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Does Standardization Improve Carbon Emission Efficiency as Soft Infrastructure? Evidence from China

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Abstract: Standardization in energy-saving and emission-reduction measures has become increasingly important. The impact of standardization on carbon-emission efficiency in China was explored by using panel data from 2002 to 2017. The results showed that standardization significantly improved China's carbon-emission efficiency, which remained robust after a series of tests. Furthermore, the development of industry standards had a greater effect on the improvement of carbon-emission efficiency in the economically developed coastal areas, while the development of national standards significantly promoted the improvement of carbon-emission efficiency in the inland areas. An assessment of the impact mechanism demonstrated that standardization affects carbon-emission efficiency through technological progress, industrial modernization, and economies of scale. We compared our findings with the existing literature regarding the governance of a low-carbon economy; we also considered the subsequent policy implications of our findings in terms of sustainable economic development.

Keywords: standardization; carbon-emission efficiency; national standard; industry standard

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1. Introduction

In recent years, there have been many advances in the economic development of China. However, the conflicts among economic growth, energy consumption, and environmental pollution are becoming increasingly acute [1,2]. The extensive use of energy has resulted in the generation of serious levels of carbon pollution in China. The National Standardization System Construction and Development Plan (2016–2020) states that the "standardization +" effect should be fully implemented to provide technical support for the green development of China's economy and society. In 2021, China proposed the National Outline for Standardization Development, which emphasized that the development of standardization will be an important measure for achieving a carbon peak and long-term carbon neutrality. Therefore, it is crucial to study the impact of Chinese standardization in the transition to a post-carbon economy. We must place the current issues in the larger context of economic development in latecomer countries that seek to reach a level of development comparable to Western economies.

The improvement of carbon-emission efficiency through technological progress is the key to the development of a low-carbon economy [3]. Standards serve as the technical basis for economic and social activities, while providing an important component of the national quality infrastructure; thus, they have fundamental and strategic roles in promoting technological progress [4]. In theory, standards can be regarded as institutions that support efficiency improvements in regional industries, as well as knowledge spillover and the expansion of green innovation by reshaping the production mode. Some researchers have studied a few unique standards, such as ISO14000, and their impacts on environment at the micro-level [5–7]. However, there is little information concerning the impact of standardization on carbon-emission efficiency at the macro-level. This study addresses this important issue.

Considering the limitations of previous studies, we used a panel dataset for 30 provinces in China from 2002 to 2017; we conducted an empirical study to investigate the influence of standardization on carbon-emission efficiency. In this study, we used the non-radial super-efficiency slacks-based measure (SBM) model to accurately measure the carbon-emission efficiencies of various provinces in China. Because the dynamic generalized method of moments (GMM) estimation can overcome the endogeneity problem in a regression analysis, we estimated the effects of Chinese standardization on carbon-emission efficiency by using a systematic GMM method in a regression model. The results showed that standardization significantly improved China's carbon-emission efficiency, which remained robust after a series of tests. We also found that technological progress, industrial modernization, and economies of scale were the transmission pathways through which standardization affected the carbon-emission efficiency. Furthermore, we performed the first comparison of the impacts of national and industrial standardization in different regions; we found that market-led industrial standardization had a greater impact on coastal areas, while government-led national standardization had a greater impact on inland areas. Regional and differentiated standardized development support policies from the Chinese government can reinforce the role of standardization in promoting carbon-emission efficiency.

This study makes three contributions to the research field. First, to our knowledge, this is the first study to explore the impact of standardization on carbon-emission efficiency. Second, this study used big data to identify the level of standardization. In previous studies, the level of regional standardization has been evaluated through extensive and long-term exploration by experts in the field of standardization; however, because of insufficient detailed and accurate data support, qualitative evaluation has been the main method for assessment of standardization. This study considered the research and development (R&D) of standards to be an important proxy variable for standardization; it measured the extent to which the regional standard drafting units contribute to the development of standards within a specific range (e.g., national and industry standards). Our research used two important indicators: the national standard development index (nsindex) and the industry standard development index (isindex). An empirical analysis was conducted by estimating the impact of China's standardization from the two dimensions of the development of national and industry standards, yielding more comprehensive and accurate analysis results. Third, this study identified the environmental consequences of standardization. We examined whether China's standardization supported carbon-emission efficiency. Furthermore, we verified the effect of standardization through the technical efficiency of production, industrial structure, and scale effects.

The remainder of the paper is arranged as follows. Section 2 provides a literature review covering carbon-emission efficiency and the role of standardization, with a focus on enhancing energy efficiency. Section 3 describes the theoretical mechanism by which standardization affects the carbon-emission efficiency. Section 4 outlines the methodology and provides an empirical model. Section 5 describes the analysis of empirical results. Section 6 provides our conclusions and presents some policy implications.

2. Literature Review

2.1. Measurement of Carbon-Emission Efficiency

Preliminary research concerning carbon-emission efficiency mainly focused on carbon-emission-efficiency measurement and methods. Kaya et al. [8] first proposed the concept of carbon-production efficiency, and Ang [9] used unit gross domestic product (GDP) energy consumption (energy intensity) as a carbon index to measure carbon-emission performance. Subsequent researchers proposed carbon-efficiency-measurement indicators (e.g., carbonization index and carbon-emission intensity), all of which adopted a "single element" measurement method expressed by the ratio of total carbon emissions to a specific element. As research has progressed, the measurement of carbon-emission efficiency has become more comprehensive. Ramanathan [10] reported that carbon-emission efficiency is the result of multiple factors, including energy consumption and economic development. It has the characteristics of "full-factors". Carbon-emission efficiency can be evaluated by considering related factors, such as fixed capital, labor, GDP, and carbon-emission-measurement indexes. Zhang et al. [11] systematically evaluated the advantages and disadvantages of existing carbon dioxide (CO_2) emission indicators; on this basis, they considered new evaluation indicators (e.g., per capita unit GDP emissions and cumulative industrialization per capita emissions) to be reasonable, fair, and scientific for measurements of carbon-emission efficiency. Some researchers have focused on indicators for estimating emission savings from resource-efficiency projects. For example, Rentschler et al. [12] built on existing greenhouse gas emission factor–based calculations; they proposed an indicator that considers the characteristics of resource-efficiency projects and allows for a consistent ex ante estimation of lifetime carbon savings from corporate resource-efficiency investments.

In full-factor research, the data envelopment analysis (DEA) model is widely used for the measurement of environmental efficiency [13,14]. Fare [15] was the first to propose the use of the DEA model for environmental-efficiency evaluation, under the assumption of weak disposability based on undesired outputs. Tone [16] incorporated undesired outputs into the SBM model to evaluate the environmental efficiency of industrial production. This approach highlighted the sustainable development requirements of energy saving and emission reduction. In recent years, the DEA model has been widely used to measure China's carbon-emission efficiency [17–20].

2.2. Factors Influencing Carbon-Emission Efficiency

The factors influencing carbon-emission efficiency have become a major research topic in recent years. Previous studies have shown that there are large differences in carbon-emission efficiency among regions, which are affected by factors such as economic development, energy consumption, technological innovation, carbon tax policy, and investment. Wang [21] used the Shephard distance function to measure the performance of 23 Organization for Economic Cooperation and Development countries and then conducted a comparative analysis. The results showed that technological progress considerably influenced the improvement of carbon emissions. Ramanathan [22] used the DEA method to measure the global carbon-emission efficiency and then analyzed the impact of energy consumption on the changes in emissions. Cason [23] and Buckley [24] analyzed the impact of emissions trading on carbon-emission efficiency. Gorg and Strobl [25] and Albornoz et al. [26] conducted empirical research on the micro-data of enterprises; they showed that foreign direct investment technology spillover had a positive impact on the improvement of carbon-emission efficiency. Zhang and Chen [27] used data from China's Yangtze River Economic Belt for the period from 2008 to 2017; they found that the impacts of industrialization and urbanization on carbon-emission efficiency followed a U-shape. With advances in industrialization and urbanization, the impacts on carbon-emission efficiency tended to initially decrease and then increase.

In terms of the factors influencing China's carbon-emission efficiency, Li Tao and Fu [28] measured the carbon-emission efficiencies of 29 provinces in China during 1986–2008, using the Ruggiero three-stage model; they found that technological progress significantly improved carbon-emission efficiency. Zha [29] constructed multiple DEA models to measure China's industrial carbon-emission performance, and then conducted an empirical study on its influencing factors. The results indicated that enterprise scale, foreign investment, and technological innovation could significantly improve industrial carbon-emission performance. The structure of property rights increases in capital, and both industrial and energy generation structures had significant inhibitory effects on industrial carbon-emission performance. Qu [30] analyzed the influencing factors based on the calculation of China's provincial carbon-emission efficiency; the findings suggested that government intervention, industrial structure, structure of property rights, and foreign trade all had important roles in carbon-emission efficiency. Udemba et al. [31] concluded that CO_2 emissions have a positive association with foreign direct investment, energy consumption, and tourist arrivals.

2.3. Innovation and Low Carbon

Innovation can be described as anything that increases the level of technology [32]. Innovative development is an important factor that affects energy and environment. The role of innovative policies in promoting energy efficiency is becoming crucial in the transition to the post-carbon economy [33]. Bian et al. [34] argued that the recovery of energy may significantly influence regional primary energy consumption and CO_2 emissions; they concluded that the adoption of advanced energy-conversion technologies or the modernization of existing technologies would help to improve regional energy efficiency and reduce CO_2 emissions in China. Mele and Magazzino [35] analyzed the relationships among the iron and steel industries, air pollution, and economic growth in China; they observed a reduction in polluting emissions over time. This result confirmed the hypothesis of sustainable economic growth through improvements in steel-production technology and efficiency in the sector. Zhang and Wei [36] reported that the carbon-emission efficiency of China's transportation sector increased by 6.2% during 2000–2012, mainly because of technological innovation. Xie et al. [37] conducted a study of the carbon-emission efficiencies of 59 countries from 1998 to 2016; they hypothesized that technological progress would lead to a significant increase in carbon-emission efficiency, but this effect differed among countries with different efficiency levels. Some researchers hold the opposite view, in which the rebound effect of technological progress has a slight negative impact on carbon-emission efficiency. Energy-consumption structure, government intervention, and foreign trade all have negative impacts on carbon-emission efficiency [38–40].

2.4. Standards and Low Carbon

In the research literature concerning standards and the low-carbon economy, standards are often regarded as environmental regulations or environmental policies. Previous studies have focused only on the impacts of specific standards (e.g., the Intensity Based Technical Performance Standards for the United States (US) Electric Power Sector), as a means of reducing emissions. Healey and Jaccard [41] analyzed the impact of the US power sector emission-intensity standard (metric ton of CO_2 per MWh) on the US final energy demand. Burtraw et al. [42], Murray et al. [43], and Paul et al. [44] compared Technical Performance Standards with other policy specifications, focusing on changes in the power sector and significant changes in CO_2 emissions. In addition, Fischer et al. [45] investigated the welfare impacts of raising corporate average fuel economy standards for new passenger vehicles, including the impacts on local and global pollution.

Previous studies have treated standards as an environmental policy tool in individual sectors. There has been minimal reflection on the essence of standardization and its role in influencing the effectiveness of the post-carbon economy.

3. Theoretical Mechanism

Thus far, no mature theoretical system has been proposed to explain the relationship between standardization and carbon-emission efficiency. The present study expanded on the proposal by Grossman and Krueger [46] that economic growth affects environmental quality through technology, structure, and scale. It considered the mechanism by which the development of standardization influenced carbon-emission efficiency via three aspects: production efficiency, industrial structure, and scale effects.

First, standardization affects carbon-emission efficiency through production efficiency. Standard economics theory indicates that compatibility standards can effectively prevent the loss of invalid innovations; technical standardization can transform chaotic technological innovations into systematic technological innovation activities, thus enabling the coordinated development of technology [47]. Standardization also promotes the improvement of labor productivity. When companies must comply with high-demand standards, they often achieve substantial increases in productivity [48]. Environmental standards [49] and safety standards [50] have been shown to positively impact labor productivity. The increase in labor productivity supports the reduction of "resource dependence" during economic growth. Technological progress can improve labor productivity and reduce carbon emissions [51,52]. Therefore, the introduction of standardization leads to improved labor-production efficiency, thereby improving the carbon-emission efficiency.

Second, standardization affects carbon-emission efficiency through industrial structure. Standardization provides the supporting foundation for the technological modernization of industry overall. Open technical standards will establish a clear target and behavioral reference system for the technical activities of industrial enterprises; they will also promote the proliferation of industrial technology. Because some enterprises (e.g., small- and medium-sized enterprises) do not usually engage in formal R&D activities [53], standardization will help them to systematically improve R&D capabilities and management techniques, resulting in improvements to these enterprises. Standardization is also beneficial for industrial collaboration. Compatible standards provide the potential for vertical and horizontal industrial linkages, as well as the collaborative innovation of high-tech industries and traditional industries; they support the optimization of industrial structure and the formation of emerging industries. In addition, the implementation of strict standards will intensify inter-industry competition and promote industrial modernization. Because the adjustment of industrial structure is an effective method to reduce carbon emissions [54,55], we presume that standardization will improve carbon-emission efficiency by promoting industrial modernization.

Finally, standardization affects carbon-emission efficiency by accelerating market expansion. Standardization is beneficial for reducing product diversity and promoting product compatibility. Technology-compatible products can generate large network externalities [56], which will help manufacturers to achieve large-scale production. In addition, the promotion of standardization reduces the information asymmetry between consumers and manufacturers; it improves the possibility and acceptance of new product introduction [57], while supporting market expansion. The impact of market size on carbon-emission efficiency is more complex. The expansion of the market scale and the increase in production activities carried out by various production factors may increase their environmental impacts. Concurrently, the expansion of the market size provides enterprises with incentives and opportunities to adopt new technologies, thus promoting the realization of clean or green production. In theory, the impact of market size on carbon-emission efficiency depends on the dynamic balance between the decline in carbon-emission efficiency related to the increase in total carbon emissions and the increase in carbon-emission efficiency related to the increase in energy-consumption efficiency.

Therefore, we regard standardization as an important factor that affects carbon-emission efficiency, but the net effect of the impact and the impact mechanism must be confirmed through empirical research.

4. Research Design

4.1. Panel Regression Method

We first examined the impact of standardization on carbon-emission efficiency using panel regressions. The basic model specification can be expressed as follows:

$$carbon_{it} = \alpha + \beta standard_{it} + \vartheta control_{it} + \lambda_i + u_t + \varepsilon_{it} \quad (1)$$

where i and t are subscripts representing the province and year, respectively; $standard_{it}$ is the key explanatory variable that indicates the standardized development level of province i in year t; and $control_{it}$ is a vector of the control variables at the province level that have been shown to affect carbon-emission efficiency. The province-level control variables include industrial structure, level of openness, technological innovation, urbanization, and government intervention.

To test the channels of standardization's effect on carbon-emission efficiency, the basic model specification can be expressed as follows:

$$channel_{it} = \alpha + \beta standard_{it} + \vartheta control_{it} + \lambda_i + u_t + \varepsilon_{it} \quad (2)$$

The explained variable is the intermediary variable of its effect channels, including labor productivity, industrial structure, and company size; the remaining variables are identical to Equation (1).

Considering the possible endogeneity problems in the regression, the estimation method of dynamic GMM was used. The ordinary least squares (OLS) and fixed effect (FE) methods will bias the model estimation, but the dynamic GMM estimation can overcome the endogeneity problem of model estimation. Differential and systematic GMM estimation are two important methods for dynamic GMM estimation. Compared with the differential GMM estimation method, the systematic GMM estimation method can solve the weak tool variable problem, thus improving the estimation efficiency; it can also estimate the variable coefficients without changing the data points at any time. Because the two-step GMM estimation may bias the standard deviation of the estimation parameters, which will then affect the parameter estimation results, the model was estimated by using a one-step systematic GMM estimation method.

4.2. Data

Our research used balanced panel data from 30 provinces in China from 2002 to 2017 (Tibet was excluded from the study because its data were unavailable). The timing of the sample was limited by the availability of standardized data. Table 1 provides an overview of the variables used in the study, as well as some descriptive statistics.

Table 1. Overview of the variables used in the study.

Variable	Obs	Mean	SD	Min	Max
carbon	480	0.8253	0.2022	0.3868	3.0173
nsindex	480	1.7429	3.2723	0.0000	35.8570
isindex	480	1.9943	3.3271	0.0184	27.5472
nsl	480	0.7449	1.5847	0.0000	19.5600
isl	480	1.2263	2.1230	0.0100	17.2300
nsp	480	2.2055	3.1071	0.0000	31.6300
isp	480	2.8419	3.9035	0.0300	27.6500
stru	480	0.4586	0.0792	0.1901	0.5905
open	480	6.5666	1.6724	2.4772	10.3248
inno	480	8.8934	1.6684	4.2485	12.7149
urban	480	0.5123	0.1470	0.2507	0.8960
gov	480	7.2280	0.9167	4.5447	9.2860
prod	480	10.3474	5.5270	1.5151	28.8134
size	480	2.5397	2.1684	0.4159	14.2327

4.2.1. The Explanatory Variable

The basic DEA method does not include undesired outputs and cannot manage instances of "bad" output. In this study, the SBM model in the DEA non-radial method was used to measure the carbon-emission efficiency. The SBM model can better reflect the advantages of efficiency evaluation when solving the problem of input slackness and the efficiency evaluation problem of undesired outputs. A super-SBM model was constructed, as in the work by Tone [58], which considered the expected and undesired outputs. Capital input (K), energy consumption (F), and labor input (L) were regarded as the three major input elements; CO_2 emissions (C) and power production (E) were the two major output variables. The production process was characterized as S = {K, L, F, E, C}:{K, L, F} can produce *{E, C}* and measure the regional carbon-emission efficiency index. The data used were obtained from the "China Statistical Yearbook", "China Electric Power Yearbook", and "China Energy Yearbook".

4.2.2. Explanatory Variables

Existing studies are in the exploratory stage of measuring the regional standardization level; the application of the standardization index system is often limited by data availability. We presumed that the degree of participation in standard R&D reflects a region's contribution to the development of standardization; it also partially reflects the level of standardization in the region.

In China, national standards stipulate a basic and common content; they are implemented nationwide. Industry standards exist as a refinement and improvement of national standards; they are implemented in specific industries. Some advanced science and technology principles can be prioritized through standards. Standard implementation in industry will also help to improve domestic and international competitiveness. If a national standard does not provide for specific content, industry and enterprises can initially formulate a standard to regulate it; when conditions allow it, the standard will be upgraded to a national standard. Based on big data from the China Standards platform, the revised national and industry standards of Chinese provinces from 2002 to 2017 were obtained and assigned a corresponding weight according to the standard ranking. The term "standard leader" refers to an institution that ranks first in standard formulation; participating institutions were then ranked accordingly in the drafting of a standard. The contribution indexes of standard leader and participators were 1.0, 0.8, 0.6, 0.4, and 0.2, respectively; a ranking of 6 and above had an index value of 0.1. After the above treatment, we calculated the weighted total annual contributions of national and industry standards in each province. Upon division of the weighted total by 100, the nsindex and isindex values for each of 30 provinces in China from 2002 to 2017 were obtained.

The nsindex and the isindex were used to represent the standardization level of the region. In the robustness test, we used the leading national standard development number (nsl), the leading industry standard development number (isl), the participating national standard development number (nsp), and the participating industry standard development number (isp) as different proxy variables for the standardization level.

4.2.3. Control Variables

Industrial structure (stru): The proportion of GDP originating from high-tech industries was used as a proxy variable for the industrial structure. The data were obtained from the China Economic Data Platform. A higher degree of industrial development is generally presumed to be more conducive to rationalizing the allocation of various elements, modernizing the industrial structure, and promoting energy conservation and emission reduction; it also has a more positive impact on the carbon-emission efficiency.

Level of openness (open): This was expressed in terms of the proportion of GDP from each region's exports; it was determined by using data obtained from the website of the National Bureau of Statistics. The impact of trade on low-carbon growth cannot be ignored. Specifically, the impact of opening up on green development has had a "pollution refuge" effect, with a negative impact on emission efficiency. However, opening up to the outside world may also allow the host country to obtain a spillover effect from foreign advanced technology, which will improve the carbon-emission efficiency.

Technological innovation (inno): This was expressed by regional patents, based on data obtained from the website of the National Bureau of Statistics. There are two contrasting perspectives regarding the impact of technological innovation on carbon-emission efficiency. One perspective is that technological innovation is beneficial for improving dependence on resources, especially green patent R&D; this effectively promotes the improvement of carbon-emission efficiency. The other perspective is that technology innovation promotes the growth of economic scale; greater output may also lead to greater resource consumption, thus hindering the optimization of carbon-emission efficiency.

Urbanization (urban): This was expressed as the ratio of urban population to total population, based on data obtained from the website of the National Bureau of Statistics. The impact of urbanization on carbon-emission efficiency depends on the dynamic balance between the decline in carbon-emission efficiency related to the increase in total carbon emissions and the increase in carbon-emission efficiency related to the increase in energy-consumption efficiency.

Government intervention (gov): This was expressed as the ratio of fiscal expenditure to GDP, based on data obtained from the website of the National Bureau of Statistics. China's current energy-saving and emission-reduction initiatives are led by the government and promoted by society overall, with the main impacts on industrial enterprises. The government is an important promoter of energy-saving and emission-reduction policies. The government's support for energy-saving measures and environmental protection has partially promoted the improvement of carbon-emission efficiency.

5. Empirical Tests and Results of the Analysis

5.1. Benchmark Regression Analysis

The basic test results of the impact of regional standardization on carbon-emission levels in China are shown in Table 2. Columns 1, 2, and 3 show the impact of the nsindex on carbon-emission efficiency. The first two columns of Table 1 show the estimated results from using the OLS and FE methods. Column 3 considers the dynamics of carbon-emission efficiency and the endogeneity of the core explanatory variables; it uses the GMM system for a regression analysis. The results show that the core explanatory variable, nsindex, had a strong and stable positive correlation with carbon-emission efficiency. Its regression coefficient was positive with a significance level of greater than 5%, indicating that China's regional standardization significantly promoted the improvement of local carbon-emission efficiency.

Table 2. Benchmark regression results.

	1	2	3	4	5	6
	OLS	**FE**	**SYS-GMM**	**OLS**	**FE**	**SYS-GMM**
nsindex	0.0087 ***	0.0080 ***	0.0153 **	-	-	-
	(0.0033)	(0.0028)	(0.0071)	-	-	-
isindex	-	-	-	0.0123 ***	0.0112 ***	0.0231 ***
	-	-	-	(0.0034)	(0.0024)	(0.0049)
stru	0.1779	0.1618	0.3881 ***	0.1900	0.1768	0.2449 ***
	(0.1172)	(0.1571)	(0.0657)	(0.1164)	(0.1598)	(0.0669)
inno	−0.0496 ***	−0.0477 **	−0.0777 ***	−0.0573 ***	−0.0541 ***	−0.0544 ***
	(0.0190)	(0.0203)	(0.0111)	(0.0191)	(0.0208)	(0.0129)
urban	0.3132 ***	0.4160 ***	0.2920 ***	0.2650 ***	0.3685 ***	0.2700 ***
	(0.0923)	(0.1006)	(0.1092)	(0.0930)	(0.1089)	(0.0763)
open	0.0255 **	0.0077	0.0172	0.0283 **	0.0106	0.0004
	(0.0129)	(0.0138)	(0.0156)	(0.0128)	(0.0140)	(0.0129)
gov	−0.0132	0.0341	0.0492 **	−0.0092	0.0357	0.0304
	(0.0244)	(0.0389)	(0.0223)	(0.0243)	(0.0389)	(0.0231)
cons	0.9973 ***	0.7057 ***	0.8071 ***	1.0322 ***	0.7463 ***	0.7764 ***
	(0.0815)	(0.1711)	(0.1006)	(0.0821)	(0.1689)	(0.0970)
L.carbon	-	-	0.0295	-	-	0.1294
	-	-	(0.0822)	-	-	(0.1019)
Obs	480	480	464	480	480	464
R-squared	0.1500	0.1763	-	0.1611	0.1852	-
AR(1)	-	-	0.0428	-	-	0.0252
AR(2)	-	-	0.1771	-	-	0.0730
Sargan			1.0000			1.0000

Standard errors in parentheses; *** $p < 0.01$ and ** $p < 0.05$.

Columns 4, 5, and 6 show the impact of the isindex on carbon-emission efficiency. Columns 4 and 5 show the results from using the OLS and FE static estimation methods, while the results in Column 6 were obtained by using the systematic GMM and two-stage least-squares regression methods. The empirical results indicate that the isindex also had a significant positive correlation with carbon-emission efficiency, confirming that the comprehensive impact of standardization on carbon-emission efficiency was significantly positive. Based on our theoretical analysis, the role of promoting the healthy and sustainable development of the economy through standardization is worthy of attention; the outcome is comparable to the findings of other studies regarding individual standards [5,41].

As expected, industrial standardization had a slightly higher impact coefficient on carbon emissions than did national standardization. This was because China's industry standards serve to refine and improve national standards, thus enabling the implementation of advanced science and technology principles in industrial settings; this implementation also improves industry and international competitiveness. Some of China's industry standards may have high technical requirements, particularly those involving green technology innovation; their roles in promoting carbon-emission efficiency will be greater.

In terms of the control variables, the modernization of industrial structure and improvements in the level of urbanization had a moderately significant positive impact on carbon-emission efficiency. This finding indicates that China's industrial modernization has promoted the rationalization of the allocation of various elements, and this is beneficial for energy conservation and emission reduction. The increase in carbon-emission efficiency related to the increase in energy-consumption efficiency that has occurred alongside China's urbanization was consistent with the results of previous studies [59]. The results showed that the impact of opening up to the outside world was not detectable, presumably because of the "pollution refuge" and technology spillover effects that occurred after China opened up to the outside world. We found that patents represent technological innovations that have a negative impact on carbon-emission efficiency. The current trend of patented green technologies may be undetectable, and green technologies may be beneficial to the improvement of carbon-emission efficiency; however, they have not yet reached the threshold level where this benefit becomes detectable. According to Du et al. [60], the high diffusion cost of new green technologies is clear, especially in developing countries; this causes patents to have an insignificant effect on the promotion of carbon emissions. Preliminary research concerning green-technology R&D in China has shown that the efficiency of the green technological transformation thus far is generally low [61], as is consistent with the conclusions of this study.

5.2. Robustness Analysis

To further test the stability of the estimated results of the impact of standardization development on carbon-emission efficiency, a distinction was made between standard-development leadership and standard-development participation. The regression results are shown in Tables 3 and 4. Columns 7–9 show the influence of the number of national standard-development leaders on carbon-emission efficiency, while Columns 10–12 show the influence of the number of national standard development leaders on carbon-emission efficiency. At the provincial level, for both national-standard dominance and participation, there was a significant positive correlation with carbon-emission efficiency. Columns 13–15 show the influence of industry-standard development's leading numbers on carbon-emission efficiency, while Columns 16–18 show the influence of industry-standard development's leading numbers on carbon-emission efficiency. The regression results show that the industry-standard-development leadership and participation have significantly improved carbon-emission efficiency. Furthermore, a comparison of Tables 3 and 4 indicates that the development of industry standards, as a result of market competition in industrial technology, had a greater effect on carbon-emission efficiency than did the development of national standards. The analysis confirmed that the results of the benchmark regression were robust.

Table 3. Impacts of national standard dominance and national standard participation on carbon-emission efficiency.

	7	8	9	10	11	12
	OLS	**FE**	**SYS-GMM**	**OLS**	**FE**	**SYS-GMM**
nsl	0.0135 **	0.0103 *	−0.0071	-	-	-
	(0.0064)	(0.0052)	(0.0195)	-	-	-
nsp	-	-	-	0.0097 ***	0.0105 ***	0.0129 ***
	-	-	-	(0.0037)	(0.0037)	(0.0046)
stru	0.1703	0.1511	0.4097 ***	0.1703	0.1566	0.3577 ***
	(0.1175)	(0.1572)	(0.0552)	(0.1170)	(0.1561)	(0.1089)
inno	−0.0471 **	−0.0434 **	−0.0698 ***	−0.0506 ***	−0.0505 **	−0.0776 ***
	(0.0190)	(0.0203)	(0.0106)	(0.0191)	(0.0202)	(0.0111)
urban	0.3311 ***	0.4500 ***	0.3201 **	0.3221 ***	0.4133 ***	0.3110 ***
	(0.0931)	(0.1022)	(0.1269)	(0.0912)	(0.0966)	(0.0939)
open	0.0264 **	0.0071	0.0244 **	0.0244*	0.0064	0.0152
	(0.0129)	(0.0139)	(0.0106)	(0.0129)	(0.0137)	(0.0115)
gov	−0.0144	0.0330	0.0470	−0.0153	0.0348	0.0457 *
	(0.0245)	(0.0391)	(0.0315)	(0.0244)	(0.0388)	(0.0264)
L.carbon	-	-	0.0081	-	-	0.0758
	-	-	(0.0864)	-	-	(0.0956)
Cons	0.9744 ***	0.6699 ***	0.7289 ***	1.0189 ***	0.7273 ***	0.7962 ***
	(0.0806)	(0.1724)	(0.1692)	(0.0837)	(0.1738)	(0.1023)
Obs	480	480	464	480	480	464
R-squared	0.1452	0.1711	-	0.1496	0.1785	-
AR(1)	-	-	0.0297	-	-	0.0501
AR(2)	-	-	0.1456	-	-	0.1735
Sargan			1.0000			1.0000

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

Table 4. Impacts of industry standard leadership and industry standard participation on carbon-emission efficiency.

	13	14	15	16	17	18
	OLS	**FE**	**SYS-GMM**	**OLS**	**FE**	**SYS-GMM**
isl	0.0166 ***	0.0137 ***	0.0245 ***	-	-	-
	(0.0051)	(0.0036)	(0.0079)	-	-	-
isp	-	-	-	0.0107 ***	0.0104 ***	0.0130 ***
	-	-	-	(0.0031)	(0.0024)	(0.0039)
stru	0.1902	0.1733	0.3621 ***	0.1699	0.1600	0.2612 ***
	(0.1169)	(0.1586)	(0.0929)	(0.1162)	(0.1581)	(0.0611)
inno	−0.0534 ***	−0.0497 **	−0.0612 ***	−0.0579 ***	−0.0554 ***	−0.0549 ***
	(0.0190)	(0.0204)	(0.0109)	(0.0192)	(0.0206)	(0.0123)
urban	0.2713 ***	0.3818 ***	0.2750 ***	0.2784 ***	0.3782 ***	0.3086 ***
	(0.0944)	(0.1089)	(0.0995)	(0.0928)	(0.1054)	(0.0854)
open	0.0277 **	0.0108	0.0111	0.0283 **	0.0093	0.0005
	(0.0128)	(0.0141)	(0.0103)	(0.0128)	(0.0139)	(0.0136)
gov	−0.0090	0.0324	0.0348	−0.0133	0.0360	0.0308
	(0.0244)	(0.0392)	(0.0278)	(0.0242)	(0.0388)	(0.0252)
L.carbon	-	-	−0.0070	-	-	0.1214
	-	-	(0.0605)	-	-	(0.0962)
Cons	1.0009 ***	0.7288 ***	0.8407 ***	1.0570 ***	0.7543 ***	0.7655 ***
	(0.0808)	(0.1729)	(0.1254)	(0.0851)	(0.1713)	(0.1146)
Obs	480	480	464	480	480	464
R-squared	0.1565	0.1788	-	0.1579	0.1847	-
AR(1)	-	-	0.0673	-	-	0.0320
AR(2)	-	-	0.2483	-	-	0.0954
Sargan			1.0000			1.0000

Standard errors in parentheses; *** $p < 0.01$ and ** $p < 0.05$.

5.3. Analysis of Heterogeneity

Despite continuous interventions by the Chinese government, the socioeconomic gap between the less-developed inland provinces and the mainland regions has increased over time [35]. Because there may be regional differences in the impact of standardized development on carbon-emission efficiency, we conducted a sub-sample regression based on the division of provinces into developed coastal areas and underdeveloped inland areas. The regression results are shown in Table 5. Columns 19 and 20 show a regional comparison of the influence of the national standard development contribution index on carbon-emission efficiency, while Columns 21 and 22 show a regional comparison of the influence of the industry standard development contribution index on the carbon-emission efficiency. The empirical results show that the development of industry standards in coastal areas has significantly improved carbon-emission efficiency, while the development of national standards in inland areas has been beneficial for the improvement of carbon-emission efficiency.

Table 5. Comparison of regional differences in carbon-emission efficiency.

	19	20	21	22
	Coastal	**Inland**	**Coastal**	**Inland**
nsindex	−0.0050 *	0.0214 ***	-	-
	(0.0027)	(0.0051)	-	-
isindex	-	-	0.0120 ***	0.0003
	-	-	(0.0033)	(0.0041)
stru	0.4334 ***	0.7184 ***	0.2587 ***	0.7801 ***
	(0.0358)	(0.2710)	(0.0489)	(0.1265)
inno	−0.0031	−0.0293	−0.0023	−0.0649**
	(0.0211)	(0.0409)	(0.0203)	(0.0303)
urban	−0.2274 ***	−0.4075	−0.1394 **	−0.0310
	(0.0417)	(0.4063)	(0.0695)	(0.2796)
open	0.0283 ***	0.0455 ***	0.0298 ***	0.0418 ***
	(0.0095)	(0.0155)	(0.0079)	(0.0136)
gov	0.0254	−0.2103	−0.0176	−0.1131
	(0.0345)	(0.1377)	(0.0330)	(0.0974)
L.carbon	0.2409 ***	0.3010 ***	0.1190 ***	0.2343 **
	(0.0391)	(0.1027)	(0.0395)	(0.0947)
Cons	0.7628 ***	2.6291 ***	0.8992 ***	2.0445 ***
	(0.1574)	(0.7417)	(0.1377)	(0.5286)
Obs	144	320	144	320
AR(1)	0.9519	0.0723	0.3813	0.0171
AR(2)	0.2127	0.2450	0.7730	0.0807
Sargan	1.0000	1.0000	1.0000	1.0000

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$.

This finding was not surprising, because the nsindex coefficient varies widely in the coastal and inland areas. The level of standard development in the coastal area was negatively associated with carbon-emission efficiency, while there was a positive association in inland areas. This was because the new national standards usually do not impose highly technical requirements on the more advanced coastal enterprises. The role of technological improvement and industrial modernization is generally limited for industrial enterprises in this area, which is reflected by their expansion in the market. Market expansion and large-scale production activities will often cause more environmental pollution. Many of China's new national standards have been adopted after a consideration of existing international standards; the implementation of national standards also leads to significant increases in exports and economic activity, eventually aggravating environmental pollution. Similar to the findings by Zhang [62], Fang et al. [63] reported that economic development generated CO_2 emissions.

Compared with coastal areas, inland areas do not have an absolute advantage in national and industry standard R&D, but they have a comparative advantage in national standard R&D. The development of standardization development through national standards improves carbon-emission efficiency. The impact of this effect was clear: the level of economic development in coastal areas is high, the capacity for technological innovation is stronger, and industry standard R&D and participation are more prominent. Compared with national standards, the development of standardization through industry standards with high technical requirements is more likely to have a substantial impact on carbon-emission efficiency because it leads to improved labor productivity and optimized industrial structure. The impact of national standards is more clearly reflected in the scale effect of market expansion, which has a negative impact on carbon-emission efficiency. Previous studies [64–66], found that China's overall carbon-emission efficiency is constantly expanding, but there are regional differences. The improvement in the leading areas is generally occurring rapidly, while the improvement in the non-leading areas is slow and has even regressed in some years. The results of this study suggest that standardization will help to alleviate this trend.

5.4. The Mechanism of Influence

According to the theoretical mechanism of influence, the development of standardization affects carbon-emission efficiency through impacts on the three factors of production efficiency, industrial structure, and economies of scale. Therefore, the intermediary variables selected in this study were labor productivity (prod), industrial structure (stru), and firm size (size). The isindex was used to represent the level of standard development, labor productivity was expressed by the ratio of industrial added value to employees, industrial structure was measured by the proportion of GDP supplied by high-tech industries, and the scale of enterprises was expressed by the ratio of enterprise assets to the number of enterprises. The data for the intermediary variables were all sourced from China's economic data platform.

Tables 6–8 show the estimated results for the mediation effects between standardization and carbon-emission efficiency. Column 23 in Table 5 confirms that the standardization level (i.e., isindex) had a significant effect on carbon-emission efficiency (carbon). Column 24 shows that the estimated isindex coefficient was significantly positive, indicating that standardization will promote an increase in local labor productivity. Column 25 contains both the isindex and prod variables. Compared with the estimated result in Column 23, which did not include the prod variable, the estimated isindex coefficient was significantly smaller (from 0.0246 to 0.0230), indicating that labor productivity had an intermediary mediating effect. The development of standardization in China has promoted the improvement of carbon-emission efficiency through improvements in production efficiency. The results shown in Tables 6 and 7 are similar to the results in Table 5. The estimated isindex coefficients in Columns 27 and 30 were both significantly positive, indicating that the development of standardization promotes the modernization of industrial structure and the expansion of economies of scale. In Table 6, after including the stru variable, the estimated isindex coefficient in Column 28 decreased to 0.0185 compared to Column 26. In Table 7, after including the size variable, the estimated isindex coefficient in Column 31 was reduced to 0.0226, compared with the estimated result in Column 29. The above results showed that the mediating effect of industrial structure and economies of scale was also significant.

Table 6. Mediation effect of labor productivity.

	23	24	25
	Carbon	**Prod**	**Carbon**
isindex	0.0246 ***	0.1876 ***	0.0230 ***
	(0.0027)	(0.0221)	(0.0049)
prod	-	-	0.0209 ***
	-	-	(0.0009)
Control variable	Yes	Yes	Yes
Cons	1.2423 ***	−10.8515 ***	1.2587 ***
	(0.0622)	(0.8531)	(0.1249)
Obs	464	464	464
AR(1)	0.0410	0.0029	0.0336
AR(2)	0.1008	0.8064	0.0743
Sargan	1.0000	1.0000	1.0000

Standard errors in parentheses; *** $p < 0.01$.

Table 7. Intermediary effect of industrial structure.

	26	27	28
	Carbon	**Stru**	**Carbon**
isindex	0.0246 ***	0.0100 ***	0.0185 ***
	(0.0027)	(0.0009)	(0.0047)
stru	-	-	0.2723 ***
	-	-	(0.0682)
Control variable	Yes	Yes	Yes
Cons	1.2423 ***	−0.0675 ***	0.8158 ***
	(0.0622)	(0.0259)	(0.1065)
Obs	464	464	464
AR(1)	0.0410	0.0003	0.0273
AR(2)	0.1008	0.4278	0.0904
Sargan	1.0000	1.0000	1.0000

Standard errors in parentheses; *** $p < 0.01$.

Table 8. Intermediary effect of economies of scale.

	29	30	31
	Carbon	**Size**	**Carbon**
isindex	0.0246 ***	0.2808 ***	0.0226 ***
	(0.0027)	(0.0170)	(0.0037)
size	-	-	0.0147 ***
	-	-	(0.0028)
Control variable	Yes	Yes	Yes
Cons	1.2423 ***	−0.2129	1.1060 ***
	(0.0622)	(0.1297)	(0.0495)
Obs	464	464	464
AR(1)	0.0410	0.0004	0.0361
AR(2)	0.1008	0.1011	0.0950
Sargan	1.0000	1.0000	1.0000

Standard errors in parentheses; *** $p < 0.01$.

This result was consistent with the findings by Swann and Lambert [47], who argued that a well-functioning standardization system and strategy can work as a catalyst for translating inventions and discoveries into productivity-enhancing innovation. This result was also consistent with findings by Ernst et al. [4] regarding the effects of standards on industrial structure and economies of scale.

6. Conclusions, Limitations of the Study, and Future Research

6.1. Conclusions

China's energy and environmental issues have received considerable attention from researchers. In recent years, standardization has contributed to environmental improvement and economic development, including energy-saving and emission-reduction measures. However, there have been few studies concerning the relationship between standardization and carbon-emission efficiency in China. On the basis of the existing literature, we proposed a theoretical mechanism and investigated standardization and carbon-emission efficiency by using provincial-level data for the period of 2002–2017 in China. We found a positive influence of standardization on carbon-emission efficiency; technological progress, industrial modernization, and economies of scale had important intermediary roles in this process. We divided the standardization approaches into the two groups of national and industrial standardization; carbon-emission efficiency was more strongly promoted by market-led industrial standardization than by national standardization. To our knowledge, this study is the first to investigate the impacts of standardization on energy efficiency and environmental protection. Our findings explain how standardization generates emission-reduction effects.

The study findings also support the notion that the establishment of differentiated regional standardization development policies is vital for standardization to positively influence emission reductions. Regional differences were identified in the impact of China's standardization development on carbon emissions. The development of industrial standardization had a clear effect on the improvement of carbon-emission efficiency in the economically developed coastal areas, while the development of national standardization had a greater role in promoting carbon-emission efficiency in the underdeveloped inland areas. In areas with a generally low level of economic development, the level of technological innovation is also low; the development of standardization led by national standards will help to lay an industrial foundation, thus promoting production efficiency and industrial modernization. This impact of standardization counterbalances the negative effects of market expansion. In economically developed areas, there is substantial capacity for technological innovation. Compared with national standards, the development of standardization led by industry standards with higher technical requirements is crucial to the improvement of carbon-emission efficiency. Hence, a standardization policy should focus on sustainable development. Other programs and actions concentrating on innovativeness are likely to fail unless they consider regional specificity (Lewandowska et al., 2021) [32].

6.2. Limitations of This Study and Future Research

This study had a few limitations, which provide important avenues for future research. First, the data sample only covered China. The impact of standardization on carbon-emission efficiency in a developing-economy context may vary from the impact of standardization in developed countries. Studies of a similar sample in other regions or countries would help to consolidate our findings and indicate future directions for research. Second, the selection of intermediary variables was limited to standardization and carbon-emission efficiency. From a macro-enterprise perspective, more variables may be required to explore the impacts of standardization on carbon-emission efficiency.

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