that the policy has a more pronounced promotional effect on export enterprises in resource-based cities, heavily polluting industries, technology-intensive industries, and those employing executives with environmental protection backgrounds. The study's conclusions provide policy implications for leveraging standardization to empower green economic transformation..*

Key words*: standardization; green total factor productivity; export enterprises; institutional transaction costs; green innovation*

JEL classification*: F18, L15, D24, O33.*

1. INTRODUCTION

Standardization is emerging as a key driver for corporate green transformation by promoting green innovation and resource conservation through unified technical specifications and optimized institutional frameworks. The "15th Five-Year Plan" proposal explicitly calls for "establishing a green and low-carbon standard system." However, Chinese enterprises face a dual dilemma of external barriers and internal inefficiency. Can standardization resolve this dilemma? Few studies address this, and exploring this issue holds significant value for advancing the "dual carbon" goals. Regarding the economic consequences of standardization, existing literature falls into two categories: government involvement and social self-regulation. The former finds that standard provision enhances technology diffusion (Wang Lijun et al., 2021), innovation efficiency (Li Sijia et al., 2024), reshapes industrial division of labor (Dize et al., 2023), and reduces export compliance costs (Julia, 2022). The latter finds that firm participation in standard-setting reduces R&D uncertainty, enhances innovation capacity (Du Wenqin et al., 2024), and optimizes operational performance (Zhu Jigao, 2022). However, existing research has not incorporated green total factor productivity (GTFP) into its analytical framework.

Regarding GTFP determinants, policies can be divided into environmental regulations and institutional development. The former drive transformation through price signals: carbon trading boosts GTFP (Wang Di et al., 2025), environmental protection taxes promote green innovation (Wang Pei et al., 2022), "Zero-Waste City" pilots enhance green innovation (Liu Mingguang et al., 2026), while green credit policies suppress green transformation (Wen Xuezhou et al., 2025). The latter provide development frameworks: the "Broadband China" pilot promotes green transformation (Fu Chenyu et al., 2025), "Industry-Service Integration" boosts GTFP (Li Xu et al., 2024), and mixed-ownership reforms optimize governance (Chen Lin et al., 2024). However, these studies have not incorporated standardization into their frameworks, and its impact on exporting firms' GTFP remains unclear.

The marginal contributions of this paper are threefold: First, it extends standardization research to the micro level of corporate green performance. Second, it incorporates standardization into the GTFP determinants framework. Third, it reveals that standardization enhances GTFP through reducing institutional transaction costs and stimulating green innovation.

2. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

2.1. POLICY BACKGROUND

China's standardization efforts have long been hindered by unclear government-market responsibilities, outdated standards, and insufficient international alignment. To address these issues, the State Council launched the "Plan for Deepening the Reform of Standardization Work" in 2015, followed by the "National Standardization Development Outline" in 2021 and the "14th Five-Year Plan for Building a National Standardization System," which set the goal of establishing a comprehensive, internationally aligned system by 2035.

Since 2016, five provinces including Zhejiang have been approved to conduct pilot reforms in national standardization, focusing on technological innovation, modern services, and social governance. The reforms are advanced in three phases: first, reforming institutional mechanisms; second, establishing government-market collaboration; and third, forming a provincial-specific framework. By the end of 2023, Zhejiang had led the formulation of 55 international and 2,819 national standards, with enterprises publishing over 330,000 standards, laying a solid foundation for the reform's promotion**.**

2.2. RESEARCH HYPOTHESES

2.2.1. Mechanism of Institutional Transaction Costs

Standardization reduces enterprises' institutional transaction costs in two ways. First, by standardizing government service processes, it promotes "uniform acceptance and consistent processing," lowering labor and time costs and reducing administrative friction. Second, it reduces compliance costs: domestically, by clarifying energy and environmental requirements, it reduces redundant reporting; internationally, by aligning domestic standards with global ones, it lowers testing and certification burdens for exporters .

Lower institutional transaction costs help optimize resource allocation and expand market capabilities, thereby improving GTFP. Cost reductions decrease non-productive spending, freeing resources for green R&D and facility upgrades . Cost advantages also enhance price competitiveness and market reach; as export scales grow, economies of scale spread green transformation costs . Additionally, stable policy expectations boost firms' confidence in green investment, driving continuous green innovation. Based on this, the following hypothesis is proposed:

H1: Comprehensive standardization reforms enhance the green total factor productivity of exporting firms by reducing institutional transaction costs.

2.2.2. Green Innovation Mechanism

Standardization promotes corporate green innovation in three ways. First, it reduces R&D trial-and-error costs by providing clear technical specifications, minimizing redundant investments and increasing innovation success rates . Second, it intensifies external scrutiny, creating regulatory pressure that compels enterprises to upgrade production processes and phase out outdated capacity. Third, it promotes knowledge sharing by transforming advanced technologies into replicable standards, lowering learning curves and driving green technology diffusion across the industrial chain. Green innovation supports GTFP improvement in exporting enterprises. From the production perspective, enterprises transition to low-carbon, intensive models by developing low-carbon processes and upgrading energy-efficient equipment, reducing energy use and emissions per unit output. From the market perspective, green technology upgrades help circumvent green trade barriers, create product differentiation, expand green market share, and generate economies of scale. In the long term, green innovation helps establish sustainable competitive advantages and drives dynamic GTFP growth. Based on this, the following hypothesis is proposed:

H2: Comprehensive standardization reforms enhance the green total factor productivity of exporting enterprises by promoting green innovation.

3. SPECIFICATION OF THE ECONOMETRIC MODEL, VARIABLE SELECTION, AND DATA DESCRIPTION

3.1. Specification of the Econometric Model

This study focuses on examining the impact of standardization efforts on the GTFP of exporting firms. Drawing on the literature and considering the characteristics of the data used in this study, the following econometric model is constructed:

$$GTFP_{it}=\beta_0+\beta_1 DID_{it}+\beta_2 X_{it}+d_i+d_t+\varepsilon_{it} \quad (1)$$

In Equation (1), `$GTFP_{it}$` denotes the GTFP of firm `$i$` in year `$t$`. `$DID_{it}$` is the treatment group dummy variable, which is set to 1 starting from the year the pilot reform was first implemented in the pilot regions, and to 0 for years prior to the pilot and for non-pilot provinces. `$X_{it}$` is the firm-level control variable. Additionally, to avoid omitting important explanatory variables, this study also includes year and firm fixed effects. `$d_i$` represents the firm-level fixed effects,d_t represents the year-level fixed effects, and ε_{it} represents the random disturbance term.

3.2. VARIABLE SELECTION

3.2.1. Dependent Variables

This study uses MaxDEA software to estimate firms' green total factor productivity (GTFP) via the super-efficiency SBM model, incorporating inputs, desired output, and undesired output.

To capture dynamic changes, we further adopt the ML index approach of Zhang Yanyan et al. (2022), taking 2012 as the base year (GTFP=1) and deriving annual GTFP by cumulating the ML index. Following Jiang et al. (2021), inputs include labor, capital, and energy; desired output is total operating revenue; and undesired output covers industrial "three wastes".

3.2.2. Explanatory variables

The interaction term for standardization development is `$DID_{it}$`. This study employs a multi-period difference-in-differences model, represented by the dummy variable `$DID_{it}$`, which is obtained by the interaction of `$treat$` and `$post$`. `$treat$` is the policy indicator variable; if the enterprise's `$i$` office is located in a province designated as a national comprehensive standardization reform pilot province `$treat$`, it takes the value 1; otherwise, it is 0. `$post$` is the time dummy variable, which is 0 before policy implementation `$post$` and 1 after implementation.Specifically, the value is set to 1 if the firm's office is located in Zhejiang Province and the time is 2017 or later; it is also set to 1 if the office is located in Shanxi, Jiangsu, Shandong, or Guangdong Provinces and the time is 2018 or later; all other cases are assigned a value of 0.

3.2.3. Control Variables

Based on existing research on firm GTFP, this study selects the following five control variables: (1) Firm size (Size), measured by the natural logarithm of year-end total assets. (2) Fixed asset ratio (Fixed), defined as the ratio of net fixed assets to total assets. (3) Cash flow ratio (Cashflow), defined as the ratio of net cash flow from operating activities to total assets. (4) Debt-to-Asset Ratio (Lev), defined as the ratio of total liabilities at year-end to total assets at year-end. (5) Firm Growth (Growth), defined as the ratio of current-year operating revenue to the previous year's operating revenue minus 1.

3.3. DATA DESCRIPTION

This study focuses on Chinese A-share listed export companies from 2012 to 2023, as they face increasing green trade barriers and greater pressure for green transition, making GTFP analysis suitable for assessing the green effects of standardization. Given data availability, the sample includes A-share listed export firms, excluding financial institutions and ST/*ST firms, removing observations with missing key GTFP indicators (net fixed assets, energy consumption, employees), and trimming continuous variables at the 1% level. The final sample covers 3,700 firms with 24,648 observations. Firm-level data come from the China Customs Database, CSMAR, and CNRDS; regional data from the China Urban Statistical Yearbook; pollution data from the China Environmental Statistical Yearbook; and energy data from the China Energy Statistical Yearbook.

4. EMPIRICAL ANALYSIS

4.1. BASELINE REGRESSION

Table 3 presents the baseline regression results. In Column (1), without controls, the DID coefficient is 0.023($p<0.05$). Columns (2)-(5) show that after adding controls stepwise, the DID coefficient remains significantly positive and stable, indicating that standardization significantly promotes GTFP growth in exporting firms.

Among controls, firm size and fixed asset ratio are positively associated with GTFP; the debt-to-equity ratio is also positive, suggesting reasonable debt supports green investment. Cash flow ratio and firm growth are negatively associated: the former reflects crowding-out of green investment under financial pressure, while the latter suggests that firms in rapid expansion may prioritize short-term gains over green production, negatively affecting GTFP.

Table 1. The Impact of Standardization on Green Total Factor Productivity (GTFP) in Export Enterprises: Baseline Regression

Dependent Variables:$GTFP$	(1)	(2)	(3)	(4)	(5)
DID	0.0230**	0.0220**	0.0219**	0.0210**	0.0210**
	(0.0091)	(0.0091)	(0.0091)	(0.0090)	(0.0090)
_cons	0.8311***	0.4552***	0.4197***	0.4888***	0.4873***
	(0.0033)	(0.1267)	(0.1307)	(0.1350)	(0.1350)
Control variable	Yes	Yes	Yes	Yes	Yes
Fixed effects by year	Yes	Yes	Yes	Yes	Yes
Firm-specific effects	Yes	Yes	Yes	Yes	Yes
N	24648	24648	24648	24648	24648
R^2	0.2288	0.2301	0.2304	0.2314	0.2315

*Note: The values in parentheses are robust standard errors aggregated to the firm level; ***, **, and *denote significance levels of 1%, 5%, and 10%, respectively.*

Source: authors

4.2. VALIDITY TESTS

4.2.1. Parallel Trends Test

The parallel trends test is a core prerequisite for the validity of the difference-in-differences (DID) model.

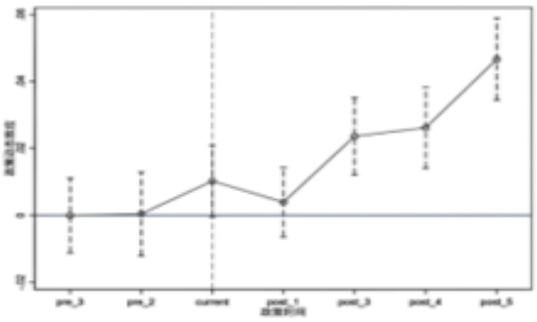
This paper employs a multi-period DID model to examine the dynamic changes in firm-level GTFP before and after the pilot program. The model specification is as follows:

$$GTFP_{it}=\eta_0+\eta_m EVENT_{it}^{n}+\eta_j X_{it}+d_i+d_t+\varepsilon_{it} \quad (2)$$

The parallel trends test results are shown in Figure 2. Using the year prior to policy implementation as the base period, no significant difference in GTFP levels existed between the treatment and control groups before the pilot, satisfying the parallel trends assumption.

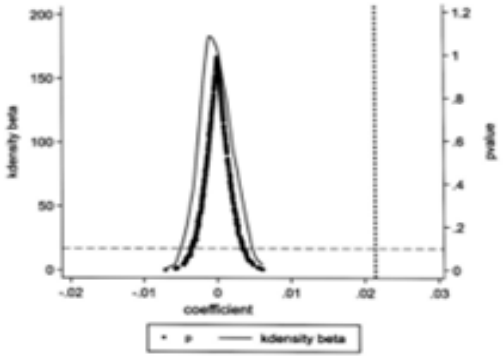
After implementation, the policy effect became significantly positive and continued to rise, indicating that standardization's positive impact on GTFP gradually strengthened over time.

Figure 1. *Parallel Trends Test*



Source: authors

Figure 2. Placebo Test



Source: authors

4.2.2. Placebo Test

To rule out unobservable factors, this study conducts a placebo test by randomly reassigning policy treatment identifiers 500 times. The kernel density of placebo coefficients centers near 0, with most p-values above 0.1, while the true DID coefficient lies far to the right of this distribution. This confirms the baseline results are not driven by random factors or omitted variables, validating the robustness of the conclusions.

4.3. ROBUSTNESS TESTS

4.3.1. Changing the Dependent Variable

We re-measured GTFP using the SBM-GML index. As shown in Table 4, Column (1), the DID coefficient remains significantly positive (0.003, $p<0.10$), consistent with the baseline results and confirming the robustness of the core findings.

4.3.2 Changing the Sample Range

To avoid interference from the 2015 new Environmental Protection Law, we excluded the 2015 sample and re-estimated the model. The results (Table 3, Column 1) show a DID coefficient of 0.0214 ($p<0.05$), consistent with the main regression, indicating that the conclusions remain valid after controlling for the policy shock.

4.3.3. Incorporating Combined Fixed Effects

We further incorporated industry and regional fixed effects into the model. The results (Table 4, Column 3) show a DID coefficient of 0.0211 ($p<0.05$), again confirming the robustness of the findings.

4.3.4. Changing the Clustering Level

To mitigate spatial and serial correlations within provinces, we adjusted the clustering level from firm to province. The results (Table 4, Column 4) show a significantly positive DID coefficient ($p<0.10$), consistent with the baseline, further validating the model specification and conclusion reliability.

Table 2. The Impact of National Standardization on the Green Total Factor Productivity of Exporting Firms: Robustness Tests

Dependent Variable:$GTFP$	(1) Change the dependent variable	(2) Change the sample range	(3) Add joint fixed effects	(4) Change clustering level
DID	0.003*	0.021**	0.021**	0.021*
	(0.002)	(0.009)	(0.009)	(2.387)
Control variables	Yes	Yes	Yes	Yes
Fixed effects for year	Yes	Yes	Yes	Yes
Firm-specific effects	Yes	Yes	Yes	Yes
N	24,294	22,860	24,183	24,294
R^2	0.954	0.863	0.867	0.862

Source: authors

4.4. ENDOGENEITY TESTS

Propensity Score Matching (PSM)

To mitigate sample selection bias, this study employs Propensity Score Matching (PSM) to match control group firms with similar characteristics to the treatment group. Firm size, proportion of fixed assets, cash flow, debt-to-asset ratio, and firm growth were selected as covariates. Propensity scores were estimated using a Logit model, and 1:1 nearest-neighbor matching was applied, ultimately yielding 3,374 valid samples.Balance tests show that the absolute values of the standardized deviations for each covariate fell below 2% after matching, and the P-values of the t-tests were all greater than 0.1, satisfying the balance assumption. The results of the difference-in-differences (DID) regression based on the matched samples indicate that the DID coefficient is 0.0192, which is significantly positive at the 10% level. This is consistent with the conclusions of the baseline regression and validates the robustness of the findings in this study.

Table 3. PSM Validity Test

Variable	Sample	Mean		Standard Error (%)	Standard Error (Absolute)	t-test	
		Treatment group	Control group		Reduction in absolute value (%)	T-value	P-value
Size	Unmatched	22.05	22.44	-29.40	97.70	0	0.67*
	Match	22.05	22.04	0.700		0.620	0.537
Fixed	Unmatched	0.203	0.200	2.400	20.30	0.0640	0.83*
	Match	0.203	0.201	1.900		1.570	0.116
Cashflow	Unmatched	0.0513	0.0474	5.700	79.90	0	0.93*
	Match	0.0513	0.0505	1.100		0.950	0.343
Lev	Unmatched	0.392	0.419	-13.30	86.10	0	0.83*
	Match	0.392	0.389	1.900		1.530	0.125
Growth	Unmatched	0.226	0.342	-1.600	84.90	0.207	0.26*
	Match	0.226	0.244	-0.200		-0.360	0.716

Source: authors

4.5. MECHANISM TESTING

As mentioned earlier, national standardization efforts have significantly improved the GTFP of exporting firms.

The underlying mechanism may involve standardization driving GTFP improvements through green technology innovation effects, institutional transaction costs, and financing constraints. To test this mechanism, the following mediation model is constructed:

$$M_{it}=\beta_0+\beta_1 DID_{it}+\beta_2 X_{it}+d_i+d_t+\varepsilon_{it} \quad (3)$$

where M_{it} represents the mediating variables, including green technological innovation ($Patent$) and institutional transaction costs ($Cost$), while the other variables remain consistent with the baseline regression model in Equation (1).

This section focuses on the sign and significance of the coefficient β_1. If β_1 exhibits a significant correlation, it indicates that M_{it} has a mediating effect.

4.5.1. Reducing Institutional Transaction Costs

Standardization effectively reduces firms' institutional transaction costs by unifying production standards and lowering compliance barriers. This study measures institutional transaction costs as the ratio of the sum of sales, general and administrative, and financial expenses to total assets. Regression results show that standardization significantly reduces institutional transaction costs for exporting firms.

This is because standardization unifies technical requirements and simplifies approval processes, thereby reducing non-productive expenditures. Firms can then allocate more resources to green technology R&D and energy efficiency improvements, thereby driving improvements in GTFP. Research Hypothesis 1 is supported.

4.5.2 Promoting Green Innovation

Standardization promotes increased green innovation output by unifying green technology specifications and reducing innovation uncertainty. This study measures green innovation using the logarithm of the total number of green innovation patents.

Regression results show that standardization significantly promotes green innovation among exporting firms.

This is because standardization clarifies the green technology framework and reduces R&D trial-and-error costs, giving firms greater incentive to increase green R&D investment, drive clean technology upgrades, and ultimately improve GTFP. Research Hypothesis 2 is confirmed.

Table 4. The Impact of National Standardization on the Green Total Factor Productivity of Exporting Enterprises: Testing the Mechanism

Variables	(1)	(2)	(3)	(4)
	Cost	*Cost*	*Patent*	*Patent*
DID	-0.0039**	-0.0037**	0.0537**	0.0496**
	(0.00182)	(0.0017)	(0.0222)	(0.0219)
_cons	0.085***	0.552***	0.312***	-1.510***
	(0.0006)	(0.0323)	(0.0164)	(0.355)
Control variables	Yes	Yes	Yes	Yes
Fixed year	Yes	Yes	Yes	Yes
Corporate Fixed	Yes	Yes	Yes	Yes
N	**24149**	**24149**	**24126**	**24126**
R^2	**0.818**	**0.838**	**0.719**	**0.720**

Source: authors

4.6. HETEROGENEITY ANALYSIS

Given variations in pollution levels, factor intensity, and corporate governance, the effect of standardization on exporting firms' GTFFP exhibits significant heterogeneity. This study conducts group-specific analyses across multiple dimensions, with results presented in Table 8.

4.6.1. Urban Resource Heterogeneity

Categorized by the National Sustainable Development

Plan for Resource-Based Cities, standardization significantly boosts GTFP for export firms in resource-based cities, but not in non-resource-based cities. Resource-based cities face stricter environmental oversight and higher pollution pressure, creating stronger incentives for green transformation; non-resource-based cities already have solid green development foundations, leaving limited marginal improvement space.

4.6.2. Heterogeneity of Pollution Across Industries

Standardization significantly improves GTFP in heavily polluting industries, with no significant effect in lightly polluting industries.

Heavily polluting industries have greater room for green production improvement and stronger incentives

for technological upgrades under standard constraints, while lightly polluting industries show limited marginal gains.

4.6.3. Heterogeneity in Industry Factor Intensity

The policy effect is significant only for technology-intensive exporting firms, with no impact on asset- or labor-intensive firms.

Technology-intensive firms rely more on innovation and standard compliance, making them more responsive to standardization; other industries' production models are less sensitive to such regulatory changes.

4.6.4. Heterogeneity in the Environmental Background of Corporate Executives

Standardization significantly improves GTFP in firms without executives with environmental backgrounds, but not in firms with such executives.

Firms lacking environmental leadership rely on external regulation to drive green upgrades, while firms with environmentally conscious executives already have mature green governance systems, resulting in minimal marginal policy effects.

Table 5. The Impact of National Standardization on the Green Total Factor Productivity of Exporting Firms: Heterogeneity Test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variables	Resource-based Cities	Non-resource-based Cities	Heavily Polluting industries	Non-heavily Sectors	Assets Intensive	Labor Intensive	Technology Intensive	Appointing executives with an environmental background	No executives with an environmental background
DID	0.053*	0.009	0.069***	0.014	0.013	0.015	0.027*	0.004	0.027***
	(1.880)	(0.931)	(2.785)	(1.600)	(1.090)	(0.729)	(1.718)	(0.009)	(0.006)
_cons	0.583	0.471***	0.612*	0.512***	0.287*	0.697**	0.784***	0.350**	0.519***
	(1.614)	(3.433)	(1.822)	(4.037)	(1.684)	(2.214)	(3.060)	(0.157)	(0.095)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects by year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-specific effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2208	19217	1981	22,298	13,644	4,090	5,978	12,284	10,239
R^2	0.876	0.851	0.892	0.850	0.843	0.859	0.870	0.899	0.866

Source: authors

CONCLUSIONS AND POLICY RECOMMENDATIONS

Standardization plays a foundational role in guiding the green transformation of export enterprises by unifying technical specifications and optimizing institutional provisions. Based on data from A-share listed export companies from 2012 to 2023, this study utilizes the National Comprehensive Standardization Reform Pilot Program as a quasi-natural experiment and employs a multi-period DID model to examine the impact of standardization on the GTFP of export enterprises.The results indicate: First, standardization significantly promotes the improvement of GTFP in export enterprises, a conclusion that holds even after multiple robustness tests. Second, mechanism tests show that standardization exerts its effects through two pathways: reducing institutional transaction costs and stimulating green innovation.

Third, heterogeneity analysis reveals that the policy effects are more pronounced in resource-based cities, heavily polluting industries, technology-intensive industries, and export enterprises that have not appointed executives with environmental protection backgrounds.

Based on the above findings, this paper proposes the following three recommendations: (1) Deepen the development of the standardization system. The government should continue to advance comprehensive standardization reforms, accelerate the formulation of green standards for key export industries, establish a dynamic evaluation mechanism, encourage enterprises to participate in the formulation of domestic and international standards, and transform green technology advantages into standardization advantages. (2) Facilitate intermediary transmission channels. To address institutional transaction costs, efforts should be made to standardize government services to achieve “uniform acceptance and consistent processing,” strengthen mutual recognition of domestic and international standards, and provide one-stop testing and certification services.

To promote green innovation, support for green technology R&D should be increased through special subsidies or tax incentives, information-sharing platforms should be established, and the dissemination of green technologies should be

accelerated. (3) Implement differentiated policies. For resource-based cities and heavily polluting industries, strictly enforce mandatory standards and establish special funds; for non-resource-based cities and lightly polluting industries, integrate standardization with the cultivation of emerging industries; for technology-intensive industries, encourage participation in international standard-setting; for labor- and capital-intensive enterprises, reduce compliance costs through fiscal subsidies and government procurement to avoid a "one-size-fits-all" approach.

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