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The Effects of Government Environmental Subsidies and Corporate Environmental Investments on Carbon Emissions of Chinese Firms

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Abstract: This study investigates the effects of environmental investments and environmental subsidies on carbon emissions by Chinese listed firms on Shanghai Stock and Shenzhen Stock Exchanges from 2008 to 2018. Year-firm data from the RESSET database and financial data from CSMAR database including accounting, financial market, and Chinese government subsidization were utilized. To reflect the tangled relationships between carbon emission, environmental subsidies, and environmental investments, we applied simultaneous equation models (SEMs) and finite lag fixed effects models and report following unique empirical results. First, the government's environmental subsidies were found to have correlate with increasing carbon emissions significantly in the short- and long-term. Second, environmental investments by Chinese firms significantly correlated with short- and long-term carbon emission increases. Third, four other factors—exports, largest shareholding, government shareholding, and firm size—all have a significant effect on carbon emissions. Whether a firm has foreign shareholding is not statistically significant in all analyses. The results imply that most Chinese firms, if not all, have increased their carbon emissions despite receiving governmental environmental subsidies.

Key Words: Carbon Emission, China, Environmental Investment, Environmental Subsidy, Limited Lag Fixed Effects Panel Model, Simultaneous Equation Model, Firm Level Data

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I. Introduction

Generally, pollution is considered a serious threat to the environment. However, in the industrial sector, it is also seen as a threat to its competitiveness. Carbon emissions, particularly carbon dioxide (CO_2) emissions, are thought to be the primary driver of global warming. Most nations have signed the Kyoto Protocol, promising to reduce their green house gases including carbon dioxide emissions in order to avert global warming (Hamilton and Thorton, 2002; Yang and Sun, 2010; Liu et al., 2017). However, carbon emission problems have been very serious not only in China, but also in neighboring countries like Korea.

Since China introduced reform and opening-up policies in the late 1970s to promote industrialization, environmental pollution has become more and more serious. Environmental pollutions caused by Chinese firms have been of concern around the world (Liu and Wang, 2019). As the traditional high input, low efficiency, and environmental pollution-causing production method are promoted, their limitations of such policies have been pointed out for a long time. In addition, as the level of personal income increased due to economic growth, Chinese people have became more aware of the seriousness of environmental problems than before (Yang and Sun, 2010; Liu et al., 2017).

In 2012, at the 18th National People's Congress, the Communist Party of China proposed the slogan "Building a Beautiful China" and included the goal of building an ecological civilization in the political report for the first time. In the 19th Representative Meeting in 2017, the policy direction for "green production and green consumption" was announced. Recently, there has been an increase in global interest in corporate social responsibility (CSR). In China, long-term CSR goals have been defined since 2007, with an economic growth model based on sustainable growth adopted by most Chinese firms.

The Chinese government realized that investing in environmental infrastructure, manufacturing environmentally friendly products, and generating renewable energy could be an important factor for sustainable long-term economic growth (Liu et al., 2017; Liu and Wang, 2019). Environmental policies have been implemented, combined with government-controlled environmental management methods. Despite persistently strengthening policies by the Chinese government, environmental pollution problems are not improving (Liu et al., 2017).

Only direct or indirect production expenses are reported and controlled by firms, while environmental costs such as individual health fees due to unhealthy working environment are not reflected in the income statement. It is because environmental costs arise as a kind of bad externality, where social costs, not corporate, are passed on to nearby residents or citizens in the form of medical or non-medical expenses. In this context, the government has an incentive to intervene in corporate activities which might have effects on environments. Environmental policies to eliminate bad externality can be designed in various forms, for instance, emission taxes and subsidies. Frye and Shleifer (1996) find that subsidies increase the firm's profitability. As the external environment worsens, the government subsidies is one of the most effective means to overcome the difficulties of businesses. Both emission taxes and subsidies have the same policy goal of improving the environment. On the other hand, the government can use the environmental tax revenues to subsidize the environment protection industry to reduce emissions (Liu et al., 2017).

Similar to this study, Yang and Sun (2010) assessed the effects on the carbon emission of Chinese firms through environmental subsidies and environmental investment expenditures. Since many existing studies have focused on the effect of government subsidies to help firms financially (Kim et al., 2020), there have been virtually no empirical studies on the effect of environmental subsidies on carbon emissions. This study investigates the short-term and long-term effects on carbon emission in terms of long-lasting effects of financial expenses and subsidy payments, following a similar limited finite lag model in Kim et al. (2020).

Similarly to the panel SEM setup in Kim et al. (2021), regarding earnings management, return and related party transactions to reflect entangled relationships between carbon emission, environmental subsidies, and environmental investments, we applied simultaneous equation panel regression models (SEM: simultaneous equation model) and report following unique empirical results: (1) The government's environmental subsidies for firms increase carbon emissions and (2) environmental investments by firms in China also increase carbon emissions for a long time.

In addition, taking into account the endogenous and causal relationship between firm carbon emission and government environmental subsidies, a panel SEM model with dependent and explanatory variables with finite lags in differences of major factors are used to enhance the reliability of the research results, by eliminating the cumulative effects in the subsequent periods. The differences in the attempts and methodologies of these studies suggest major research results in higher reliability and validity than existing studies.

This study proceeds as follows. First, following the introduction of Chapter Ⅰ, Chapter Ⅱ examines related prior studies, and Chapter Ⅲ defines major hypotheses and research models. Chapter Ⅳ provide the results of empirical analysis, with analyses of the data regarding the discriminant and relevant factors used in the regressions. Finally, in Chapter V, the results of the empirical analyses are summarized, and implications are drawn.

II. Literature Review

1. Environmental Investment and Carbon Emissions

Porter et al. (1995) propose that pollution should be considered as inefficiency in the production process rather than a loss of resources. As a result, any expenditures that improve the overall efficiency of the manufacturing process qualifies as an environment investment. As a result, environmental investments go beyond energy efficiency and renewable energy to cover waste processing and recycling, water sanitation, industrial pollution control, biodiversity preservation, and climate change mitigation and adaptation (Lindenberg, 2014; Krushelnytska, 2018). Dikau and Volz (2019) emphasize the importance of environmental financing in improving the environment and claim that financial institutions should support firms to invest in facilities for carbon reduction. Azhgaliyeva et al. (2019) claim that firms should increase their investments for environmentally responsible growth. Private investments by firms will reduce global carbon emissions and accelerate the transition to a low-carbon economy.

As pollution gets more severe, several countries are working to establish a low-carbon economy (Liu et al., 2017; Liu and Wang, 2019; Henisz et al., 2019). A significant research topic is developing solutions for lowering carbon emissions, with a focus on building sustainable economies using low-carbon energy sources (Hughes et al., 2013; Van Sluisveld et al., 2018; Matthew et al., 2019; Wang et al. 2020). Hongo (2019) also focuses on carbon pricing as a means of supporting green energy development. Furthermore, David and Venkatachalam (2018) highlight the role of public-private partnership investment in ensuring low-carbon infrastructure. Investment in public-private partnerships is more viable in nations with strong institutions and governance, as well as more market experience and investor protection.

2. Environmental Subsidies

Chinese and international studies on firm environmental performance stem from firm social responsibility, which was first proposed by American scholar Clark in 1916 in his paper 'The Changing Basis of Economic Responsibility'. The relationship between environmental investment performance and government subsidy policy has been the subject of study by many scholars. Magat (1979) reports the effect of various policies on a firm's environmental management and said that among various policies, firms can effectively promote environmental management through government subsidies. O'Toole et al. (1999) points out that the social responsibility (CSR) borne by a firm is divided into environmental responsibility, employee responsibility, and partner responsibility, in accordance with differences in stakeholders. The government's environmental subsidy policy, according to Yao (2005), is a strategy that encourages the growth of environmentally friendly firms in the private sector by providing government subsidies and advantages such as tax revenues. The government's eco-friendly policies are beneficial in promoting the development of environmental protection industries such as preferential loans for green industries, increasing the utilization of available resources, and improving the quality of the environment. This means that environmental conservation and economic development can be realized.

Yang and Sun (2010) argues that the government grants environmental subsidies to firms to improve working methods and ecological environment and reduce environmental pollution. Lu et al. (2019) analyze the effects of governmental subsidies on environmental investment and environmental responsibility perception of 247 publicly traded listed firms from 2010 to 2016. It is found that after receiving financial subsidies, the awareness of environmental responsibility increases resulting in more environmental investment. In addition, it is argued that the positive encouraging factors are policy guidance and government supervision.

Tian and Sun (2020) point out that government subsidies have already become an important financing method for firms' green innovation. Wang and Zheng (2020) examine firms listed on the Shanghai and Shenzhen exchanges from 2010 to 2017 and report that those firms have improved environmentally. Fu (2021) reports that in the province where the firm is located, the agricultural subsidy policy can improve the environmental efficiency of fertilizer investment and the environmental performance.

Ⅲ. Hypothesis and Test Models

1. Hypotheses

Previous studies argue that environmental subsidies have a negative effect on the carbon emissions of firms. China also implemented various types of subsidy policies for its economic development (Park et al., 2011). Ran (2009) points out that although environmental subsidies to Chinese heavy industry firms can improve environmental management performance, the level of improvement in performance is unclear. Liu and Wang (2019) find that local government subsidies have no effects on environmental management when continuous environmental monitoring is insufficient in Liaoning Province. The Chinese government's environmental R&D subsidy might encourage firm environmental performance and investment in environmental research (Shang and Zhu, 2018). The following hypotheses are established:

H1 : The government's environmental subsidies have a negative effect on the short-term carbon emissions.
H2 : The government's environmental subsidies have a negative effect on the long-term carbon emissions.

The government's environmental investment subsidy for firms can improve the environmental improvement performance of firms and promote corporate investments in environmental research, emphasizing the importance of the government's role in this process (Shang and Zhu, 2019). The effect of resources available on the role of environment investment is limited. However, there have been a number of case studies that highlight the importance of environmental investments in promoting economic growth and reducing carbon emissions. The importance of supporting environmental initiatives and environmental investments in attaining sustainable development goals is examined by Lu and Deng (2019). The following hypotheses are established:

H3 : Environmental investments of a firm have a positive effect on short-term carbon emissions.
H4 : Environmental investments of a firm have a positive effect on

long-term carbon emissions.

2. Empirical Models

In this study, the natural logarithm of carbon emissions ($\mathrm{Ln}(Carbon)$) is used as a dependent variable for analyses. In relation to the hypotheses, the ratio of environmental subsidies ($EnvirSub\_R$) is used as one of the factors that affect the $\mathrm{Ln}(Carbon)$, calculated in [environmental subsidies (t)/total assets (t-1)]. Then, the environmental investment ratio ($EnvirInvt\_R$) is introduced, measured as [environmental investment (t)/total assets (t-1)]. In addition, the export ratio ($\mathrm{Exp}ort\_R$) is introduced as [Exports (t)/Total assets (t-1)]. Similarly, a manufacturing company dummy ($Manu\_D$) is introduced. In order to consider the characteristics of the firm's financial structure, the tangible ratio ($Tang\_R$) and the debt ratio ($Debt\_R$) are introduced. The total return on assets (ROA) and total assets in natural logarithm ($\mathrm{Ln}(Asset)$) are also introduced as control variables.

The following equation (1) is used to diagnose the effect of environmental subsidies and environmental investments on the short-term carbon emissions of a firm. In order to accurately study the concurrent effects of some critical factors in the same year, current year values are used in the test equation (1) as follows:

$$\begin{aligned}\mathrm{Ln}(Carbon)_{i,t} = \beta_0 &+ \beta_1 EnvirSubR_{i,t} + \beta_2 EnvirInvtR_{i,t} + \beta_3 \mathrm{Exp}ortR_{i,t} \\ &+ \beta_4 Manu\_D_{i,t} + \beta_5 Largest\_SH_{i,t} + \beta_6 Govt\_SH_{i,t} \\ &+ \beta_7 Fgner\_SH_{i,t} + \beta_8 TangR_{i,t} + \beta_9 DebtR_{i,t} + \beta_{10} ROA_{i,t} \\ &+ \beta_{11} \mathrm{Ln}(Asset)_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t}\end{aligned} \tag{1}$$

In order to test the long-term effects of firm environmental subsidies and environmental investment on carbon emissions, we introduce the lagged variables to study delayed effects of some critical factors in the model, where the years of lags are denoted with time subscript $(t-j)$ in test Equations (2) and (3) as follows, following a similar lag model in Kim et al. (2020).

$$\begin{aligned} \mathrm{Ln}(Carbon)_{i,t} = \; & \beta_0 + \beta_1 EnvirSubR_{i,t-j} + \beta_2 EnvirInvtR_{i,t-j} + \beta_3 \mathrm{Exp}ortR_{i,t} \\ & + \beta_4 Manu\_D_{i,t} + \beta_5 Largest\_SH_{i,t} + \beta_6 Govt\_SH_{i,t} \\ & + \beta_7 Fgner\_SH_{i,t} + \beta_8 TangR_{i,t} + \beta_9 DebtR_{i,t} + \beta_{10} ROA_{i,t} \\ & + \beta_{11} \mathrm{Ln}(Asset)_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t} \end{aligned} \tag{2}$$

The model above incorporates the long-term effects of some critical factors, with interactive effects of such factors in the earlier periods to those of the subsequent periods. To avoid such overlapping effects and this for marginal cumulative long-term effects for each period, separately, we introduce a limited finite lag model in Kim et al. (2020).

$$\begin{aligned} \mathrm{Ln}(Carbon)_{i,t} = \; & \beta_0 + \beta_1 EnvirSubR_{i,t} + \sum_1^5 \beta_{1+j}(EnvirSubR_{i,t-i} - EnvirSubR_{i,t}) \\ & + \beta_7 EnvirInvtR_{i,t} + \sum_1^5 \beta_{7+j}(EnvirInvtR_{i,t-j} - \beta_9 EnvirInvtR_{i,t}) \\ & + \beta_{13} \mathrm{Exp}ortR_{i,t} + \beta_{14} Manu\_D_{i,t} + \beta_{15} Largest\_SH_{i,t} + \beta_{16} Govt\_SH_{i,t} \\ & + \beta_{17} Fgner\_SH_{i,t} + \beta_{18} TangR_{i,t} + \beta_{19} DebtR_{i,t} + \beta_{20} ROA_{i,t} \\ & + \beta_{21} \mathrm{Ln}(Asset)_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t} \end{aligned} \tag{3}$$

To test the effects of government environmental subsidies and environmental investment on carbon emissions, a simultaneous equations model (SEM), similarly to the panel SEM setup in Kim et al. (2021), is introduced as follows:

$$\begin{aligned}\mathrm{Ln}(Carbon)_{i,t} = \beta_0 &+ \sum_{0}^{5}\beta_{1+j}EnvirSubR_{i,t-j} + \sum_{0}^{5}\beta_{7+j}EnvirInvtR_{i,t-j} \\ &+ \beta_{13}\mathrm{Exp}ortR_{i,t} + \beta_{14}Manu\_D_{i,t} + \beta_{15}Largest\_SH_{i,t} \\ &+ \beta_{16}Govt\_SH_{i,t} + \beta_{17}Fgner\_SH_{i,t} + \beta_{18}TangR_{i,t} \\ &+ \beta_{19}DebtR_{i,t} + \beta_{20}ROA_{i,t} + \beta_{21}\mathrm{Ln}(Asset)_{i,t} \\ &+ \lambda_t + \mu_i + \epsilon_{i,t}\end{aligned} \tag{4}$$

$$\begin{aligned}EnvirSubR_{i,t} = \beta_0 &+ \sum_{0}^{5}\beta_{1+j}\mathrm{Ln}(Carbon)_{i,t-j} + \sum_{0}^{5}\beta_{7+j}EnvirInvtR_{i,t-j} \\ &+ \beta_{13}\mathrm{Exp}ortR_{i,t} + \beta_{14}Manu\_D_{i,t} + \beta_{15}Largest\_SH_{i,t} \\ &+ \beta_{16}Govt\_SH_{i,t} + \beta_{17}Fgner\_SH_{i,t} + \beta_{18}TangR_{i,t} \\ &+ \beta_{19}DebtR_{i,t} + \beta_{20}ROA_{i,t} + \beta_{21}\mathrm{Ln}(Asset)_{i,t} \\ &+ \lambda_t + \mu_i + \epsilon_{i,t}\end{aligned} \tag{5}$$

$$\begin{aligned}EnvirInvtR_{i,t} = \beta_0 &+ \sum_{0}^{5}\beta_{1+j}\mathrm{Ln}(Carbon)_{i,t-j} + \sum_{0}^{5}\beta_{7+j}EnvirSubR_{i,t-j} \\ &+ \beta_{13}\mathrm{Exp}ortR_{i,t} + \beta_{14}Manu\_D_{i,t} + \beta_{15}Largest\_SH_{i,t} \\ &+ \beta_{16}Govt\_SH_{i,t} + \beta_{17}Fgner\_SH_{i,t} + \beta_{18}TangR_{i,t} \\ &+ \beta_{19}DebtR_{i,t} + \beta_{20}ROA_{i,t} + \beta_{21}\mathrm{Ln}(Asset)_{i,t} \\ &+ \lambda_t + \mu_i + \epsilon_{i,t}\end{aligned} \tag{6}$$

$\mathrm{Ln}(Carbon)$: The carbon emissions in natural logarithm

$EnvirSub\_R$: Environmental subsidy ratio. [Environmental subsidy (t)/total assets (t−1)]

$EnvirInvt\_R$: Environmental investment ratio [Environmental Investment (t)/Total Assets (t−1)]

$\mathrm{Exp}ort\_R$: The exports ratio. [Exports (t)/Total Assets (t−1)]

$Manu\_D$: Manufacturing dummy. 1 if manufacturing industry, 0 otherwise

$Largest\_SH$: Largest investor's shareholding [Number of largest shareholder's shares (t)/Number of total shares (t)]

$Govt\_SH$: Government shareholding
[Number of government shares (t)/Number of total shares issued (t)]

$Fgner\_SH$: Foreign shareholding
[Number of foreign shares (t)/Number of total shares issued (t)]

$Tang\_R$: Tangible asset ratio. [Tangible assets (t)/Total asset (t)]

$Debt\_R$: Debt ratio. [Total liabilities (t)/Total asset (t)]

ROA : Return on Asset. [Net income (t)/Total asset (t−1)]

$\text{Ln}(Asset)$: The total assets in natural logarithm. [Ln(Total Assets, Amount: RMB)]

μ_i : Firm effects

λ_t : Year effects

$\varepsilon_{i,t}$: Error terms for each firm in a specific year

Ⅳ. Data and Regression Analyses

1. Samples and Descriptive Statistics

For this study, listed firms that provided financial information necessary for research for more than two years during an 11-year study period from 2008 to 2018 on the Shenzhen and Shanghai Stock Exchanges in China are selected as sample firms. The RESSET database is used for government subsidies and environmental data, and the CSMAR database information is used for stock prices and accounting-related information. Outliers that cause large fluctuations in research results with very few data or firms without relevant information are excluded from the study.

〈Table 1〉 Distribution of firms by year and global and non-global firms

Year	Total Firms (A)	Global Firms (B)	Non-Global Firms	Proportion (B/A)
2008	1,110	273	837	24.59%
2009	1,215	511	704	42.06%
2010	1,483	688	795	46.39%
2011	1,673	830	843	49.61%
2012	1,782	1,064	718	59.71%
2013	1,827	1,105	722	60.48%
2014	1,894	1,107	787	58.45%
2015	2,005	1,245	760	62.09%
2016	2,146	1,393	753	64.91%
2017	2,339	1,583	756	67.68%
2018	2,345	1,610	735	68.66%
Total	19,819	11,409	8,410	57.57%

Accordingly, 19,819 observations were used on a firm-year basis. The total firms used in the study are classified into global firms and non-global firms every year according to their exports and overseas investments reported in their financial statements. 〈Table 1〉 shows the number of firms in the two groups and their proportions by year.

In 〈Table 2〉, the results of basic statistical analysis on the characteristic variables of the sample firms are presented in this section. The distribution will be explained using the mean, median, and standard deviation, excluding the minimum and maximum values for each variable. First, the observed average of the carbon emission in natural log ($\mathrm{Ln}(Carbon)$), the dependent variable used in this study, is about 0.277, and its standard deviation is about 1.778.

〈Table 2〉 Summary statistics of variables

Variable	Observations	Mean	Median	Std. Dev.	Min	Max
$\mathrm{Ln}(Carbon)$	19,819	0.277	0.000	1.778	0.000	24.532
$EnvirSub\_R$	19,819	0.001	0.001	0.000	0.000	0.025
$EnvirInvt\_R$	19,819	0.001	0.000	0.006	0.000	0.380
$\mathrm{Exp}ort\_R$	19,819	0.084	0.001	0.178	0.000	1.944
$Manu\_D$	19,819	0.047	0.000	0.212	0.000	1.000
$Largest\_SH$	19,819	35.015	32.880	15.435	0.290	99.000
$Govt\_SH$	19,819	0.070	0.000	0.171	0.000	1.000
$Fgner\_SH$	19,819	0.019	0.000	0.088	0.000	0.990
$Tang\_R$	19,819	0.926	0.958	0.099	0.105	1.000
$Debt\_R$	19,819	0.447	0.444	0.217	0.001	0.989
ROA	19,819	0.106	0.036	4.609	−0.350	1.950
$\mathrm{Ln}(Asset)$	19,819	22.145	21.917	1.527	14.947	30.963

Among explanatory variables, the averages of environmental subsidy ratio ($EnvirSub\_R$) and environmental investment ratio ($EnvirInvt\_R$) are about 0.1%, respectively. In addition, the ratio of exports to total assets ($\mathrm{Exp}ort\_R$) is on average 8.4%, the median is 0.1%, with the standard deviation of 17.8%. The mean of the manufacturing firm dummy ($Manu\_D$) is 0.047, which means that 4.7% of the sample companies are manufacturing firms.

Among the control variables, the average shareholding of the largest shareholder ($Largest\_SH$) is about 35.02%; the average government ownership ($Govt\_SH$) is about 7.0%; the average foreign ownership ($Fgner\_SH$) is about 1.9%; and the average tangible asset ratio ($Tang\_R$) is 92.6%. The average return on assets (ROA) is 10.6%, while the average debt ratio ($Debt\_R$) is 44.7%.

2. Correlation Analyses

The correlations between the variables used in this study are measured with the Pearson correlation coefficients, and are shown in ⟨Table 3⟩. In multivariate analyses, the validity of correlation analyses might be limited, because the existence of multicollinearity between variables might distort the results of regression results. Therefore, individual correlations are of little significance.

⟨Table 3⟩ Pearson pair-wise correlation matrix

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
$\text{Ln}(Carbon)$	1.000										
$EnvirSub\_R$	0.003	1.000									
$EnvirInvt\_R$	0.126***	0.005	1.000								
Export_R	0.012*	-0.007	0.018**	1.000							
$Manu\_D$	-0.020***	-0.008	-0.011	-0.051***	1.000						
$Largest\_SH$	0.053***	-0.006	0.011	-0.002	0.057***	1.000					
$Govt\_SH$	0.015**	0.001	-0.009	-0.063***	-0.038***	0.255***	1.000				
$Fgner\_SH$	-0.010	-0.008	-0.016**	0.060***	0.165***	0.123***	-0.050***	1.000			
$Tang\_R$	0.012*	0.006	-0.002	0.003	0.084***	0.116***	0.054***	0.040***	1.000		
$Debt\_R$	0.070***	0.016**	0.011	-0.007	-0.204***	0.035***	0.158***	-0.116***	0.114***	1.000	
ROA	-0.001	-0.001	-0.001	-0.004	-0.004	0.023***	-0.001	-0.002	0.008	0.008	1.000
$\text{Ln}(Asset)$	0.194***	-0.010	0.059***	-0.038***	-0.148***	0.172***	0.205***	-0.076***	0.021***	0.492***	0.000

Note: 1. (1) is $\text{Ln}(Carbon)$. (2) is $EnvirSub\_R$. And, so on

2. ***, ** and * are statistically significant at the level of 1%, 5% and 10%, respectively

The correlation between carbon emissions ($\text{Ln}(Carbon)$) and the explanatory variable the ratio of environmental subsidies ($EnvirSub\_R$), does not show any statistical significance. The environmental investment ratio ($EnvirInvt\_R$) and the largest shareholding ($Largest\_SH$) show a significant positive correlation at the level of 1% each with carbon emissions.

The manufacturing firm dummy ($Manu\_D$) shows a significant negative correlation with carbon emissions ($\text{Ln}(Carbon)$) at the 1% level. The government shareholding ($Govt\_SH$) has a significant positive correlation at the 5% level with respect to carbon emissions ($\text{Ln}(Carbon)$).

The correlations between carbon emissions and the export ratio to total assets ($\text{Exp}ort\_R$) and the ratio of tangible assets ($Tang\_R$) are statistically significant at the 10% level. The correlations between carbon emissions ($\text{Ln}(Carbon)$) and debt ratio ($Debt\_R$) and company size ($\text{Ln}(Asset)$) are both significant at the 1% level. In addition, it can be confirmed that there is a significant level of correlation between other independent variables.

Such high correlations between independent variables suggest the existence of multicollinearity. Multicollinearity is tested using variance inflation factor (VIF) to avoid their distorting effects on the size and statistical significance of the coefficient values and standard errors in regression analyses.

3. Mean Difference Tests

〈Table 4〉 shows the t-test results assuming unequal variance and obtaining the average values of key variables between global firms and non-global firms. For the dependent variable, carbon emission

(Ln(*Carbon*)), the difference in means is statistically significant at the 1% level, 5.8% points higher for the non-global firm group than for the global firm group.

Regarding one of the explanatory variables, the ratio of environmental subsidies ($EnvirSub\_R$), is 0.01% point higher in non-global firm groups, significant at the 1% level. The environmental investment ratio ($EnvirInvt\_R$) is 0.1% point higher in global firm groups, which is significant at the 5% level. The ratio of exports to total assets ($Export\_R$) shows a difference of 3.9% points between the two groups.

⟨Table 4⟩ Group mean tests between global firms and non-global firms

Variables	Global (A)	Non-Global Firms (B)	Difference (A-B)		t-statistic
Ln(*Carbon*)	0.250	0.308	-0.058	**	-2.30
$EnvirSub\_R$	0.000	0.001	-0.001	***	-3.49
$EnvirInvt\_R$	0.001	0.000	0.001	**	1.97
$Export\_R$	0.103	0.064	0.039	***	15.51
$Manu\_D$	0.015	0.083	-0.068	***	-22.72
$Largest\_SH$	35.894	34.029	1.865	***	8.51
$Govt\_SH$	0.068	0.073	-0.006	**	-2.30
$Fgner\_SH$	0.020	0.019	0.001		0.79
$Tang\_R$	0.917	0.937	-0.019	***	-13.56
$Debt\_R$	0.395	0.506	-0.111	***	-37.22
ROA	0.205	-0.006	0.211	***	3.22
Ln(*Asset*)	22.132	22.160	-0.029	*	-1.32

Note: ***, ** and * are statistically significant at the level of 1%, 5% and 10% (one-side tests), respectively

Looking at the control variables, the difference between the global and non-global firm groups is about 1.87% point and -0.6% point, respectively, for the largest shareholding ($Largest\_SH$) and the government shareholding ($Govt\_SH$). However, the average values for foreign shareholding ($Fgner\_SH$), tangible asset ratio ($Tang\_R$), debt ratio ($Debt\_R$), and return on assets (ROA) are 1.9%, 9.37%, 50.6%, and -0.6% points, respectively, higher in non-global firm groups, and all significant at the 1% level.

4. Regression Analyses

This study selects a better fit model between random effects mode (REM) and fixed effects model (FEM) and for panel data between the panel models and ordinary least squares (OLS). The panel models with year effects are selected through Lagrange multiplier tests (LM tests) over ordinary least-squares regression models with p-values smaller than 1% of significance. The fixed effects panel models, reflecting the idiosyncratic characteristics of a firm, are selected as better fitted than the random effects panel models through Hausman tests. Thus, the constant terms from FEM regressions are different across firms, reflecting firm-specific effects.

1) The Short-Term Effects of Environmental Subsidies and Investments on Carbon Emissions

In this section, the effects of the environmental subsidies ($EnvirSub\_R$) and environmental investments ($EnvirInvt\_R$) on short-term carbon emissions ($\mathrm{Ln}(Carbon)$) are diagnosed in relation to the tests from H1 to H3, and the results of the fixed-effects multi-variate panel analyses are shown in ⟨Table 5⟩.

〈Table 5〉 The short-term effects of environmental subsidies and investments on carbon emissions

Variables Ln($Carbon$)		(1-1) All Firms		(1-2) Global Firms		(1-3) Non-Global Firms	
		Coefficient	t stat	Coefficient	t stat	Coefficient	t stat
$EnvirSub\_R$		-13.973	-0.48	-8.138	-0.20	-13.720	-0.35
$EnvirInvt\_R$		22.601 ***	9.93	20.982 ***	7.33	25.623 ***	6.52
Export_R		-0.168 *	-1.60	-0.159	-1.10		
$Manu\_D$		-0.083 *	-1.33	-0.062	-0.75	-0.014	-0.13
$Largest\_SH$		-0.005 ***	-2.69	-0.007 **	-2.28	-0.002	-0.81
$Govt\_SH$		-0.570 ***	-6.03	-0.428 ***	-2.61	-0.416 ***	-3.77
$Fgner\_SH$		-0.135	-0.63	0.172	0.56	-0.633 **	-1.79
$Tang\_R$		0.476 ***	2.56	0.782 ***	2.58	0.143	0.58
$Debt\_R$		-0.284 ***	-2.52	-0.451 ***	-2.44	-0.133	-0.92
ROA		0.000	0.15	-0.031	-0.26	0.000	0.12
Ln($Asset$)		0.197 ***	10.24	0.316 ***	8.43	0.117 ***	5.10
Constant		-4.177 ***	-8.35	-6.881 ***	-7.14	-2.383 ***	-4.03
Observations(Firms)		19,819 (2,502)		11,409 (1,881)		8,410 (1,551)	
R^2	Within	0.017		0.017		0.014	
	Between	0.076		0.089		0.053	
	Overall	0.041		0.051		0.042	
F test		26.60 ***		15.22 ***		9.89 ***	
LM test		2900.64 ***		1857.12 ***		332.71 ***	
Hausman test		125.30 ***		56.05 ***		96.31 ***	
VIF test		1.00-1.40		1.00-1.51		1.00-1.36	

Note: ***, ** and * are statistically significant at the level of 1%, 5% and 10% (one-side tests), respectively

Global firms and non-global firms are classified and analyzed according to whether they have global business with exports and/or outward foreign direct investments (FDIs). The F test statistic is also significant at the 1% level, and the variance inflation factor (VIF) tests also show statistics at a low level of 1.00-1.51. With the maximum value only 1.51, which is significantly lower than the general rejection threshold of 10, we can ignore multicollinearity problems between independent variables.

According to the results of the fixed effects model, environmental investments ($EnvirInvt\_R$), an explanatory variable, have a significant positive effect at the 1% level in all firms and global firms on carbon emissions ($\text{Ln}(Carbon)$). Environmental subsidies ($EnvirSub\_R$) have a negative effect on carbon emissions ($\text{Ln}(Carbon)$), although it is not significant level even at 10% level. Exports ($\text{Exp}ort\_R$) have a negative effect on carbon emissions ($\text{Ln}(Carbon)$), significant at the 10% level.

〈Table 6〉 The cumulative effects of environmental subsidies and investments on carbon emissions

Variables	Same Year(t)		1 Year Later(t-1)		2 Year Later(t-2)		3 Year Later(t-3)		4 Year Later(t-4)		5 Year Later(t-5)	
$\text{Ln}(Carbon)$	Coefficient	t stat	Coefficient	t stat	Coefficient	t stat	Coefficient	t stat	Coefficient	t stat	Coefficient	t stat
$EnvirSub\_R$	-13.973	-0.48	72.730***	4.07	37.020**	1.70	45.912*	1.31	-9.976	-0.27	84.377**	2.23
$EnvirInvt\_R$	22.601***	9.93	14.736***	6.32	14.596***	5.76	9.789***	2.69	7.459**	1.90	5.458*	1.31
$\text{Exp}ort\_R$	-0.168*	-1.60	-0.187**	-1.70	-0.190**	-1.72	-0.189**	-1.71	-0.128	-1.12	-0.126	-1.08
$Manu\_D$	-0.083*	-1.33	-0.100*	-1.44	-0.112*	-1.57	-0.115*	-1.61	-0.091	-1.22	-0.100*	-1.29
$Largest\_SH$	-0.005***	-2.69	-0.005***	-2.71	-0.005***	-2.79	-0.006***	-2.89	-0.006***	-3.17	-0.007***	-3.43
$Govt\_SH$	-0.570***	-6.03	-0.582***	-6.12	-0.585***	-6.12	-0.576***	-6.01	-0.529***	-5.43	-0.461***	-4.61
$Fgner\_SH$	-0.135	-0.63	-0.151	-0.69	-0.167	-0.76	-0.174	-0.79	-0.087	-0.39	-0.038	-0.16
$Tang\_R$	0.476***	2.56	0.489***	2.61	0.508***	2.69	0.518***	2.74	0.496***	2.60	0.515***	2.66
$Debt\_R$	-0.284***	-2.52	-0.298***	-2.63	-0.315***	-2.76	-0.323***	-2.83	-0.317***	-2.75	-0.308***	-2.63
ROA	0.000	0.15	0.000	0.14	0.000	0.14	0.000	0.14	0.000	0.15	0.000	0.15
$\text{Ln}(Asset)$	0.197***	10.24	0.200***	10.34	0.201***	10.32	0.202***	10.39	0.200***	10.15	0.202***	9.98
Constant	-4.177***	-8.35	-4.245***	-8.43	-4.260***	-8.42	-4.291***	-8.47	-4.212***	-8.21	-4.255***	-8.12
Obs. (Firms)	19,819 (2,502)		19,385 (2,448)		19,000 (2,245)		18,819 (2,088)		18,585 (2,066)		18.194 (2,063)	
R^2 Within	0.017		0.015		0.014		0.018		0.011		0.010	
R^2 Between	0.076		0.061		0.078		0.080		0.081		0.083	
R^2 Overall	0.041		0.037		0.035		0.032		0.031		0.030	
F test	26.60 ***		22.99 ***		20.75 ***		18.06 ***		15.87 ***		14.94 ***	
LM test	2,900.64 ***		2,945.62 ***		2,976.11 ***		2,946.64 ***		3,048.70 ***		3,138.06 ***	
Hausman test	125.30 ***		107.58 ***		159.07 ***		136.75 ***		88.49 ***		69.43 ***	
VIF test	1.00-1.40		1.00-1.39		1.00-1.38		1.00-1.38		1.00-1.37		1.00-1.37	

Notes: 1. Results of FEM (fixed effects models), best fit ones based on model selection tests such as Breusch and Pagan Lagrange multiplier tests (LM tests) for time effects and Hausman tests for firm effects, are reported

2. ***, ** and * are statistically significant at the level of 1%, 5% and 10% (one-side tests), respectively

2) The Cumulative Effects of Environmental Subsidies and Investments on Carbon Emissions

For the cumulative long-term effects of environmental subsidies (*EnvirSub_R*) and environmental investments (*EnvirInvt_R*) regarding H2 through H4 in the earlier section, the model with t for the current year and models with lags with t-1, t-2, t-3, t-4, and t-5 for long-term carbon emissions (Ln(*Carbon*)) are tested, using empirical test model (2). The analysis results are shown in 〈Table 6〉. The F test statistics are significant at the 1% level. In addition, the variance inflation factor (VIF) test statistics are also low enough with the range of 1.00-1.40, significantly lower than the general rejection threshold of 10.

According to the results of the fixed-effects panel model analysis, environmental subsidies (*EnvirSub_R*) introduced as an explanatory variable show a significant positive effect on the dependent variable, carbon emissions (Ln(*Carbon*)), although the results are not significant in the test models with the lag of four years (t-4). Environmental investments (*EnvirInvt_R*) have a significant positive effect on carbon emissions (Ln(*Carbon*)) in all samples. We can conclude that both the government's environmental subsidies and corporate environmental investments increase carbon emissions and such effects persist for some years.

3) The Marginal Effects of Environmental Subsidies and Investments on Carbon Emissions

In this section, we test H1 through H4 with respect to the marginal long-term effects of environmental subsidies (*EnvirSub_R*) and environmental investments (*EnvirInvt_R*) on carbon emissions. The models are tested with finite time lags of five years to diagnose their long-term effects on future carbon emissions ($\mathrm{Ln}(Carbon(t-j))$), using empirical test model (3). The test models are to test the accumulative marginal effect for each period after reflecting all the effects from the year of the government's environmental subsidization and corporate environmental investments. Theoretically, the results from Model (3) are considered better estimators than those from Model (2), since the former model estimates the marginal effects up to the year, after eliminating the multi-collinear effects among the lagged factors during the periods.

According to the results of the fixed effects panel model analyses, environmental subsidies ($EnvirSub\_R$) have a significant positive effect on carbon emissions ($\mathrm{Ln}(Carbon)$), during the same year and in one year. Environmental investments ($EnvirInvt\_R$) show a significant positive effect on long-term carbon emissions ($\mathrm{Ln}(Carbon(t-j))$) at the 1% or 5% level from 1 year to 5 years. Exports of firms ($\mathrm{Exp}ort\_R$) and a manufacturing company dummy ($Manu\_D$) do not show any statistically significant effects on corporate carbon emissions.

In this section, we have verified that both the government's environmental subsidies and corporate environmental investments increase carbon emissions and such effects persist for some years. Compared with the results in the previous section, our results in this section are consistent, which is also true with those from the panel SEMs in the following section, and thus we consider the test results in this section as robust ones.

〈Table 7〉 The marginal effects of environmental subsidies and investments on carbon emissions

Variables Ln($Carbon$)	(1-1) All Firms		(1-2) Global Firms		(1-3) Non-Global Firms	
	Coefficient	t stat	Coefficient	t stat	Coefficient	t stat
$EnvirSub\_R$	287.496 ***	3.16	281.425 **	1.97	278.233 **	2.05
$EnvirSub\_R1$	72.262 ***	3.99	76.243 **	1.72	74.921 ***	4.61
$EnvirSub\_R2$	41.380 **	1.89	55.377 **	2.07	-26.454	-0.57
$EnvirSub\_R3$	52.558 *	1.47	22.035	0.44	118.713 ***	2.39
$EnvirSub\_R4$	13.261	0.35	19.978	0.39	-23.566	-0.37
$EnvirSub\_R5$	97.815 ***	2.54	92.863 **	1.83	136.380 **	2.08
$EnvirInvt\_R$	50.305 ***	6.55	49.787 ***	4.73	90.411 ***	7.35
$EnvirInvt\_R1$	14.397 ***	6.04	14.821 ***	4.84	11.383 ***	2.89
$EnvirInvt\_R2$	13.376 ***	5.21	11.024 ***	3.33	16.913 ***	4.12
$EnvirInvt\_R3$	5.322 *	1.44	1.722	0.32	15.243 ***	3.20
$EnvirInvt\_R4$	7.818 **	1.97	9.625 **	1.71	10.886 **	2.12
$EnvirInvt\_R5$	9.400 **	2.21	12.604 **	2.04	9.351 **	1.74
$Export\_R$	-0.123	-1.06	-0.111	-0.68		
$Manu\_D$	-0.088	-1.14	-0.070	-0.67	-0.008	-0.06
$Largest\_SH$	-0.006 ***	-3.06	-0.009 ***	-2.55	-0.002	-0.64
$Govt\_SH$	-0.438 ***	-4.38	-0.431 ***	-2.49	-0.236 **	-2.07
$Fgner\_SH$	-0.046	-0.19	0.293	0.86	-0.681 **	-1.80
$Tang\_R$	0.504 ***	2.60	0.858 ***	2.70	0.164	0.65
$Debt\_R$	-0.264 **	-2.25	-0.514 ***	-2.65	-0.089	-0.61
ROA	0.000	0.15	-0.029	-0.24	0.000	0.12
Ln($Asset$)	0.191 ***	9.43	0.323 ***	8.11	0.101 ***	4.30
Constant	-4.064 ***	-7.77	-7.063 ***	-6.91	-2.120 ***	-3.51
Obs. (Firms)	18,192 (2,062)		10,392 (1,543)		7,800 (1,345)	
R^2 Within	0.016		0.018		0.025	
R^2 Between	0.113		0.106		0.137	
R^2 Overall	0.044		0.051		0.065	
F test	12.54 ***		7.51 ***		8.13 ***	
LM test	2,935.88 ***		1,807.67 ***		329.43 ***	
Hausman test	95.87 ***		19.21 ***		442.91 ***	
VIF test	1.00-1.38		1.00-1.50		1.00-1.36	

Notes: 1. Results of FEM (fixed effects models), best fit ones based on model selection tests such as Breusch and Pagan Lagrange multiplier tests (LM tests) for time effects and Hausman tests for firm effects, are reported
2. ***, ** and * are statistically significant at the level of 1%, 5% and 10% (one-side tests), respectively

4) The Simultaneous Effects of Carbon Emissions, Environmental Subsidies and Investments

In this section, based on the separate studies in the previous sections, simultaneous equations models (SEMs) are used to consider the endogenous interrelationships between major dependent variables, which are one of the most important issues in recent studies. The results of empirical analyses of simultaneous effects on carbon emissions are presented in 〈Table 8〉.

〈Table 8〉 Simultaneous effects among carbon emissions, environmental subsidies and investments

Variables	(1) Carbon Emission $\mathrm{Ln}(Carbon)$			(2) Environmental Subsidy ($EnvirSub\_R$)			(3) Environmental Investment ($EnvirInvt\_R$)		
	Coefficient		Z stat	Coefficient		Z stat	Coefficient		Z stat
$\mathrm{Ln}(Carbon)$				0.003	***	30.72	-2.078	***	-12.56
$\mathrm{Ln}(Carbon)\_1$				0.001	***	10.04	-0.097	*	-1.32
$\mathrm{Ln}(Carbon)\_2$				0.001	***	7.21	0.006		0.07
$\mathrm{Ln}(Carbon)\_3$				0.001	***	11.86	-0.183	*	-1.64
$\mathrm{Ln}(Carbon)\_4$				0.001	***	24.88	-0.672	***	-5.10
$\mathrm{Ln}(Carbon)\_5$				0.001	***	29.04	-1.283	***	-8.53
$EnvirSub\_R$	424.950						-68100.770		
$EnvirSub\_R1$	46.986	***	2.36				-3765.840	***	-27.99
$EnvirSub\_R2$	30.269		1.26				-4634.123	***	-28.57
$EnvirSub\_R3$	81.962	**	2.26				-13672.760	***	-55.86
$EnvirSub\_R4$	69.030	**	1.87				-16955.580	***	-67.98
$EnvirSub\_R5$	147.275	***	3.93				-17890.510	***	-70.77
$EnvirInvt\_R$	415.860			0.092					
$EnvirInvt\_R1$	75.243	***	29.09	0.010	***	4.29			
$EnvirInvt\_R2$	74.191	***	25.89	0.012	***	4.64			
$EnvirInvt\_R3$	83.331	***	20.23	0.018	***	4.79			
$EnvirInvt\_R4$	90.684	***	22.94	0.026	***	7.03			

EnvirInvt_R5	92.418	***	22.34	0.025	***	6.36			
Ex*port_R*	0.121	*	1.48	0.000	**	-2.05	-0.159		-0.29
Manu_D	0.004		0.04	0.000		0.70	-0.912	*	-1.57
Largest_SH	0.003	***	3.04	0.000	***	-4.83	-0.004		-0.67
Govt_SH	-0.196	**	-2.20	0.000	***	5.26	-1.084	**	-1.80
Fgner_SH	0.077		0.42	0.000	*	1.37	-1.077		-0.86
Tang_R	0.396	***	2.78	0.000		0.22	-5.870	***	-6.10
Debt_R	-0.233	***	-2.95	0.000	***	4.94	1.153	**	2.15
ROA	-0.423	***	-2.58	0.000	***	3.26	-2.368	**	-2.14
Ln(*Asset*)	0.204	***	18.38	0.000	***	-17.51	0.050		0.65
Constant	-4.702	***	-17.77	0.004	***	15.88	5.802	***	3.18
Obs (Firms)	18,114 (2,061)								
Rho	184,455.89***								

Notes: 1. Results of FEM (fixed effects models), best fit ones based on model selection tests such as Breusch and Pagan Lagrange multiplier tests (LM tests) for time effects and Hausman tests for firm effects, are reported
2. ***, ** and * are statistically significant at the level of 1%, 5% and 10% (one-side tests), respectively

The environmental subsidies (*EnvirSub_R*) have a statistically significant positive effect on carbon emissions (Ln(*Carbon*)), continuously from the current year to 5 years later. The environmental investments (*EnvirInvt_R*) have a significant positive effect on carbon emissions (Ln(*Carbon*)) at the 1% level from, the current year to 5 years later.

Carbon emissions (Ln(*Carbon*)) have a significant positive effect on environmental investments (*EnvirInvt_R*) at the 1% level, from the current year to 5 years. Environmental investments (*EnvirInvt_R*) also have a significant positive effect on environmental investments (*EnvirInvt_R*) at the 1% level during the same year and years later. However, environmental subsidies (*EnvirSub_R*) have a significant negative effect on environmental investments(*EnvirInvt_R*) at the 1% level during the same year and for the period of subsequent three years.

Ⅴ. Conclusion

This study investigates the short-term and long-term effects of environmental investments and environmental subsidies on carbon emissions by Chinese firms. The results of this study can be served as a basis for estimating the long-term sustainability of the Chinese government's subsidies, especially environmental subsidies, which have been hot issues in the global village and in international trade market. A merged data from RESSET database and financial data from CSMAR database including accounting, financial market, subsidization of the Chinese governments, local and central, and the firm-level investment activities of 19,819 observations (year-firms), for those firms listed on Shanghai Stock and Shenzhen Stock Exchanges for 11 years from 2008 to 2018 are used.

In order to closely diagnose the sustainable effects in the long-run of environmental subsidies and environmental investments and control the interactive endogeneity effect, the mutual relationships between carbon emissions, environmental subsidies, and environmental investments are also integrated and simultaneously organized by a simultaneous equation model (SEM: simultaneous equation model) with lags to enhance the reliability of the research results. Since the results of the simultaneous equation models (SEMs), which control mutual endogeneity that exists among main variables, are logically valid and their mutual effects show statistical significance for a long time after corporate activities, we consider those from the panel SEM with lags as robust ones, given conflicts in test results. Our conclusions are as follows.

First, it is found that the government's environmental subsidies increase carbon emissions and the effects persist for some years.

Second, environmental investments by firms in China increase carbon emissions and the effects persist for some years.

Third, exports, largest shareholding, government shareholding, and firm size have a significant effect on carbon emissions. However, foreign shareholding is not statistically significant in all analyses.

The results mean that most Chinese firms, if not all, have increased their carbon emissions, even after receiving the government's environmental subsidies in the short- and long-term. Along with differentiated test methodologies applied differently from those of prior subsidy studies, and without any prior studies in this topic, our findings are unique and intriguing and provide insights to firms, the governments, local and central, and the public in the sense of corporate social responsibility (CSR), especially regarding the environment management of firms and the society, as a whole.

Nevertheless, this study has the following limitations. First of all, it is not possible to diagnose the effects of the subsidy amount by various types of environmental subsidies, which have recently become a hot issue. Second, it is not possible to diagnose the effect of corporate environmental investments or the effects of government subsidies for different goals by using firm-level yearly data. Third, long-term effects must be diagnosed by applying time-series analysis models, together with the application of the simultaneous equation models to reflect endogeneity and simultaneity. Finally, this study does not introduce significant regional factors, which might differ in accordance with the different level of globalization and economic growth.

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