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Carbon Reduction, Pollution Intensity, and Firms' Ratios of Value Added in Exports: Evidence from China's Low-Carbon Pilot Policy

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Abstract: Global warming is highlighting the importance of carbon emission reduction, while firms in developing countries are facing the dual challenges of carbon reduction and exporting real gains improvement. Using the Chinese Customs Transaction-level Trade Statistics Dataset and the Chinese Annual Survey of Industrial Firms Dataset from 2008 to 2014, we identified the impact of China's Low-carbon Pilot Policy (LCPP) on firms' ratios of the domestic value added in exports for the first time by adopting a difference-in-difference method. Our findings show that China's LCPP continuously improves firms' ratios of value added in exports, providing empirical evidence for the topic of whether carbon reduction regulations affect firms' export real gains. The heterogeneity analysis shows that the improvement impact of LCPP on dirty firms is weaker than that on clean firms. The mechanism test also shows that firms' production efficiency plays the role of partial intermediary in the relationship between LCPP and firms' ratios of domestic value added in exports. Our research extends the micro effect of LCPP to the field of exporting real gains, and enriches the research on influencing factors of firms' ratios of the domestic value added in exports.

Keywords: low-carbon policy; difference-in-difference; firms' ratios of domestic value added in exports; pollution intensity; production efficiency

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1. Introduction

Global warming is seriously threatening the sustainable development of human beings [1,2] and exacerbating the inequality of global economic development [3]. Carbon emission reduction can help alleviate global warming [4–7]. Developing countries are in the stage of rapid economic development, and their industrial production produces a large number of carbon emissions. According to the statistics of the World Development Indicators database, the average carbon dioxide emissions of high-income countries in 2018 were 0.242 kg per 2015 US$ of GDP, while that of middle and low countries were 0.691 kg per 2015 US$ of GDP. Curbing greenhouse gas emissions in developing countries is of great importance for global warming control [8].

China is in its critical stage of rapid industrialization and urbanization, and its energy structure is dominated by coal, so it has long been considered the world's largest carbon emitter [9,10]. China's carbon dioxide emissions in 2018 were about 0.764 kg per 2015 US$ of GDP, higher than not only high-income countries but also middle- and low-income countries. Therefore, China now regards climate change control to be an important strategic task. Cities are the concentration of human activities. In order to reduce carbon emissions of urban industrial production and living, China has begun to explore Low-carbon Pilot Policy (LCCP) since 2010. China's National Development and Reform Commission selected different low-carbon pilot regions in three batches in 2010, 2012, and 2017 to speed up the realization of its global responsibility for carbon emission reduction.

Meanwhile, with the deep fragmentation of global production, the sustainable and high-quality development of China's export is also facing challenges. Although China has become the world's largest exporter, its export volume cannot reflect the real gains in the international market [11]. Actually, due to the development of the global value chain and the refinement of the international labor division, firms' export value includes not only the domestic value created by the home country, but also the value of intermediate inputs imported from abroad [12,13]. To illustrate this point, let us take a simple example. Assuming that a Chinese firm's export value is 100 USD, if the production process only involves domestic factors and intermediate inputs, then the 100 USD are all created by China. However, if the production uses imported intermediate inputs worth 90 USD, only 10 USD are the real export gains. Up to now, how to improve the real trade gains of Chinese firms is still a core issue facing China [14]. The ultimate goal of the low-carbon policy is to foster economic development without harming the environment [15]. Given China's traditional economic development and trade mode characterized by high pollution and high-energy consumption, whether the implementation of the low-carbon policy will damage firms' ratios of domestic value added in exports is still a question to be answered.

From the perspective of the Porter hypothesis, the LCPP requires firms to improve their production process, reduce and eliminate backward production capacity, and strengthen staff training, which may improve firms' production efficiency. Meanwhile, market-oriented policy tools adopted by the government, such as prices, fiscal subsidies, financial channels expansion, tax incentives, etc., provide strong incentives for firms' innovation that also helps raise firms' production efficiency, which in turn enhances their value-adding ability in the export market. However, the pollution heaven hypothesis implies that dirty firms with high emission intensity and clean firms with low emission intensity face unequal emission reduction pressure and environmental compliance costs; therefore, the impact of LCPP on the ratio of domestic value added in the exports of them may be different.

Based on the above argument, applying the policy environment created by the LCPP of China, we adopted a difference-in-difference method to assess the impact of carbon reduction regulation on firms' ratios of domestic value added in exports, using the Chinese Customs Transaction-level Trade Statistics Dataset and the Chinese Annual Survey of Industrial Firms Dataset from 2008 to 2014. Due to the availability of data, the lags of policy implementation, and the potential expected effects, we only selected the first batch of pilot regions as the treated group. Simultaneously, we compared the heterogeneous impact of LCPP on the ratio of domestic value added in exports of dirty firms with that of clean firms and tested the intermediary role of production efficiency.

Our findings show that carbon-reduction regulation represented by the LCPP of China can continuously increase firms' ratios of domestic value added in exports. This effect varies between dirty firms and clean firms. Specifically, compared with dirty firms, LCPP has a greater positive effect on the ratio of value added in exports of clean firms. Additionally, we also found that the LCPP increases a firm's ratios of domestic value added in exports by improving its production efficiency, and the intermediary role of production efficiency exists not only in the full sample but also in the dirty firm sample and clean firm sample.

Our research contributes to the existing literature in the following aspects. Firstly, our research enriches the literature on the factors affecting the firm-level ratio of value added in exports. Due to the limit of data limitations on detailed micro production and trade, the existing research on the ratio of domestic value added in exports is still mainly at the industry- or country-levels. The identified influencing factors include but are not limited to the trade structure [16,17], trade barriers [18], productivity [19,20], trade liberalization [21], etc. However, there are only a few studies on the influencing factors of firms' ratios of domestic value added in exports, and the research on how environmental regulation affects firms' ratios of value added in exports has not been found yet. Utilizing data from the Chinese Customs Transaction-level Trade Statistics Dataset and the Chinese Annual Survey of Industrial Firms Dataset, our research chose a novel and specific environmental regulation, that is, the carbon reduction policy, to analyze its impact on firms' ratios of domestic value added in exports, which expands the literature on this topic.

Secondly, our research extends the micro effect of the LCPP to the field of firms' export performance. The existing research on the LCPP is mainly based on city-level data and estimates its impact on city-level productivity [22] or carbon emissions [4]. Only a handful of studies have focused on the micro effects of LCPP on firms' productivity [23] or pollution emissions [24]. However, from the perspective of firms' ratios of domestic value added in exports, our research extends LCPP's micro effect from the direct technology effect and emission reduction effect to the field of firms' export gains and proves that LCPP could affect the organization of firms' global production.

Finally, our research provides a reference to the generalization and perfection of carbon reduction regulation in developing countries, which are facing severe challenges in poverty alleviation and environmental protection. Our research shows, with evidence from China, that the implementation of carbon reduction regulation does not necessarily cause losses to firms. Through appropriate policy design, developing countries can reduce carbon and increase export gains simultaneously. Our research also shows that the positive effect of LCPP on dirty firms is less than that of LCPP on clean firms. Therefore, strengthening the precise supporting policies for dirty firms, especially the relevant supporting policies to promote the transformation of production efficiency to profitability, will help alleviate the relative comparative disadvantages of dirty firms due to high environmental compliance costs.

The rest of the paper is organized as follows. Section 2 introduces the policy background, literature review, and the research hypotheses and mechanism. Section 3 describes the empirical methodology, variables, and data. Section 4 displays the baseline result and validates our method and results. Section 5 explores the heterogeneous effect of LCPP on dirty firms and clean firms. Section 6 tests the mechanism posed in Section 2. Section 7 summarizes the conclusions and implications.

2. Policy Background, Literature Review and Hypotheses

2.1. Policy Background

Carbon emissions generated in urbanization and industrialization of developing countries have always been a concern for the international community. In 2009, China's then premier committed at the UN climate conference to "reduce carbon dioxide emissions per unit GDP by 40–45% by 2020 compared with 2005", and incorporated this target as a binding indicator into the medium- and long-term planning of national economic and social development. To fulfil this goal, the Chinese government has begun to explore LCPP. In July 2010, the Notice of the National Development and Reform Commission on Carrying out the Pilot Work of Low-carbon Provinces and Cities issued by the Chinese government established the first batch of pilot regions. Given the positive effect of the first batch of pilot policy in promoting low carbon, the Development and Reform Commission issued the second and third batch of LCPP in December 2012 and January 2017 respectively.

During the implementation of the LCPP, China's central government only provides guidance on the policy direction and the local governments formulate their low-carbon development plans and put forward their short-term and long-term goals of greenhouse gas emissions and energy consumption. For instance, the target set by Tianjin is to reduce carbon dioxide emissions per unit GDP by 19% by 2015 compared with 2010 and to increase the proportion of non-fossil energy in primary energy consumption by 2 percentage points. By 2020, the intensity of carbon dioxide emissions per unit of GDP will be reduced by more than 45% compared with 2005. Additionally, local governments also put forward specific implementation plans from five aspects, i.e., low-carbon industrial development, optimization of energy structure, energy conservation and efficiency improvement, the increase of carbon sinks, and advocacy of low-carbon life.

Compared with other types of environmental policies, the LCPP is a comprehensive one that combines command-control tools, market-based tools, and voluntary tools. The central government sets an overall emission reduction target at the national level and then the local governments of pilot regions set specific binding targets according to their resource endowments, industrial structure, energy structure, and economic development level, and impose requirements on key firms. Command-control tools including the reduction and elimination of backward production capacity, green building and energy conservation, vehicle emission standards, etc., put direct restrictions on firms' carbon emissions. Secondly, market-based tools such as carbon trading market, price, fiscal subsidies, financing channel broadening, and tax reduction provide strong incentives for firms' innovation during the implementation of LCPP. Finally, voluntary policy tools such as promoting the public and firms' environmental awareness can help firms to achieve the goals of carbon reduction and innovation in the process of pursuing a high social reputation.

A body of research has proved the significance of LCPP for carbon reduction and found that LCPP has helped improve carbon emission efficiency [9,25,26], and reduce carbon emissions [4] or carbon emission intensity [27]. Chen et al. [24] argued that low-carbon city construction could improve firms' carbon reduction performance and Yan et al. [28] found that LCPP could even effectively alleviate haze pollution at the city level.

2.2. Literature Review

Research on environmental regulation is based on two theories. Copeland and Taylor [29] first proposed the Pollution Heaven Hypothesis with a North-South trade model. They demonstrated that under free trade, strict environmental regulation in high-income countries would push pollution-intensive industries to low-income countries with loose environmental regulations, thus aggravating pollution in low-income countries. Some studies have provided empirical evidence for this hypothesis. Wang et al. [30] found that the environmental regulation targeting water quality protection had driven heavy-polluting firms out of the market and harmed the output of surviving firms. Cai et al. [31] used the Two Control Zones policy implemented in China in 1998 to find that environmental regulation led to a decrease in foreign direct investment in China. The second theory is called the Porter Hypothesis which was proposed by Porter and Van der Linde [32]. It argued that the Pollution Heaven Hypothesis placed the environment-competitiveness relationship in a static framework that presumed that technologies, products, processes, etc., are fixed. However, the reality was that a properly designed environmental policy will force firms to increase research and development investment, so in the long run, it will promote firms' innovation and technological upgrading. A large body of research has supported this hypothesis. Ambec and Barla [33] found that environmental regulation had increased firms' benefits by reducing their agent costs through a renegotiation model, which provided a theoretical foundation for the Porter Hypothesis. Klassen and McLaughlin [34] claimed a positive effect of strong environmental management on firms' stock market value with an event analysis methodology. Kong et al. [35] revealed that environmental regulation increased firms' environmental protection activities and further enhanced firms' market value.

The first strand of literature related to our research focused on China's LCPP. So far, part of the research on LCPP in China has mainly explored its development status [10,36–38]. These studies not only affirmed the achievements of LCPP but also unveiled the unbalanced development of pilot regions. Some studies have also found the productivity improvement effect and green innovation effect of LCPP at the city level [22,39,40] or the firm level [23,41]. However, the most relevant studies assessed its carbon emission reduction effect [4,9,24–27].

The second strand of related literature mainly explored the determinants of firms' ratios of domestic value added in exports. The domestic value added in exports is an important part of GDP, reflecting a country's gains from international trade [19,20,42]. With microdata of firms' production and trade, Upward et al. [12] calculated the ratio of domestic value added in exports, which refers to how much domestic value added was contained in one unit value of firms' export. Following Upward et al. [12], Kee and Tang [43] analyzed the reasons for the increase in Chinese firms' ratios of domestic value added in exports from

2000 to 2007 and suggested that it was the substitution of domestic inputs for imported inputs caused by trade and foreign direct investment liberalization that led to this increase. Vrh [44] explored the impact of a firm's organizational structure on its domestic value added in exports and demonstrated that the ratio of domestic value added in exports of firms with foreign ownership was lower while that of non-affiliated firms with permanent suppliers abroad was higher. With microdata of Chinese firms from 2000 to 2007, Wu et al. [45] claimed that China's value-added tax reform in 2004 increased firms' ratios of domestic value added in exports.

The third strand of relevant literature examined how environmental regulation or environmental pollution affected the ratio of value added in exports. Using PM2.5 as a measurement of air pollution, Du et al. [46] analyzed LCPP's impact on Chinese firms' ratios of domestic value added in exports. The study showed that air pollution may reduce the ratio of domestic value added in exports by damaging firms' productivity and innovation ability. With panel data of 270 prefecture cities in China from 2003 to 2016, Huang [47] found that the intensity of environmental regulation had a U-shape effect on the ratio of domestic value added in exports. With data from OECD and BRICS countries and the gravity model, Koźluk and Timiliotis [48] disclosed that strict domestic environmental regulations led to the relatively comparative disadvantage of dirty industries and comparative advantage of clean industries, and it had a greater impact on domestic value added than gross export.

In summary, the existing studies have not linked carbon reduction regulation with the firms' ratios of value added in exports and empirically examined the impact of the former on the latter.

2.3. Research Hypotheses

2.3.1. LCPP and Firms' Ratio of Domestic Value Added in Exports

Some studies have found that environmental regulation can improve firms' export probability and export scale [49], increase firms' export density [50], and improve firms' export green sophistication [51] and product quality [52]. However, in the long term, firms are more concerned about their real gains in the international market. Both the increase in export probability and the expansion in export volume do not necessarily mean more real export gains, because they can be achieved through imported inputs in production. In addition, firms with high export product quality could adopt low-price competition strategies, resulting in a decrease in real gains in the export market. Compared with the aforementioned indicators, the ratio of domestic value added in exports can more intuitively reflect this content. However, the research to evaluate the impact of comprehensive carbon reduction regulation on the ratio of domestic value added in exports has not yet appeared.

On the one hand, almost all low-carbon development plans of pilot regions emphasize increasing financial support for firms. For example, Yunnan province proposed to invest 1 billion and 0.5 billion RMB to carry out low-carbon industrial park construction projects and firms' low-carbon transformation projects respectively. Shenzhen also formulated detailed financial support policies especially for low-carbon technological innovation and industrial low-carbon transformation. From the perspective of the Porter Hypothesis, these supportive policies could help to promote firms' innovation capacity and production technological upgrading [53]. Further, LCPP also urges firms to improve their energy structure [27], increase energy utilization efficiency, and reduce production costs, which improves the ratio of domestic value added in exports. On the other hand, starting from the Pollution Heaven Hypothesis, the strict emission targets and clear technical standards adopted by low-carbon regions will increase firms' cost pressure. To survive in the market and maintain their profits, firms usually adopt measures such as optimizing resource allocation [23] and improving production efficiency, which also improves the ratio of domestic value added in exports.

To obtain the original evidence about the impact of LCPP on firms' ratios of domestic value added in exports, we summarize the changes in the average ratio of domestic value added in exports of firms in pilot regions and non-pilot regions before and after the implementation of LCPP in Table 1. It can be seen that after the implementation of LCPP, the average ratio of domestic value added in exports of firms in pilot regions increased by 0.75 percentage points, which was significant at the 1% statistical level, while that in non-pilot regions decreased but was not statistically significant. Based on the above arguments, we proposed the first hypothesis.

Table 1. The changes in average ratio of domestic value added in exports of firms in pilot regions and non-pilot regions.

Regions	Before	After	Difference	t-Statistics
Pilot	0.9013	0.9088	0.0075 ***	6.9051
Non-pilot	0.9610	0.9608	−0.0002	−0.2599

Notes: Data are calculated by authors. *** represents 1% significant level.

H1. *LCPP can positively increase firms' ratios of domestic value added in exports.*

2.3.2. LCPP, Pollution Intensity and Firms' Ratio of Domestic Value Added in Exports

According to the Pollution Heaven Hypothesis, loose environmental regulation is essentially a source of comparative advantage. When a country tightens its environmental regulation, industries with high pollution intensity will suffer losses [54]. Therefore, environmental regulations may impact firms differently according to their pollution intensities. Cai et al. [31] found that strict environmental regulations have a greater negative impact on FDI in industries with higher pollution intensity because of the higher environmental compliance costs. Du and Li [55] also believed that environmental regulation makes the production cost of pollution-intensive firms higher than that of clean firms. LCPP aims to control carbon emissions. Therefore, when facing constraints posed by LCPP, firms in industries with high carbon dioxide emissions intensity need to invest more capital in carbon reduction and thus face higher environmental compliance costs, resulting in the discount of policy effect.

To illustrate this point, we followed Cai et al. [31] to calculate the carbon dioxide emissions per unit industrial output value of each 2-digit CIC industry in 2008 (Cai et al. [31] has used sulfur dioxide emission intensity to measure pollution intensity. However, LCPP aims to reduce carbon dioxide emissions, thus we use carbon dioxide emission intensity to measure pollution intensity in this paper), and divide the sample into dirty firms with carbon dioxide emission intensity greater than the median value and clean firms with carbon dioxide emission intensity less than the median value. Table 2 reports the changes in the ratio of domestic value added in exports of two types of firms in pilot regions and non-pilot regions before and after the implementation of LCPP. For the pilot regions, LCPP increases the ratio of domestic value added in exports of dirty firms and that of clean firms by 0.25 and 1.03 percentage points respectively, but the former is temporarily not statistically significant, while the latter is significant at a 1% statistical level. For non-pilot regions, the ratio of domestic value added in exports of dirty firms decreases while that of clean firms increases, but neither of them is statistically significant. In general, the LCPP has a greater positive impact on clean firms. Therefore, we proposed the second hypothesis.

Table 2. The changes in average ratio of domestic value added in exports of firms with different pollution intensity.

Regions	Group	Before	After	Difference	t-Statistics
Pilot	Dirty	0.9329	0.9354	0.0025	1.3592
	Clean	0.8895	0.8998	0.0103 ***	7.847
Non-pilot	Dirty	0.9690	0.9681	−0.0009	−1.026
	Clean	0.9558	0.9562	0.0005	0.5803

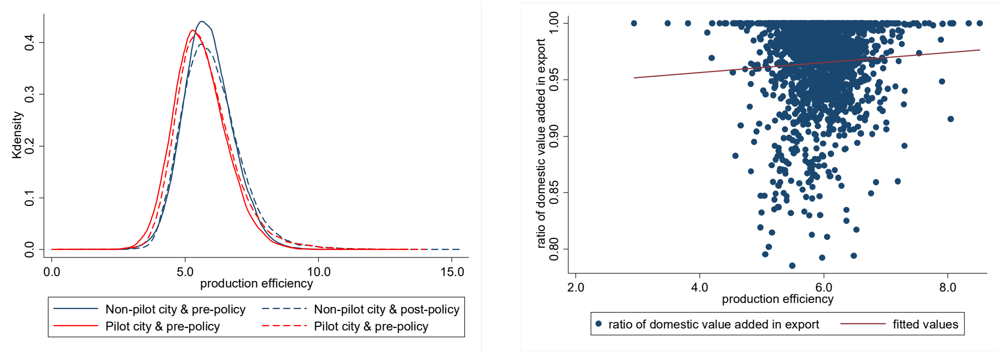
Notes: Data are calculated by authors. *** represents 1% significant level.

H2. *Compared with that of dirty firms, LCPP has a greater effect on the ratio of domestic value added in exports of clean firms.*

2.3.3. LCPP, Production Efficiency and Firms' Ratio of Domestic Value Added in Exports

LCPP may improve firms' ratios of domestic value added in exports by improving their production efficiency. Firstly, although LCPP brings firms higher cost pressure, firms may gradually realize the necessity of improving production efficiency from the increased cost in the long run, and then make up for their profit losses [54]. At this time, the green environmental protection behaviors adopted by firms in the process of carbon emission reduction, such as improving the production process, purchasing environmental equipment, and training employees, increase firms' production efficiency [56]. Secondly, the government's innovation support also helps improve firms' production efficiency. Almost all low-carbon development plans of pilot regions emphasize the importance of science, technology, and innovation. For example, Chongqing stressed the need to "strengthen scientific and technological support and promote low-carbon technology innovation" in its low-carbon work plan and formulated various innovative strategies. They included strengthening basic scientific and technological research, research and promotion of clean processing technology, energy conservation, emission reduction technology and low-carbon agricultural technology and so on. These innovation support measures could help improve firms' innovation ability [57], thereby improving firms' production efficiency and continuously boosting firms' domestic value added. Finally, according to a World Bank's investment survey of Chinese firms, 75% of Chinese firms are troubled by financing constraints [58], which may hurt their production efficiency. The fiscal and financial subsidies in pilot regions can effectively relieve this problem, and help firms improve their technology and production efficiency.

To test the relationship between the LCPP, production efficiency and firms' ratios of domestic value added in exports, we first drew the distribution of firms' production efficiency in pilot and non-pilot regions before and after the implementation of LCPP (shown in Figure 1a). Referring to Du and Li [55], we used the total industrial output value per employees to measure firms' production efficiency. To reduce the problem of heteroscedasticity, we too the natural logarithm of this ratio, which was positively correlated with firms' production efficiency. The blue solid line and dash line in panel (a) represent the changes in the distribution of firms' production efficiency in non-pilot regions before and after the implementation of LCPP respectively, while their red counterparts represent the changes in the distribution of firms' production efficiency in pilot regions. It shows that after the implementation of LCPP, the distribution of production efficiency of firms in non-pilot regions almost remains unchanged, while that of firms in pilot regions shifted to the right, indicating that LCPP might improve firms' production efficiency in pilot regions. We further calculated the simple average ratio of domestic value added in export and production efficiency at the city-year level and depicted panel (b) in Figure 1. The horizontal and the vertical axis represent the average production efficiency and the average ratio of domestic value added in exports respectively. The black upward slash is the fitting line between the two indicators, which implies a positive correlation between firms' production efficiency and firms' ratios of domestic value added in exports. Based on the above arguments, we proposed the third hypothesis.



(**a**) (**b**)

Figure 1. LCPP, production efficiency and the ratio of domestic value added in exports. (**a**) Changes in production efficiency; (**b**) Correlation between production efficiency and the ratio of domestic value added in exports.

H3: *LCPP increases firms' ratios of value added in exports through its production efficiency improvement effect.*

3. Empirical Methodology

3.1. Identification Strategy

Carbon emissions or pollution behavior always interacts with firms' production and trade, which is supported by research on the impact of trade on pollution and the impact of environmental policies or pollution on trade. Recently, the empirical method combing the exogenous policy shock and difference-in-difference framework can alleviate the endogeneity between environmental issues and trade. By adding a control group, the difference-in-difference method can effectively reduce the number of covariates that need to be considered and well curb the endogeneity in regression [59]. Most of the existing studies on the impact of LCPP also apply this methodology [22,28,60].

Following the existing studies, we also applied the difference-in-difference identification strategy to estimate the impact of LCPP on firms' ratios of domestic value added in exports. More specifically, we only chose the first batch of LCPP in our analysis. There were three reasons for this. The first was the availability of data. The currently available Chinese Annual Survey of Industrial Firms dataset is up to 2014, so it was impossible to take the third batch of LCPP issued in 2017 into consideration. The second was the lag of policy implementation. The second batch of LCPP was issued at the end of 2012, and most governments in pilot regions did not prepare low-carbon development plans and take action until 2013 or later. Considering that the sample in our analysis is up to 2014, it was not accurate to investigate the dynamic effect of the second batch of LCPP. The third was the potential expected effects of the second batch of LCPP. The process of establishing low-carbon pilot regions mainly includes two stages. In the first stage, the local government applies to the central government. Then in the second stage, the central government reviews and determines the pilot regions according to applications. After implementing the first batch of LCPP, the local governments that intend to declare the second batch may take action to reduce carbon emissions in advance to increase their possibility of success. That is to say, there might be an expected effect in the samples from the second batch of LCPP, resulting in a bias in estimation results. Therefore, we excluded the observations from the second batch. Further, we also noticed that although the first batch of LCPP was announced in 2010, most of the listed local governments took 2011 as the starting year of low-carbon development, so we set 2011 as the year of policy implementation in our analysis.

The estimation specification is as follows:

$$\mathrm{DVAR}_{fct} = \alpha + \beta treat_c \times post_t + \sum_{n=1}^{N_f} \gamma^n Control_{ft}^n + \sum_{m=1}^{M_c} \gamma^m Control_{ft}^n + \delta_f + \tau_t + \sigma_c + \varepsilon_{fct} \quad (1)$$

where f, c and t index firm, city and year. DVAR$_{fct}$ is the ratio of domestic value added in exports of firm f in city c in year t. $treat_c$ is a dummy that takes the value 1 when city c belongs to pilot regions, otherwise it takes the value 0. $post_t$ is a dummy as well that takes the value 1 when the year is equal to or later than 2011, otherwise it takes the value 0. $Control^n_{ft}$ and γ^n denote the n-th covariate at the firm level and its coefficient, respectively. N_f is the number of firm-level covariates. Similarly, $Control^m_{ct}$ and γ^m denote the m-th covariate at the city level and its coefficient, respectively. M_c is the number of city-level covariates. To exclude the impact of other unobserved firm-level factors on our result, we added firm-fixed effects δ_f. In addition, we added year-fixed effects τ_t to the model to control for the impact of national environmental or macroeconomic policies. In addition, some unobserved factors, such as the historical preference of residents for environmental protection and the government's awareness of the rule of law, may interfere with the effectiveness of LCPP. Therefore, we add city-fixed effects σ_c to the model (If the location of each firm does not change during the whole sample period, the city-fixed effects in the model will be absorbed by firm-fixed effects. However, we notice that some firms migrated during the sample period, so it is necessary to add city-fixed effects to the model for sake of the standard difference-in-difference specification. We also regress the model without city-fixed effects, and find that the baseline conclusions remain unchanged). ε_{fct} is the error term and β captures the impact of LCPP on firms' ratio of domestic value added in exports.

To test the intermediary effect of production efficiency, we follow Baron and Kenny [61] and applied the following two specifications based on specification (1):

$$\text{Efficiency}_{fct} = \alpha_1 + \beta_1 treat_c \times post_t + \sum_{n=1}^{N_f} \gamma^n Control^n_{ft} + \sum_{m=1}^{M_c} \gamma^m Control^n_{ft} + \delta_f + \tau_t + \sigma_c + \varepsilon_{fct} \quad (2)$$

$$\text{Efficiency}_{fct} = \alpha_2 + \beta_2 treat_c \times post_t + \pi \text{Efficiency}_{fct} + \sum_{n=1}^{N_f} \gamma^n Control^n_{ft} + \sum_{m=1}^{M_c} \gamma^m Control^n_{ft} + \delta_f + \tau_t + \sigma_c + \varepsilon_{fct} \quad (3)$$

The impact of LCPP on firms' production efficiency can be estimated with specification (2) and the corresponding coefficient is β_1. Specification (3) can be used to assess the impacts of LCPP and production efficiency and the corresponding coefficients are β_2 and π. When both β and β_1 are statistically significant, if β_2 is statistically significant and $\beta_2 < \beta$, production efficiency is a partial intermediary. Contrarily, if β_2 is not statistically significant, then production efficiency is a full intermediary.

3.2. Variables and Data

3.2.1. Measurement of Firms' Ratio of Domestic Value Added in Exports

We followed the method of Upward et al. [12] and Kee and Tang [43] to calculate firms' ratios of domestic value added in exports. The sale Y_f of firm f consists of export by processing trade EXP^{pro}_f, export by ordinary trade EXP^{ord}_f and domestic sale D_f, with

$$Y_f = EXP^{pro}_f + EXP^{ord}_f + D_f \quad (4)$$

value added in exports is $DVA_f = EXP_f - IMP_f$, where EXP_f is the export value and IMP_f is the import value of intermediate inputs used for the production of export (According to Ahn et al. [62] and Lu et al. [63], there are a large number of trade intermediaries in China that do not engage in production but specialize in importing and exporting for other firms. We use the proportion of the import volume of trade intermediaries in each industry to adjust the observed import value of intermediate products and get firms' actual use of imported intermediate input. Following these two studies, we identify trade intermediaries as firms with the words "importer", "exporter", or "trader" or with those that have English-equivalent meanings in their titles. Taking the processing-trade-related import as an example, $IMP^{pro}_f = \sum_k \frac{IMP^{pro\_cus}_f}{1-Intermshr_k}$, where $IMP^{pro\_cus}_f$ is the observed processing-trade-related import value and $Intermshr_k$ represents the proportion of the import volume of trade intermediaries in industry k. The calculation of ordinary-trade-related imports is similar to that of processing-trade-related imports). All the firm's imports through processing trade are used to produce output and all the outputs are used to export, which means the firm's processing-trade-related output Y_f^{pro} equals the processing-trade-related export EXP_f^{pro}. The ratio of value added in processing-trade-related exports of firm f is:

$$DVAR_f^{pro} = \frac{EXP_f^{pro} - IMP_f^{pro}}{EXP_f^{pro}} = \frac{Y_f^{pro} - IMP_f^{pro}}{EXP_f^{pro}} = 1 - \frac{IMP_f^{pro}}{EXP_f^{pro}} \tag{5}$$

Based on the proportionality assumption, the proportion of imported intermediate inputs used to produce ordinary-trade-related exports in the firm's total ordinary-trade-related intermediate inputs import (IMP_f^{ord}) is equal to the proportion of ordinary-trade-related export (EXP_f^{ord}) in the firm's total output excluding processing-trade-related output ($Y_f - EXP_f^{pro}$) (Apart from intermediate inputs, firms' ordinary-trade-related imports also includes consumer goods and capital goods which are generally not included in firms' intermediate inputs. The BEC classification provided by the United Nations statistics office is used to identify firms' intermediate inputs). Therefore, the imported input used to produce ordinary-trade-related exports is $IMP_f^{pro} \times \left(EXP_f^{ord} / \left(Y_f - EXP_f^{pro}\right)\right)$ and the firm's ratio of value added in processing-trade-related exports is:

$$DVAR_f^{ord} = \frac{EXP_f^{ord} - IMP_f^{pro} \times \left(EXP_f^{ord} / \left(Y_f - EXP_f^{pro}\right)\right)}{EXP_f^{ord}} = 1 - \frac{IMP_f^{ord}}{Y_f - EXP_f^{pro}} \tag{6}$$

The ratio of value added in total exports equals the weighted average ratio of value added in two types of exports and the weight is export share. That is,

$$DVAR_f = \frac{EXP_f^{pro}}{EXP_f^{pro} + EXP_f^{ord}} \times DVAR_f^{pro} + \frac{EXP_f^{ord}}{EXP_f^{pro} + EXP_f^{ord}} \times DVAR_f^{ord} \tag{7}$$

The data used to calculate firms' ratios of domestic value added in exports come from the Chinese Customs Transaction-level Trade Statistics Dataset and the Chinese Annual Survey of Industrial Firms Dataset.

3.2.2. Explanatory Variable and Covariates

- Low-carbon pilot policy ($treat_c \times post_t$). The core explanatory variable is the product of the dummy $treat_c$ and the dummy $post_t$, the former indexing whether the city where the firm is located is the pilot region determined by the first batch of LCPP, and the latter denoting whether the observed year is 2011 or later. We acquired the list of pilot provinces and cities determined by the first batch of LCPP from the official website of the National Development and Reform Commission of China. For a given pilot province, we set all prefecture cities under its jurisdiction as pilot cities.
- Production efficiency ($Efficiency_{fct}$). The LP method and OP method are usually used to estimate firms' total factor productivity. However, due to the lack of vital indicators for calculation in the Chinese Annual Survey of Industrial Firms Dataset after 2008, such as aggregate intermediate inputs and industrial value-added, we cannot use total factor productivity to measure firms' production efficiency. Fryges and Wagner [64] have suggested that labor productivity measured by sales income per capita is highly correlated with total factor productivity. Based on Du and Li [55], we used firms' total industrial output per employee to measure production efficiency. We further took the natural logarithm of the ratio to eliminate the potential heteroscedasticity.

Data for calculation of production efficiency were from the Chinese Annual Survey of Industrial Firms Dataset.

- Other covariates. On one hand, following Wu et al. [45], we controlled some time-variate firm-level factors that might influence firms' ratios of domestic value added in exports, including assets intensity ($assets\_intensity$) reflecting the firms' factor input structure, the natural logarithm of firms' employment ($lnworker$) reflecting firms' size, and the natural logarithm of firms' age ($lnage$) (Firm's age is obtained by subtracting the year of establishment from the current year and adding 1. The fixed assets intensity refers to the ratio of the fixed assets to the number of employees). Additionally, we also added dummies $state$ and $foreign$ to the model to indicate whether the observed firm was a state-owned or a foreign firm. Data for covariates at the firm level were all from the Chinese Annual Survey of Industrial Firms Dataset.

On the other hand, based on the national and local governments' requirements in implementing LCPP, we also added some city-level covariates that might affect the possibility of a city being chosen as a pilot city. Referring to existing studies, we controlled the economic development level measured by the natural logarithm of GDP ($lnGDP$) [65], population size measured by the natural logarithm of total population ($lnPOP$), the industrial structure measured by the proportion of the value added in GDP of the secondary industry ($VAshr\_ind2$) and that of the tertiary industry ($VAshr\_ind3$) (Jiang et al. [66] have suggested that the secondary industry is the main source of carbon emissions and Wang et al. [67] have believed that the transformation and upgrading of the industrial structure to the tertiary industry is conducive to reducing carbon emissions.), electricity consumption measured by the natural logarithm of the electricity consumption per capita ($lnElectr$) (According to the data from the China Statistical Yearbook, in 2018, about 71.3% of China's electricity supply came from coal-fired power generation. The combustion of coal will produce a lot of carbon dioxide.), carbon basin measured by green coverage of built-up areas ($Green$). We additionally added some city characteristics that might influence firms' ratios of value added in exports, including research and development expenditure measured by the logarithm of the per capita science and technology expenditure ($lnSCI$), traffic convenience measured by per capita road area ($lnRoad$), tariff levels ($tariff$) and the wage measured by the logarithm of the average wage of urban on-the-job employees ($lnwage$). Data for the calculation of tariffs were from the WITS database and the Chinese Customs Transaction-level Trade Statistics Dataset. Data of other covariates at the city level were from the China City Statistical Yearbook. Considering the interference from the financial crisis and the time LCPP was implemented, we used samples after 2008 for analysis.

We referred to the method of Brandt et al. [68] to process the Chinese Annual Survey of Industrial Firms Dataset and then we matched it with the Chinese Customs Transaction-level Trade Statistics Dataset according to the firms' names, legal person, phone numbers, and zip codes of the postal district from where the firms were located. The matched micro dataset was then merged with the data from China City Statistical Yearbook, and various covariates were calculated based on the final sample data. After dropping the observations with missing or unreasonable values of key variables, we obtained 290,584 firm-year observations from 252 cities. The descriptive statistics of all variables are shown in Table 3 below. During the sample period, the ratio of domestic value added in exports of Chinese firms was high, possibly because the proportion of processing trade gradually reduced and export participation without imports increased. The observations regulated by the LCPP account for about 16.03% of the full sample.

Table 3. The descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
DVAR	290,584	0.9379	0.1565	3.5300×10^{-5}	1
treat × post	1659	0.1603	0.3670	0	1
Efficiency	290,584	5.8332	1.0626	0.0050	15.3471
lnage	290,584	2.1699	0.6570	0	5.0876
lnworker	290,584	5.5078	1.0970	0.6931	12.3717
asstes_intensity	290,584	3.8254	1.4456	0.0019	15.4502
state	290,584	0.0076	0.0867	0	1
foreign	290,584	0.4357	0.4959	0	1
lnGDP	1659	15.2674	1.1116	12.3707	18.8907
lnPOP	1659	4.5646	0.7330	2.7147	7.5725
VAshare_ind2	1659	52.2213	11.6158	9.7400	90.9700
VAshare_ind3	1659	41.1721	10.3977	8.5800	78.6600
lnElectr	1659	8.3490	0.7984	5.1246	11.2945
Green	1659	38.3237	7.7324	0.38	95.25
lnSCI	1659	4.2956	1.2781	−0.2932	8.3624
lnRoad	1659	2.2700	0.5752	−1.1769	4.6852
lnwage	1659	10.5003	0.3123	9.4043	11.3663
tariff	1659	5.8109	2.6357	0	16.4323

Notes: The statistics in this table are calculated from the final sample data. All statistics of explained variables and firm-level covariates are computed at the firm level. All statistics of core explanatory variables and the city-level covariates are calculated at the city level.

4. Empirical Findings

4.1. Baseline Results

We adopted specification (1) to evaluate the impact of the LCPP on firms' ratios of domestic value added in exports. Columns (1)–(3) in Table 4 give the estimation results after gradually adding fixed effects, covariates at the firm level, and covariates at the city level. Considering the possible serial correlation among firms in the same city each year, the robust standard errors are clustered to the city-year level. It is obvious that no matter what covariates are added to the model, LCPP has a significantly positive impact on firms' ratios of domestic value added in exports at a 1% statistical level. This result shows that the implementation of LCPP increased firms' ratios of domestic value added in exports by 1.3 percentage points, which verifies hypothesis 1 in Section 2.3.

Table 4. Baseline results.

	(1)	(2)	(3)
	DVAR	DVAR	DVAR
treat × post	0.0164 ***	0.0135 ***	0.0130 ***
	(0.0030)	(0.0022)	(0.0022)
Efficiency		0.0101 ***	0.0102 ***
		(0.0013)	(0.0013)
lnage		−0.0046 ***	−0.0045 ***
		(0.0017)	(0.0017)
lnworker		0.0052 ***	0.0053 ***
		(0.0015)	(0.0015)
asstes_intensity		−0.0054 ***	−0.0053 ***
		(0.0009)	(0.0009)
state		0.0048	0.0048
		(0.0068)	(0.0068)
foreign		−0.0001	−0.0001
		(0.0025)	(0.0025)
lnGDP			−0.0038
			(0.0048)
lnPOP			−0.0049
			(0.0063)

Table 4. *Cont.*

	(1)	(2)	(3)
	DVAR	**DVAR**	**DVAR**
VAshare_ind2			−0.0018 ***
			(0.0006)
VAshare_ind3			−0.0019 ***
			(0.0006)
lnElectr			−0.0046 *
			(0.0028)
Green			0.0000
			(0.0001)
lnSCI			−0.0030
			(0.0020)
lnRoad			−0.0019
			(0.0032)
lnSalary			0.0192 ***
			(0.0073)
tariff			0.0011
			(0.0009)
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
City FE	Y	Y	Y
N	260,604	260,604	260,165
r2	0.7100	0.7110	0.7111

Notes: (1) Standard errors are in parentheses and clustered to city-year level. (2) * and *** indicate 10% and 1% significant levels, respectively. (3) Constant terms are not reported in this table. (4) Firm FE, Year FE, and City FE represent firm-fixed effects, year-fixed effects, and city-fixed effects.

The benchmark regression result supports the Porter Hypothesis and extends the research on how environmental regulation affects firms' export behavior by extending this topic to carbon reduction regulation, especially the LCPP. Further, our baseline result is also in line with the findings of Du et al. [46], which with PM2.5 as the proxy of air pollution, has argued that air pollution would decrease firms' ratios of domestic value added in exports. Meanwhile, also consistent with the findings of Du et al. [46] and Wu et al. [45], we found that firms' production efficiency is positively correlated with the ratio of domestic value added in exports. Firms with smaller size, higher capital intensity, and longer life possess a lower ratio of domestic value added in exports.

4.2. Validity Test

4.2.1. Pre-Existing Trend Test

The potential assumption for utilizing a difference-in-difference identification strategy to evaluate the impact of LCPP on firms' ratios of domestic value added in exports is that the ratio of domestic value added in exports of firms in pilot regions and non-pilot regions meets the parallel trend before the implementation of LCPP. If there is a systematic difference in the outcome variable between these two groups, the baseline result will be biased. We verify this assumption by assuming that LCPP is implemented in advance. Specifically, we exclude the observations after LCPP takes effect, i.e., observations after 2011, and then assume that LCPP takes effect in 2010 and 2009, respectively. Based on that, we generate virtual policy indicators $treat_c \times post_{2010}$ and $treat_c \times post_{2009}$ ($post_{2010}$ is a dummy variable that takes value 1 when the observed year is or is later than 2010, otherwise, it takes value 0. Similarly, when the observation belongs to 2009 or later, the value of $post_{2019}$ takes value 1, otherwise, it takes value 0.), and replace the core explanatory variable in the baseline model with them to carry out regression. The results are shown in columns (1) and (2) of Table 5. It shows that when the assumed effective time of LCPP is advanced to 2010 and 2009, its impact on firms' ratios of domestic value added in exports is no longer statistically significant. This means that there is no pre-existing trend between firms in pilot and non-pilot regions in terms of the ratio of domestic value added in exports before LCPP is implemented.

Table 5. Pre-existing trend test.

	(1)	(2)
	DVAR	**DVAR**
treat × post_2010	0.0015	
	(0.0032)	
treat × post_2009		0.0022
		(0.0021)
Covariates	Y	Y
Firm FE	Y	Y
Year FE	Y	Y
City FE	Y	Y
N	101,067	101,067
r2	0.7691	0.7691

Notes: (1) Standard errors are in parentheses and clustered to city-year level. (2) Constant terms and coefficients of all covariates are not reported in this table. (3) Firm FE, Year FE, and City FE represent the firm-fixed effects, year-fixed effects, and city-fixed effects.

4.2.2. Placebo Test

Although we added a series of covariates to the baseline model to eliminate the confounding effects of factors that may simultaneously affect the implementation of LCPP and firms' ratios of domestic value added in exports, the baseline result still result from the unobserved differences between pilot regions and non-pilot regions. That is, there may be omitted variables. Further, one of the assumptions for the difference-in-difference identification strategy is that samples are randomly selected into the treated group and control group, that is, there was no self-selection effect of samples. The placebo test with the artificial treated group and control group can help to test the problem of omitted variables and sample self-selection effect in our baseline model. Referring to the method of La Ferrara et al. [69], we randomly selected 72 cities from 252 cities as the treated group and the others as the control group (The reason for this operation is that in our sample data, there are 72 cities treated.), while keeping the implemented time of LCPP unchanged. We randomly selected samples 500 times and estimated specification (1) with each random sample. Further, we graphed the following Figure 2 with all 500 coefficients and p-values.

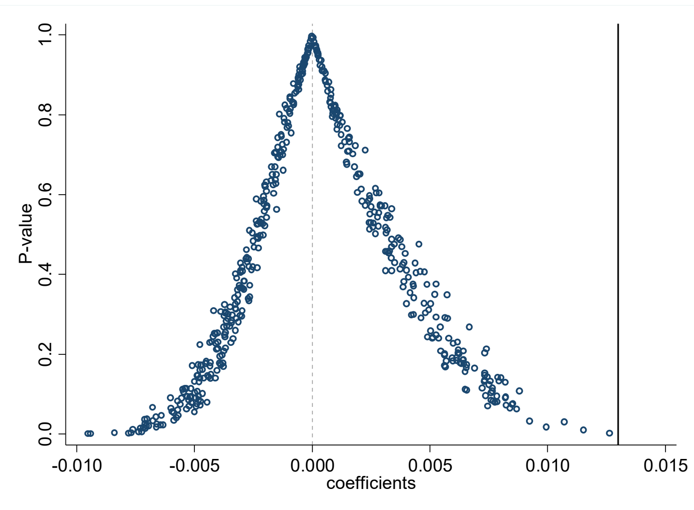


Figure 2. Placebo test.

The horizontal axis represents the coefficient of the core explanatory variable of each estimation while the vertical axis represents the corresponding *p*-value. The vertical line that lies on the right of the figure is the baseline coefficient. It shows that only a few estimation results were statistically positively significant among those 500 sampling regressions. That means that when the treated group and control group change, the effect of LCPP on firms' ratios of domestic value added in exports no longer exists. In other words, the increase in firms' ratios of domestic value added in exports is indeed brought about by the LCPP.

4.3. Dynamic Effects

We preliminarily evaluated the average impact of LCPP on firms' ratios of domestic value added in exports and tested the assumptions of application of difference-in-difference strategy. However, when it came to the macro policy, we may be more interested in the continuity of policy effect. If a policy is effective only in the implemented year, its rationality might be questioned. However, what we are concerned about is whether Chinese firms can achieve sustainable growth in domestic value added in export. Thus, we further adopted the following model to investigate the dynamic distribution of the ratio of domestic value added in exports of firms in pilot regions and non-pilot regions before and after the implementation of LCPP:

$$\mathrm{DVAR}_{fct} = \alpha + \sum_{k=2008, k\neq 2009}^{2014} \beta_k LCC_{ck} + \sum_{n=1}^{N_f} \gamma^n Control_{ft}^n + \sum_{m=1}^{M_c} \gamma^m Control_{ft}^n + \delta_f + \tau_t + \sigma_c + \varepsilon_{fct} \quad (8)$$

where k denotes a specific year and LCC_{ck} equals $treat_c \times post_k$. LCC_{c2008}, LCC_{c2009} and LCC_{c2010} are dummy variables reflecting the years before LCPP is implemented and enable us to examine the existence of parallel pre-existing trends again. LCC_{c2011}, LCC_{c2012}, LCC_{c2013} and LCC_{c2014} are dummy variables reflecting the years after the LCPP takes effect and enable us to explore the dynamic effects of LCPP. As a comparison, we excluded LCC_{c2010} from our regression. Based on the regression coefficients of specification (8), we graphed the following Figure 3. The hollow dots represent the coefficients and the bands are the 90% confidence intervals.

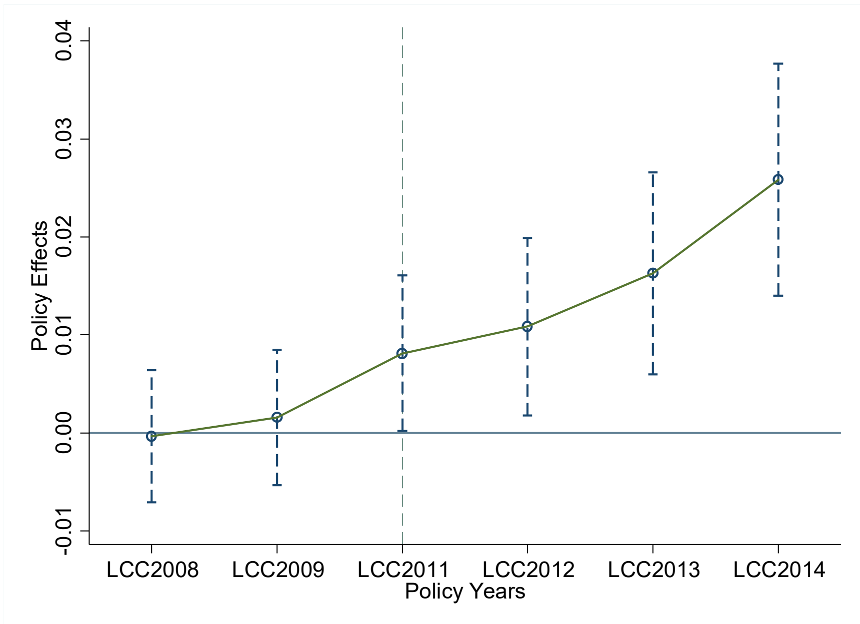


Figure 3. Dynamic effects.

Before LCPP comes into effect, the coefficients of the policy dummy variables are not statistically significant, which again verifies that there is no systematic difference in the change of the ratio of domestic value added in exports of firms in pilot regions and that in non-pilot regions. Additionally, when it comes to the dynamic effects, LCPP immediately has a significantly positive impact on firms' ratios of domestic value added in exports in the year when the policy comes into effect. With the implementation and deepening of the LCPP, its effect gradually increases. From this, we can conclude that environmental policy aiming at carbon reduction could continuously increase firms' real export gains in the international market.

4.4. Robustness Checks

We also conducted some robustness checks to ensure the stability of the baseline result. First, according to the statistics of the Chinese Customs Transaction-level Trade Statistics Dataset, some firms export without the import of any intermediate inputs. For those firms, their ratio of domestic value added in export calculated with the method in Section 3.2.1 is equal to 1. Among the baseline samples, there are 168,308 observations with a ratio of domestic value added in export equal to 1, accounting for 58% of the full samples. These extreme values may distort our baseline result. Therefore, we excluded these samples and conducted a robustness check with the remaining samples. The regression result is listed in column (1) of Table 6 and suggests that after excluding the extreme values, the impact of LCPP on firms' ratios of domestic value added in exports is still positive, and is significant at the 1% statistical level.

Table 6. Robustness checks.

	(1)	(2)	(3)
	DVAR $\neq 1$	**Excluding Provincial Capital Cities**	**Tobit Model**
treat × post	0.0182 ***	0.0150 ***	0.0300 ***
	(0.0034)	(0.0025)	(0.0046)
Covariates	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
City FE	Y	Y	N
N	103,378	221,815	290,584
r2	0.6614	0.7144	
	(4)	**(5)**	**(6)**
	Initial Status	**Treated Probability_2010**	**Treated Probability_2009**
treat × post	0.0130 ***		
	(0.0022)		
tcz × year	0.0001		
	(0.0005)		
prob2010 × post		0.0172 ***	
		(0.0042)	
prob2009 × post			0.0192 ***
			(0.0043)
Covariates	Y	Y	Y
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
City FE	Y	Y	Y
N	260,165	254,898	246,529
r2	0.7111	0.7072	0.7077

Notes: (1) Standard errors are in parentheses and are clustered to city-year level. (2) *** indicates 1% significant level. (3) Constant terms and coefficients of all covariates are not reported in this table. (4) Firm FE, Year FE and City FE represent the firm-fixed effects, year-fixed effects and city-fixed effects. (5) All explained variables are firms' ratio of domestic value added in exports.

Second, provincial capital cities have more advantages in policy, labor, capital, and technology compared with other cities [9], resulting in a higher level of low-carbon technology innovation. To eliminate the interference of these distinctions on our baseline result, we excluded samples from provincial capital cities and carried out regression again. The result is shown in column (2) of Table 6 below, which proves the stability of the baseline result.

Third, the value of the ratio of domestic value added in exports ranges between 0 and 1, and the sample data shows a characteristic of truncation. Following Puhani [70] and Alan et al. [71], we used an unbalanced panel data Tobit model to estimate the impact of LCPP on firms' ratios of domestic value added in exports. In the estimation, we still include all covariates, firm-fixed effects, city-fixed effects, and year-fixed effects (we use STATA's external command two-side to estimate the Tobit model with individual fixed effects. For the convenience of calculation, city fixed effects are not added to the model). The estimated result is shown in column (3) of Table 6, which suggests that after changing the estimation method, LCPP can still significantly promote firms' ratios of domestic value added in exports.

Fourth, Chen et al. [23] pointed out that the selection of pilot regions takes into account the following: geographical location, economic and social development, and openness of the city. The original differences in these factors may lead to a biased baseline result. Therefore, following Chen et al. [23], we used an indicator reflecting whether the city belongs to the "two control zones" established in 1998 as the proxy of the initial state of each city, and incorporated its intersection with the time trend $tcz_c \times year$ into Equation (1) for regression. Column (4) of Table 6 gives the corresponding result, which shows that the initial state of each city has not changed the baseline result.

Finally, what we can observe is whether a city is established as a pilot city, which is the post-event variable generated after the application of the local government and the review of the central government. In the absence of sample selection, some cities that are similar to the pilot cities in terms of geographical location, representativeness, and social and economic development should also be established as pilot cities if they have applied for and been reviewed by the central government. However, they did not submit applications or failed to pass through the review process, which affected their entry into the treated group or the control group. To solve this problem, with data from 2010 or 2009, we selected variables that may affect the selection of a city as a pilot city and apply a logit model to predict the probability of each city been selected into the treated group (The selection of explanatory variables takes into account the requirements of the central government and the low-carbon development plans of pilot cities, and refers to Fu et al. [25] and Shen et al. [57] as well. Those variables include the logarithm of GDP, the logarithm of population, the logarithm of the average wage, electricity consumption, the logarithm of public expenditure for science and technology, the proportion of value added of secondary industry in GDP, the proportion of value added of the tertiary industry in GDP, the proportion of labor force of the secondary industry and the proportion of labor force of the tertiary industry, as well as regional dummy variables. Using the Probit model and the data of 2008 to predict the probability does not change the baseline conclusion. Due to space constraints, we do report the estimated results of this stage. If readers are interested, they can ask the author for it). We adopt the product of predicted probability and time dummy, i.e., $prob2010_c \times post_t$ and $prob2009_c \times post_t$ to replace the explanatory variable in the specification (1). The regression results are shown in columns (5) and (6) of Table 6, which show that after considering the probability that each city would become a pilot city, the impact of LCPP on firms' ratios of domestic value added in exports was still significantly positive.

4.5. Excluding the Confounding Effects of Other Contemporaneous Policies

Other environmental policies or policies with similar functions to LCPP in the same period may also affect firms' ratios of domestic value added in exports. If they are not considered in the model, it is difficult to distinguish whether the effect of the increase in the ratio of domestic value added in exports found in the baseline model comes from LCPP or other policies instead. That is, there is a problem with omitted variables.

Firstly, we excluded the disturbance from resource-based city development policy. In 2013, the State Council of China issued the National Sustainable Development Plan for Resource-based Cities (2013–2020), which listed the resource-based cities in China. According to the requirements of the central government, those resource-based cities should improve resource conservation and comprehensive utilization, and optimize the industrial structure. We added the dummy $Resource$ to specification (1) to exclude its disturbance (When a city has been listed as a resource-based city in the observed year, the value of $Resource$ is 1, otherwise it is 0. The constructions of dummy variable $Forest$ reflecting the policy of National Forest Cities, $Clean$ reflecting the policy of cleaner production, and $Innovation$ reflecting the policy of Innovative City are similar to that of $Resource$), and the estimation result is shown in column (1) of Table 7, which shows that the impact of LCPP on firms' ratios of domestic value added in exports remains stable.

Table 7. Results excluding the confounding impacts of other policies.

	(1)	(2)	(3)	(4)	(5)
	DVAR	**DVAR**	**DVAR**	**DVAR**	**DVAR**
treat × post	0.0122 ***	0.0132 ***	0.0130 ***	0.0128 ***	0.0122 ***
	(0.0021)	(0.0021)	(0.0022)	(0.0021)	(0.0020)
Resource	−0.0073 ***				−0.0072 ***
	(0.0017)				(0.0017)
Forest		−0.0046 **			−0.0033
		(0.0021)			(0.0021)
Clean			−0.0006		−0.0005
			(0.0030)		(0.0030)
Innovation				−0.0034 **	−0.0030 *
				(0.0015)	(0.0016)
Covariates	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y
N	260,165	260,165	260,165	260,165	260,165
r2	0.7111	0.7111	0.7111	0.7111	0.7112

Notes: (1) Standard errors are in parentheses and clustered to city-year level. (2) *, **, *** indicate 10%, 5% and 1% significant levels, respectively. (3) Constant terms and coefficients of all covariates are not reported in this table. (4) Firm FE, Year FE and City FE represent the firm-fixed effects, year-fixed effects and city-fixed effects.

Secondly, the interference of national forest city policy should also be excluded in our analysis. During our sample period, China's State Forestry Administration carried out the evaluation of "National Forest cities" progressively. In order to earn this title, local governments need to increase forest coverage within their jurisdiction. This requirement is similar to some policy tools of LCPP, which may bias our baseline estimation. We added a dummy $Forest$ and re-estimated the baseline model. The result is shown in column (2) of Table 7, which shows that the national forest city construction project had no impact on our baseline result.

Thirdly, we also excluded the impact of cleaner production policies. From 2003 to 2011, the Chinese government issued Cleaner Production Standards for 56 related industries in 6 batches, involving 47 4-digital CIC industries. Cleaner Production Standards required firms to optimize their energy structure, upgrade technology and the production process, and control their pollution, which overlapped the policy tools of LCPP. Therefore, we added a dummy variable $Clean$ to the baseline model. The estimation result is given in column (3) of Table 7, suggesting that the implementation of Cleaner Production Standards does not change our benchmark conclusion.

Fourthly, we eliminated the disturbance from the pilot policy of innovative cities. In order to improve the independent innovation capacity and give full play to the core driving role of cities in accelerating the economic transformation, the Ministry of Science and Technology of China deployed the pilot work of innovative cities. This kind of policy emphasized the cultivation and development of strategic emerging industries, which has a similar function to LCPP. We collected and sorted out the list of innovative cities and the time when each city was established as an innovative city from the official website of the Ministry of Science and Technology of China, and generate a dummy *Innovation* to be included in the specification (1). The estimation result is shown in column (4) of Table 7, indicating that the pilot policy of innovative cities does not change the benchmark conclusion. The result considering all the above interfering policies is shown in column (5) of Table 7, suggesting that our baseline result remains robust.

5. Heterogeneity Effect Based on Pollution Intensity

5.1. The Impact of LCPP on the Ratio of Domestic Value Added in Exports of Firms with Different Pollution Intensities

We argue that LCPP may have heterogeneous effects on firms with different pollution intensities in Section 2.3.2 and we mainly test this argument in this section. We first used the classification criterion introduced in Section 2.3.2, which is the carbon dioxide emissions per unit output value, to group samples. When the carbon dioxide emission intensity of the industry to which a firm belongs is higher than the median value, we regarded the firm as a dirty firm; otherwise, it was regarded as a clean one. The data of carbon dioxide emission were from China's Carbon Emission Accounts and Datasets constructed by Shan et al. [72]. The gross industrial output value of each two-digit CIC industry came from the China Statistic Yearbook issued by the National Bureau of Statistics of China. To exclude the endogeneity, we used data from the year 2008 to calculate the classification criterion. Sub-sample regression was applied to test the difference of the effect of LCPP on the ratio of domestic value added in exports of firms with diverse pollution intensities. The results are shown in column (1) and column (2) in Table 8. They suggest that the implementation of LCPP increases the ratio of domestic value added in exports of dirty firms by 0.74 percentage points, lower than the average estimates (1.3 percentage points), while it increases that of clean firms by 1.49 percentage points, higher than the average level. The implementation of LCPP did have a stronger positive impact on clean firms than on dirty firms, which justifies our hypothesis 2.

Table 8. Heterogeneity effect based on pollution intensity.

	(1)	**(2)**	**(3)**	**(4)**
	Carbon Dioxide Emission Intensity		**Classification Standard by MEP**	
	Dirty	**Clean**	**Dirty**	**Clean**
treat × post	0.0074 ***	0.0149 ***	0.0102 ***	0.0137 ***
	(0.0023)	(0.0024)	(0.0032)	(0.0023)
Covariates	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
City FE	Y	Y	Y	Y
N	86,825	171,444	57,153	201,388
r2	0.6609	0.7271	0.6887	0.7184

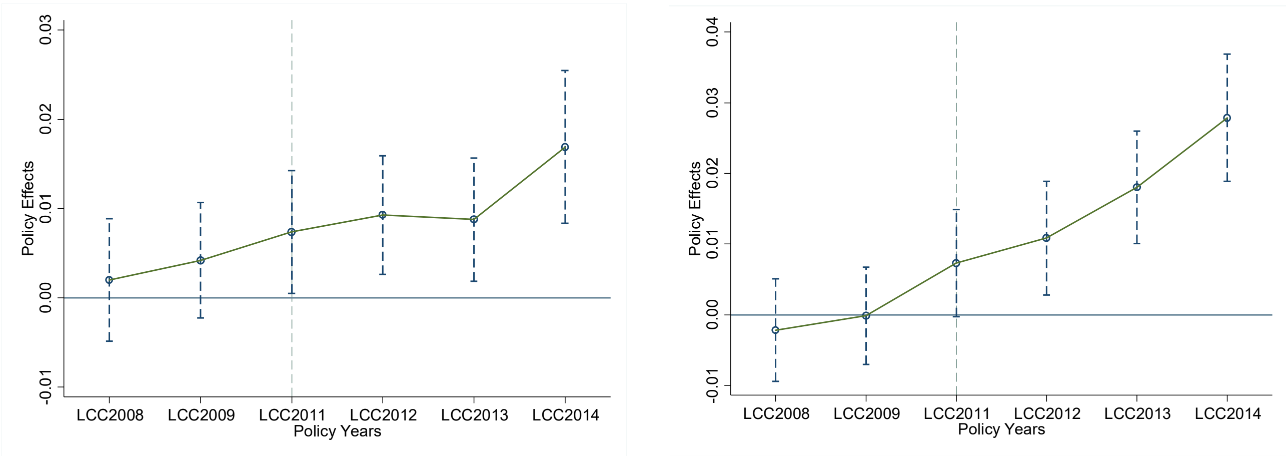
Notes: (1) Standard errors are in parentheses and clustered to city-year level. (2) *** indicates 1% significant level. (3) Constant terms and coefficients of all covariates are not reported in this table. (4) Firm FE, Year FE and City FE represent the firm-fixed effects, year-fixed effects and city-fixed effects.

It might be argued that the heterogeneous result may also result from the grouping criterion. Therefore, we use the classification standard issued by the Ministry of Environmental Protection (MEP) to test the robustness of this heterogeneous result. In 2010, the Guidelines for Environmental Information Disclosure of Listed Companies released by the MEP classified 16 categories of industries as heavy polluting industries, including thermal power, steel, cement, electrolytic aluminum, coal, metallurgy, chemical industry, petrochemical, building materials, papermaking, brewing, pharmaceutical, fermentation, textile, tanning, and mining. We manually collated the four-digit CIC industries corresponding to these 16 categories and re-classified the full samples according to whether firms belong to these industries. The re-estimation results are listed in columns (3) and (4) of Table 8, which show that after changing the grouping criterion, the positive effect of LCPP on the ratio of domestic value added in exports of clean firms was still greater than that of dirty firms.

Our finding echoes the research conclusions of Cai et al. [31] and Du and Li [55], and supports the Pollution Heaven Hypothesis to a certain degree. Although we did not find damages brought by LCPP to dirty firms, empirical evidence did show that dirty firms were at a comparative disadvantage position compared with clean ones in terms of impact coefficients. The reason might be that dirty firms face higher environmental compliance costs, which to some extent squeeze out firms' value-added investment.

5.2. Heterogeneous Dynamic Effects of LCPP Based on Pollution Intensity

The difference-difference identification strategy with sub-samples is used in Section 5.1, which means that the satisfaction of the parallel trend assumption in both sub-samples needs to be tested. Meanwhile, we were also concerned about the dynamic effects of LCPP on the ratio of domestic value added in exports of firms in two sub-samples. To achieve them simultaneously, we still used carbon dioxide emission intensity to group the samples and use specification (8) to estimate the dynamic effects on the two sub-samples. The estimation results are drawn in Figure 4. Panel (a) and (b) respectively illustrate the dynamic impact of LCPP on the ratio of domestic value added in exports of dirty firms and clean firms respectively. The dots represent the estimated coefficients and the bandwidth represents the 90% confidence interval. If the confidence interval contains the value of 0, it indicates that the corresponding estimated coefficient is not statistically significant.



(**a**) (**b**)

Figure 4. Dynamic effects of LCPP on firms with heterogeneous pollution intensities; (**a**). Dynamic effects on dirty firms; (**b**). Dynamic effects on clean firms.

On the one hand, we found that whether the firm is a dirty firm or a clean one, there was no significant distinction in the ratio of domestic value added in exports of firms in pilot regions and non-pilot regions before LCCP comes into effect, indicating that there are no pre-existing trends in both samples. On the other hand, we found that whether it is the sample of dirty firms or clean firms, LCPP has a significant and continuous positive impact on firms' ratios of domestic value added in exports.

Additionally, we also found that the impacts of LCPP on firms of two sub-samples also have some diversities. First, we found that there are differences in the timeliness of the impact of LCPP on the two groups. Specifically, LCPP can immediately increase the ratio of domestic value added in exports of dirty firms when it takes effect, while its impact on clean firms does not appear until one year after the policy takes effect. Second, from a dynamic perspective, the impact of LCPP on the ratio of domestic value added in exports of dirty firms is smaller than that of the clean ones throughout the whole policy period. Specifically, from 2012 to 2014, the impact coefficients of LCPP on dirty firms are 0.0093, 0.0088, and 0.0169 respectively, while those on clean firms are 0.0108, 0.0180, and 0.0279 respectively. The possible reason is that once LCPP is implemented, the government will immediately supervise the production and pollution discharge behaviors of dirty firms, to urge them to take immediate measures such as equipment upgrading, production efficiency improvement, and pollution reduction. Therefore, the policy effect will appear in the current year of implementation. Only after solving the emission problem of major polluters, will the government begin to extend its regulation to minor polluters. What is more, under strong supervision, dirty firms also faced higher emission reduction costs, which to some extent squeezed out their value-upgrading investment, resulting in a weaker impact on dirty firms than that clean firms.

6. Mechanism Testing

According to the discussion in 2.3.3, the LCPP may improve firms' ratios of domestic value added in exports by improving firms' production efficiency. We aimed at testing this mechanism by using the mediation effect models (2) and (3).

We first estimated the mediation effect model with the full sample. Specifically, we estimated a variant of specification (1) excluding firms' production efficiency. The result is shown in column (1) of Table 9, which suggests that the implementation of LCPP can significantly increase firms' ratios of domestic value added in exports by 1.44 percentage points without considering the impact of firms' production efficiency. Then, we used specification (1) to test the impact of LCPP on firms' production efficiency. The result in column (2) of Table 9 shows that the implementation of LCPP significantly increases firms' production efficiency by 0.133%. The benchmark result is given in column (3) as a reference, which showed that for each 1% increase in production efficiency, firms' ratios of domestic value added in exports rises by 1.02 percentage points. The results in columns (1)–(3) show that for the full sample, LCPP promotes the ratio of domestic value added in exports by improving firms' production efficiency. The hypothesis 3 is valid. Further, the coefficient of LCPP in column (1) is greater than that in column (3), indicating that firms' production efficiency plays a partial intermediary role.

Table 9. Mechanism testing: production efficiency.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Full Sample			Dirty Firms			Clean Firms		
	DVAR	Efficiency	DVAR	DVAR	Efficiency	DVAR	DVAR	Efficiency	DVAR
treat × post	0.0144 ***	0.1326 **	0.0130 ***	0.0081 ***	0.1415 ***	0.0074 ***	0.0166 ***	0.1322 **	0.0149 ***
	(0.0025)	(0.0524)	(0.0022)	(0.0024)	(0.0539)	(0.0023)	(0.0028)	(0.0534)	(0.0024)
Efficiency			0.0102 ***			0.0054 ***			0.0129 ***
			(0.0013)			(0.0010)			(0.0016)
Covariates	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	260,165	260,165	260,165	86,825	86,825	86,825	171,444	171,444	171,444
r2	0.7104	0.8596	0.7111	0.6606	0.8636	0.6609	0.7262	0.8546	0.7271

Notes: (1) Standard errors are in parentheses and clustered to city-year level. (2) ** and *** indicate 5% and 1% significant levels, respectively. (3) Constant terms and coefficients of all covariates are not reported in this table. (4) Firm FE, Year FE and City FE represent the firm-fixed effects, year-fixed effects and city-fixed effects.

In addition, we also tested the mediation effect of production efficiency with two subsamples respectively to investigate whether there is heterogeneity in the transmission channel. The regression results of dirty firms are shown in columns (4)–(6) of Table 9 and that of clean firms are shown in columns (7)–(9). On the one hand, for dirty firms, the implementation of LCPP can increase the ratio of domestic value added in export by 0.81 percentage points, which is less than the estimated result of the full sample (1.44 percentage points).

Further, the implementation of LCPP can increase dirty firms' production efficiency by 0.142%, which is slightly higher than the estimated result of the full sample (13.2%). However, for every 1% increase in production efficiency, the ratio of domestic value added in exports of dirty firms will increase by only 0.54 percentage points. The results of columns (4)–(6) show that the partial intermediary effect of firms' production efficiency is also held in the dirty sample. On the other hand, for clean firms, when the production efficiency is not added to specification (1) as a control variable, the estimation results in column (7) show that LCPP increases firms' ratios of domestic value added in exports by 1.66 percentage points, which is higher than the coefficient of the full sample. At the same time, the implementation of LCPP increased clean firms' production efficiency by 0.132% and is almost equal to the estimated result of the full sample, but slightly smaller than that of the dirty sample. However, every 1% increase in the production efficiency of clean firms will increase the ratio of domestic value added in export by 1.29 percentage points, much higher than the coefficient of the dirty sample. Columns (7)–(9) together show that the partial intermediary effect of production efficiency is established in the clean sample as well. The transmission mechanism of production efficiency found in our research favorably supports Porter Hypothesis and is consistent with the research conclusion of Chen et al. [23]. With data from Chinese A-share listed companies, Chen et al. [23] found that LCPP significantly promoted firms' total factor productivity.

7. Conclusions and Implications

To fill in the hole in the literature on the impact of environmental regulation, especially carbon reduction regulation on firms' ratios of domestic value added in exports, we used data from the Chinese Customs Transaction-level Trade Statistics Dataset and the Chinese Annual Survey of Industrial Firms Dataset from 2008 to 2014 to fill this gap. We firstly empirically tested the impact of China's LCPP on firms' ratios of domestic value added in exports with a difference-in-difference identification strategy. Our research yielded three main findings. First, our baseline finding suggests that China's LCPP significantly and continuously improves firms' ratios of domestic value added in exports, which supports the Porter Hypothesis generally, suggesting that the environmental regulation is conducive to firms' competitiveness This finding also echoes Du et al.'s [46] findings that pollution reduces firms' ratio of domestic value added in export.

Second, the heterogeneity test results based on carbon emission intensities show that although the LCPP has a continuously positive impact on both dirty and clean firms, the impact on the latter is comparatively greater, which testifies the Pollution Heaven Hypothesis. Meanwhile, the dynamic heterogeneous analysis shows that the positive effect of LCPP on dirty firms is detected immediately, while that on clean firms has a time lag. The possible reason for this is that, dirty firms face more urgent need to upgrade their equipment to reduce emission than clean firms to meet the LCPP's requirements, which is in line with the findings of Cai et al. [31] and Du and Li's [55] study on the heterogeneous impact of environmental regulations on firms with different pollution intensities.

Third, the empirical test result proves our proposition that LCPP mainly promotes the increase of firms' ratios of domestic value added in exported through the efficiency improvement effect. There are three main reasons for this. Primarily, the cost pressure exerted by LCPP on firms urges firms to adopt productivity-enhancing measures to make up for lost profits. Afterward, the innovation support and incentive measures adopted by the LCPP help to enhance firms' innovation capacity and productivity. Last but not least, the LCPP provides various fiscal and financial subsidies for firms, which financially support firms in raising productivity.

Our research has both theoretical and policy implications. At the theoretical level, our research expands the research on the microeconomic effects of LCPP. The existing research on LCPP mainly focuses on its direct effect on productivity or carbon emission reduction [4,22]. However, the development goal of LCPP requires that curbing greenhouse gas emissions and high-quality economic development go hand in hand. While existing studies have proved its effectiveness in the first goal, our study proves its effectiveness in achieving the second one, that is, to increase firms' real gains in the export market.

As for the policy implications, our research helps to enhance the confidence of Chinese firms and other developing countries in environmental protection and the implementation of carbon reduction regulations by providing a certain decision-making reference for them to formulate appropriate carbon reduction policies. Developing countries have long been concerned that developed countries are insulating them from competition from their firms by urging them to protect the environment [73]. Our finding from China suggests that the global carbon reduction regulation does not necessarily harm the competitiveness of firms in developing countries.

Further, dirty firms face higher environmental regulation costs, thus squeezing out investment in value-added actions. Therefore, the government should set up more targeted supportive policies for dirty firms. For example, the financial support should differ according to firms' pollution intensity and emission reduction targets. Additionally, as the LCPP boosts firms' ratios of domestic value added in exports by enhancing their productivity, the government needs to strengthen the guidance of firms' technological upgrading, such as providing more technology training for firms or building technology transaction networks to encourage the technology spillovers between firms.

On the other hand, we also found that dirty firms are weak in converting production efficiency into value-added compared to clean firms. This also requires the government to strengthen the guidance of dirty firms in policymaking to help them to catch up.

Apart from the above implications, our research leaves room for future study as follows. On one hand, since the firm-level data from the Chinese Annual Survey of Industrial Firms Dataset are only updated to 2014, we can only test the relationship between carbon reduction regulation and firms' ratios of domestic value added in exports with data from 2008–2014. If updated data are available in the future, it is meaningful to re-examine this topic. On the other hand, considering China has long been regarded as the world's largest carbon emitter [9,10], we conducted the empirical analysis mainly from the perspective of China. However, there are also some differences between developing countries in terms of technology level, resource endowment, industrial structure, etc. Therefore, future research on other developing countries with microdata is also important.

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