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Abstract: This research investigates the influence of green subsidies on the green innovation of environmental service firms using multiple linear regression. It covers the years 2014 through 2020 for environmental service firms listed on the Shanghai and Shenzhen Stock Exchanges. The results demonstrate that: 1) green subsidies can encourage the green innovation of environmental service firms, and research and development (R&D) investment mediates this effect; 2) the intensity of environmental regulation moderates the relationship between R&D investment and green innovation in a negative manner; 3) in less developed regions, green subsidies are more effective for promoting green innovation. These findings may assist the government in establishing green subsidy programs and developing sensible environmental policies to promote the green development of environmental service firms.

Keywords: green subsidies; green innovation; environmental regulation; environmental service; China.

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1 Introduction

One of the Chinese Central Government's five development concepts, green development, aims to achieve the harmonious development of man and nature. Owing to global warming, numerous ecological catastrophes and environmental degradation issues have developed in recent years, and 'green technology' has emerged in response (Zhang et al., 2022a; Liao and Li, 2022). The green patent system is, without a doubt, an ideal system that embodies the fundamental principle of 'human and environmental harmony' (Losacker, 2022). In addition, the environmental protection law, which came into effect in 2015, has been referred to as the 'strictest environmental protection law in history' because it further clarifies the government's responsibility for supervision and management of environmental protection and enhances the system of ecological protection red lines and total pollutant control (Liu and Liu, 2022). The new environmental protection law establishes a 'four-in-one' structure of oversight and control by the public, the National People's Congress, the executive branch, and the judiciary (Zhu et al., 2022). In the context of increasingly stringent environmental regulations and fierce market competition, the question of how to modify company strategy and impact firms' green innovation is a compelling one worthy of investigation.

China provides a priority examination system for patents (Tong et al., 2018) that concern green technology, primarily energy-saving and environmental protection, and other industries vital to the nation's economic development. Green technology innovation entails not just accidental invention and development, but also the transformation of technical innovation activities into expected firm behaviour (Kuang et al., 2022). However, the legal provisions of China's quick review system for green patents are not yet perfect; therefore, it is essential to improve the environmental protection law and the p atent law to mitigate the potential negative effects of environmental regulations on the business performance of firms.

China has recently introduced a set of standards to support the green transformation of firms to achieve sustainable development (Tian et al., 2022). Considering the struggle between 'development' and 'ecology', green subsidies are eco-friendly and can help improve resource, environmental, and economic sustainability. The actions associated with green innovation are inherently high risk, lengthy, and capital-intensive. Government must participate as a non-market participant and use subsidies and other tools to foster green innovation (Wang and Cao, 2022). As a result, researchers have focused on determining the effectiveness of government subsidies in encouraging firms toward green innovation.

Most of the research on firms' green innovation in the domestic and international markets focuses on its relationship to environmental regulation (Zhang et al., 2020; Yang et al., 2021). In the academic community, there are two primary points of view: 'Porter's hypothesis', which claims that environmental regulation promotes technological innovation in firms, and 'the other position' (Porter and van der Linde, 1995). This idea is supported by the findings of Chavez et al. (2021) and Matsumoto et al. (2020). According to Ramanathan et al. (2017), there is a positive U-shaped relationship, with the former having a 'threshold' effect on the latter. Zhang et al. (2022b) examined the effects of credit mismatch on regional green technology innovation in the context of environmental regulation inequalities. Research on green subsidies focuses primarily on their relationship with green investment, and most of the research indicates that green subsidies can encourage green investment by firms (Zheng et al., 2021; Yuan et al., 2021). Bronzini and Piselli (2016), for instance, revealed that green research and development (R&D) subsidies could boost the number of green patent filings by firms. Hattori (2017) discovered that green subsidies could solve the issue of green technology spillover that results in a decline in green R&D investment by firms. Xie et al. (2016) discovered empirically that green subsidies encourage business innovation in green processes by directly lowering company costs.

This paper's contribution is to quantify the influence of green subsidies on the green innovation of companies by collecting data on green subsidies from a sample of Chinese publicly traded environmental service firms. In addition, this study examines the effect of environmental regulation on the relationship between green subsidies and green innovation. In a dual-carbon setting, we seek to clarify the significance of acceptable green subsidies and environmental rules for energy conservation and environmental protection. Then, we provide pertinent recommendations for the future green development of environmental service firms from the perspectives of improving regulations and government policies. In addition to the introduction, Sections 2, 3, 4, 5 and 6 of this work contain the hypotheses, research design, analysis of results, discussion, and conclusion, respectively.

2 Research hypotheses

2.1 Green subsidies and green innovation of environmental service firms

Environmental protection and technological innovation are fundamental forces influencing the development dynamics of firms (Wang et al., 2017). These are crucial for economic growth, advances in environmental quality, and national security. However, environmental technology innovation requires a lengthy time frame, substantial capital expenditure, and robust public interest and fundamentals (Ren et al., 2021). This necessitates that the government offer corresponding financial support to guide and stimulate environmental R&D and scientific and technological innovation. Therefore, it is vital to develop special funds for green R&D so that the government may apply green subsidies.

The relationship between subsidies and innovation has been a common area of study. In addition, two conflicting mechanisms for the impact of government subsidies on firms' innovative output are also being considered. Some experts feel that government subsidies could encourage corporate innovation by effectively minimising the financial risk associated with technical advancement (Liu et al., 2020). This can encourage firms to actively participate in R&D activities, hence increasing the output of technological innovation. Bai et al. (2019) have confirmed that government financial support affects the number of patents obtained by firms. In addition, several researchers have discovered that government R&D subsidies encourage innovation output substantially more than indirect subsidies, such as tax incentives (Wu et al., 2022). The long-term link between government subsidies and firm patent output resembles an inverted U (Xia et al., 2022). Only when government subsidies surpass the interval range does the patent output capacity of firms have a suppressive effect.

As opposed to conventional innovation, green innovation focuses on lowering environmental impact and achieving ecological sustainability as its primary objective while pursuing product and process innovation. The government provides environmental service firms with substantial green subsidies to improve the ecology and resolve environmental issues (Du et al., 2019). These incentives are intended to alleviate the financial restrictions firms experience during the process of green innovation. After getting green subsidies, firms obtain many innovations rapidly, signalling to society their high innovation ability and gaining short-term economic benefits.

Consequently, we suggest Hypothesis 1:

H1 Green subsidies can promote green innovation among environmental service firms.

2.2 R&D investment of environmental service firms mediates the effect of green subsidies on firms' green innovation

In addition to the significant initial cost for R&D, innovation is a long-term investment whose output is frequently unclear, making it difficult to determine the short-term return on investment (Takahashi, 1997). Government subsidies can give financial assistance for innovation initiatives by raising a firm's overall profit. Subsidies focused especially on the creation of new products and research innovation could immediately reduce the cost and risk of the creative progress of new products and increase the return on the innovative progress of the new product. This encourages firms to participate in new

endeavours (Guisado-González et al., 2021). Because of the considerable risk inherent in R&D, firms must have a high risk tolerance to encourage and promote innovation (Boeing et al., 2022). Government subsidies boost R&D investment and increase innovation output by lessening the financial burden on firms (Gao et al., 2021).

Government investments and subsidies in the field of green innovation will improve the public sector's R&D innovation performance. Knowledge spillover enables firms to acquire the most recent information in linked fields; this reduces R&D-associated risks and helps firms to invest more money in R&D (Zhang et al., 2022a). In addition, firms that obtain green subsidies review innovation ideas that would otherwise be high risk and high cost, increasing the volume and scope of new projects. Thus, firms are more encouraged to spend on R&D and more inclined to invest in green innovation due to the incentive of green subsidies.

Consequently, we formulate Hypothesis 2 as follows:

H2 R&D investment of environmental service firms mediates the effect of green subsidies on green innovation.

2.3 Environmental regulation has a moderating effect between green subsidies and green innovation

Environmental regulation refers to the regulation of numerous activities that pollute the public environment; it aims to safeguard the environment and is an essential component of social regulation (Liu et al., 2018). Although environmental regulation has been demonstrated to be a useful instrument for resolving environmental issues, research on its impact on green technology innovation is more contentious (Atilaşici and Acar, 2018). The most recent research focuses on a single variable, such as government subsidies or the stringency of environmental regulations, while ignoring their relationship (Cui et al., 2022). According to the 'Porter hypothesis', the strengthening of environmental rules might encourage R&D input, thereby boosting the efficiency of manufacturing processes and the quality of products, thereby indirectly affecting the business and inventive performance of the organisation. In research examining the relationship between environmental regulation and R&D innovation in the USA, pollution control had a significant influence on the number of green patents, with a 1–2-year lag (Xu et al., 2022b). According to Zhao et al. (2022), environmental regulation had a threshold effect on R&D innovation, with only a moderate rate of change in the intensity of environmental regulation's facilitative effect on R&D innovation.

As the government imposes stringent environmental rules, environmental service firms will boost their investment in environmental management to avoid the harsh fines they face for violating applicable laws, regulations, and policies (Hancevic, 2016). This leads to an increase in production and management expenses in the short-term, which impedes business investment in green R&D and reduce green innovation (Liu and Li, 2022).

Consequently, we suggest Hypothesis 3:

H3 Environmental regulation intensity negatively moderates the relationship between green subsidies and green innovation.

3 Study design

3.1 Sample selection and data sources

The initial data contains 28 firms listed on the Shanghai Stock Exchange and the Shenzhen Stock Exchange. Panel data from 2014 to 2020 were used for analysis. The statistics regarding green patents were taken from the Chinese Research Data Services Green Patent Research Database. China Statistical Yearbook provided information on environmental regulation. The information regarding green subsidies was taken from the annual reports of firms. All remaining information came from the WIND database. This paper used the statistical analysis program Stata.

3.2 Definitions

3.2.1 Explanatory variable: green innovation (GPAT)

Green innovation is often considered to be the result of a firm's technological output (Cui et al., 2022; Liao, 2020). Thus, this article evaluates green innovation based on the number of green patent applications submitted by a firm per year (Feng et al., 2022). Analysis included any mention of the corporation, its subsidiaries, affiliates, or joint ventures. The number of applications represents the overall number of environmentally friendly inventions and utility models submitted by these subjects individually and collectively each year. The number of green patent applications or licenses can be a better measure of the level of innovation than other metrics. The application process for patent licenses involves a certain amount of time, annual costs, and a probable lack of stability and predictability. This paper uses a stable, dependable, and timely figure to represent the number of green patent applications.

3.2.2 Explanatory variable: green subsidies (GSUB)

Green subsidies are a sort of government subsidy granted to firms to tackle environmental issues or for political or commercial motives to improve their environmental protection equipment and processes. One measure of green subsidies is the number of government subsidies a business receives for environmental practices (Xie et al., 2016). Based on this, the writers manually collected data regarding green subsidies from annual reports. Data on subsidies relating to energy saving, emission reduction, green activity, environmental protection, clean energy, environment, waste gas, and other incentives connected to environmental protection were gathered from the annual reports of publicly traded firms. This represented the total amount of green subsidies obtained by the business in the current year.

3.2.3 Mediating variable: R&D investment (RD)

R&D investment refers to the cost of materials used in the R&D process or the inputs, such as salaries and bonuses paid to R&D workers. If green subsidies can affect firms' green innovation by affecting their R&D investment, the R&D investment of firms can serve as a mediating variable.

3.2.4 Moderating variable: environmental regulation (ER)

The intensity of environmental regulation reflects the expense of pollution control for firms (Chen et al., 2022). The higher the intensity of ER, the higher the expense of pollution management for firms. There is no conventional gauge of the strength of environmental regulation. In this article, we utilised the fraction of industrial pollution control investment completed in the secondary sector in the provincial administrative region where the firm is registered to measure environmental regulation (Lanoie et al., 2008).

Table 1 Definition of variables

Type	*Name*	*Symbol*	*Definition*
Explained variable	Green innovation	GPAT	Number of green patent applications by firms
Explanatory variable	Green subsidies	GSUB	Natural logarithm of green subsidies
Mediating variable	R&D investment	RD	Natural logarithm of the firm's R&D investment
Moderating variable	Environmental regulation	ER	The ratio of industrial pollution control investment completed in the secondary sector
Control variables	The asset size	SIZE	Natural logarithm of the firm's total assets
	The ratio of highly educated staff	STUD	The ratio of employees with a bachelor's or master's degree
	The size of the board	BOARD	Number on the firm's board of directors
	Return on assets	ROA	The ratio of the firm's net profit after tax to total assets
	Operating income growth rate	RATE	The ratio of the increase in the firm's operating income for the current year to the total operating income for the previous year

3.2.5 Control variables

1 The asset size (SIZE): The size of a firm's assets reflects, to some extent, the number of resources available to the firm. Larger firms generally have more resources and more assets to devote to innovation activities.

2 The ratio of highly educated staff (STUD): Human capital is the source of a firm's innovation and competitiveness, but not all employees have inventive value; only those with unique and rare expertise can provide firms with competitive advantages. Education can enhance employees' abilities to receive, decipher, and comprehend information, hence enhancing the human capital of firms (Storey, 2002). This study uses the ratio of employees with bachelor's and master's degrees as a measure of the proportion of highly educated personnel.

3 The size of the board (BOARD): The board of directors is the fundamental component of the internal firm governance structure. The size of the board of directors is crucial to the governance role of the board.

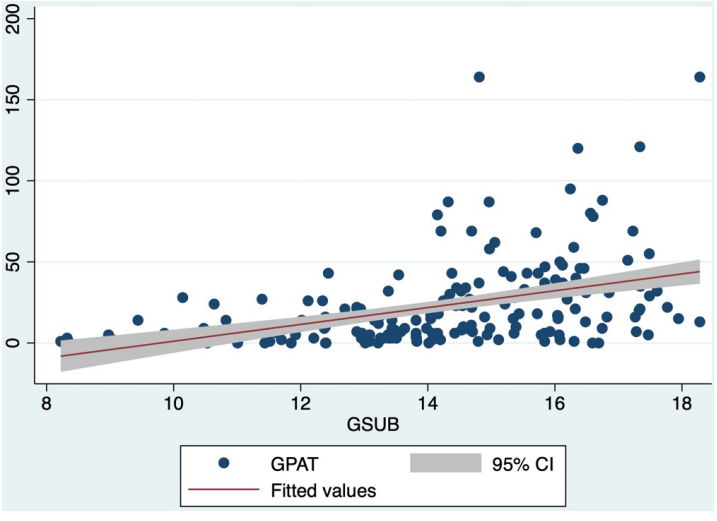
4 Return on assets (ROA): ROA measures the amount of net profit generated per asset. It is a useful measure for determining a firm's profitability relative to its total assets. The greater the indicator value, the greater the investment return.

5 Operating income growth rate (RATE): The growth rate of operating revenue is the ratio of the increase in operating revenue from the current year to the prior year's total operating revenue. It is a crucial indicator for assessing the firm's growth status and capacity for expansion.

3.3 Research model

Figure 1 is a scatter plot of green subsidies and green innovation for environmental service firms. There is a clearer linear relationship between these two variables, and the principal fitted line is positively connected. This suggests that green subsidies facilitate the promotion of green innovation among China's environmental service firms.

Figure 1 Scatter plot of GSUB and GPAT (see online version for colours)



This article explored the direct effect of green subsidies on the green innovation of environmental service firms, as well as the function of R&D investment as a mediator. As illustrated in equation (1), model 1 studies the impact of green subsidies on firms' green innovation.

1 Model 2 is a regression model assessing the impact of green subsidies on firms' R&D investment, with the variable R&D representing corporate R&D spending, as shown by equation (2).

2 Model 3 is derived from model 1 and informs a firm R&D investment variable.

We then examined the impact of green subsidies and, as demonstrated in equation (3), firm R&D investment on the green innovation of environmental service firms. ε stands for the random error term.

$$GPAT = \beta_0 + \beta_1 GSUB + \beta_2 BOARD + \beta_3 RATE + \beta_4 SIZE + \beta_5 STUD + \beta_6 ROA + \varepsilon \quad (1)$$

$$RD = \beta_0 + \beta_1 GSUB + \beta_2 BOARD + \beta_3 RATE + \beta_4 SIZE + \beta_5 STUD + \beta_6 ROA + \varepsilon \quad (2)$$

$$GPAT = \beta_0 + \beta_1 GSUB + \beta_2 BOARD + \beta_3 RATE + \beta_4 SIZE + \beta_5 STUD + \beta_6 ROA + \beta_7 RD + \varepsilon \quad (3)$$

The research then included environmental control as a moderating factor. If the cross term between ER and GSUB is statistically significant in model 4, this suggests that the moderating impact is present in the direct model. If the cross term between ER and GSUB is significant in model 5, the moderating impact is present in the first half of the mediated model path. If the cross term between ER and RD is significant in model 6, it shows that the moderating effect holds in the second half of the mediated model's path.

$$GPAT = \beta_0 + \beta_1 GSUB + \beta_2 BOARD + \beta_3 RATE + \beta_4 SIZE + \beta_5 STUD + \beta_6 ROA + \beta_7 ER + \beta_8 ER * GSUB + \varepsilon \quad (4)$$

$$RD = \beta_0 + \beta_1 GSUB + \beta_2 BOARD + \beta_3 RATE + \beta_4 SIZE + \beta_5 STUD + \beta_6 ROA + \beta_7 ER + \beta_8 ER * GSUB + \varepsilon \quad (5)$$

$$GPAT = \beta_0 + \beta_1 GSUB + \beta_2 BOARD + \beta_3 RATE + \beta_4 SIZE + \beta_5 STUD + \beta_6 ROA + \beta_7 RD + \beta_8 ER + \beta_9 ER * RD + \varepsilon \quad (6)$$

4 Results

4.1 Descriptive statistics and correlation analysis

4.1.1 Descriptive statistics

Before modelling and analysing the indicators, descriptive statistics for the variables can be used to identify the underlying information, including the mean, standard deviation, and extreme values in Table 2. The mean value of GPAT was 21.867, the minimum value was 0 and the maximum value was 164. This demonstrates that the level of green innovation differs substantially among firms. The minimum value of GSUB was 8.223 and the maximum value was 18.281. This suggests that the Government's green subsidies to firms also vary widely.

4.1.2 Correlation analysis

As demonstrated in Table 3, GSUB was significantly and positively linked with RD and GPAT at the 1% level. RD was likewise significantly and positively linked with GPAT at

the 1% level. The coefficients of the correlations between the other variables were less. This suggests that the early settings were suitable.

Table 2 Descriptive statistics

Variable	*Obs*	*Mean*	*Std. dev.*	*Min*	*Max*
GPAT	196	21.867	27.104	0	164
GSUB	193	14.03	2.268	8.223	18.281
RD	196	8.394	1.278	5.202	10.765
ER	224	0.002	0.001	0	0.008
BOARD	221	7.321	3.235	0	15
RATE	221	–0.202	0.539	–4.003	0.982
SIZE	193	22.414	0.967	20.583	24.956
ROA	221	0.03	0.06	–0.396	0.173
STUD	196	34.438	14.297	1.95	77.77

4.2 Test of mediating effect

4.2.1 Full sample analysis

In Table 4, the three regressions that follow examine the relationship between green innovation, green subsidies, and firm R&D investment. Model 1 examines the influence of GSUB on GPAT, whereas model 2 examines the influence of GSUB on RD. Model 3 does a full regression to see if GSUB can influence GPAT through RD. The findings of the regression were in Table 4.

Table 3 Correlation analysis

Variables		*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
(1)	GPAT	1.000								
(2)	RD	0.540	1.000							
		0.000								
(3)	GSUB	0.431	0.394	1.000						
		0.000	0.000							
(4)	BOARD	0.139	0.038	0.156	1.000					
		0.053	0.601	0.031						
(5)	RATE	0.016	–0.073	0.016	–0.165	1.000				
		0.825	0.315	0.829	0.014					
(6)	SIZE	0.548	0.384	0.438	0.306	0.094	1.000			
		0.000	0.000	0.000	0.000	0.195				
(7)	ROA	0.087	0.119	–0.033	0.158	–0.330	–0.129	1.000		
		0.231	0.099	0.648	0.019	0.000	0.073			
(8)	STUD	–0.137	–0.180	–0.139	0.160	–0.025	–0.266	0.120	1.000	
		0.056	0.012	0.055	0.026	0.734	0.000	0.096		
(9)	ER	–0.142	–0.122	–0.090	0.330	–0.215	–0.351	0.236	0.005	1.000
		0.047	0.090	0.214	0.000	0.001	0.000	0.000	0.944	

The coefficient of the green subsidies, GSUB, in model 1 was 2.884, and it passed the 1% significance test. This demonstrates that green subsidies have a significant active effect on the green innovation of firms. Green subsidies can encourage firms' green innovation. In model 2, the coefficient of green subsidies GSUB was 0.172, and this coefficient also passed the 1% significance test. This demonstrates that green subsidies have a strong active influence on R&D investment by firms and can considerably stimulate green innovation in firms. In model 3, the coefficients for green subsidies, GSUB, and firm R&D input RD were 1.673 and 7.028, respectively. These two coefficients pass the significance test at the 5% and 1% levels, respectively. Both green subsidies and firm R&D contributions have a substantial active effect on green innovation.

Table 4 Regression of mediating effect

	GPAT	*RD*	*GPAT*
	Model 1	*Model 2*	*Model 3*
RD			7.028*** (5.15)
GSUB	2.884*** (3.62)	0.172*** (4.26)	1.673** (2.14)
BOARD	–0.636 (–0.63)	–0.065 (–1.27)	–0.177 (–0.18)
RATE	0.568 (0.19)	–0.152 (–1.00)	1.635 (0.58)
SIZE	13.392*** (6.58)	0.375*** (3.63)	10.753*** (5.45)
ROA	68.440** (2.57)	3.104** (2.29)	46.628* (1.84)
STUD	0.005 (0.04)	–0.007 (–1.05)	0.052 (0.44)
Constant	–315.498*** (–7.55)	–1.790 (–0.84)	–302.915*** (–7.72)
Observations	190	190	190
R-squared	0.370	0.267	0.450

Notes: ***, **, and * indicate the 1%, 5%, and 10% significance levels respectively (the same below).

The above three models show a partial mediating benefit of firm R&D investment between green subsidies and green innovation. Green subsidies can directly facilitate the green innovation of firms. In addition, green subsidies can promote green innovation through corporate R&D investment.

4.2.2 Sub-sample analysis

China has rapidly fostered coordinated regional development with stronger institutional frameworks in recent years. It has successfully coordinated regional development strategies and implemented important regional strategies. The Greater Bay Area, Yangtze River Delta, and Beijing-Tianjin-Hebei are key sources of economic power for China from which high-quality growth can be led. Therefore, these three economic sectors are the most developed in China. In comparison to those in other regions, they are more transparent and better managed, and as a result, they can use their resources more effectively to promote innovation efficiency (Květoň and Horák, 2018; Jiao et al., 2016). Given the variations between the regions where environmental service firms are headquartered, it may be argued that these firms have a higher level of green innovation (Li et al., 2020; Tian et al., 2016).

This article separates the samples into underdeveloped areas (group 1) and developed areas (group 2) based on whether the registered location of firms is in one of three strategic zones (group 2). The heterogeneity of the two sample types was then evaluated. The findings of the regression were in Table 5.

Table 5 Regression by region

	Model 1 (GPAT)		*Model 2 (RD)*		*Model 3 (GPAT)*	
	Group 1	*Group 2*	*Group 1*	*Group 2*	*Group 1*	*Group 2*
RD					10.724***	3.857**
					(4.93)	(2.27)
GSUB	5.881***	1.790**	0.289***	0.081*	2.784*	1.479*
	(3.46)	(2.19)	(3.44)	(1.81)	(1.76)	(1.82)
BOARD	–0.540	–0.448	0.020	–0.145**	–0.750	0.110
	(–0.33)	(–0.35)	(0.25)	(–2.05)	(–0.54)	(0.08)
RATE	2.960	1.100	–0.202	–0.091	5.122	1.453
	(0.58)	(0.31)	(–0.80)	(–0.47)	(1.17)	(0.41)
SIZE	9.887**	12.790***	0.050	0.635***	9.347**	10.341***
	(2.39)	(6.00)	(0.25)	(5.48)	(2.64)	(4.39)
ROA	259.314**	50.836**	0.868	3.891***	250.001**	35.831
	(2.24)	(2.18)	(0.15)	(3.07)	(2.53)	(1.50)
STUD	–0.470*	0.258**	–0.016	0.001	–0.304	0.256**
	(–1.89)	(2.07)	(–1.26)	(0.08)	(–1.41)	(2.09)
Constant	–262.840***	–297.221***	3.372	–5.799**	–299.000***	–274.857***
	(–3.20)	(–6.82)	(0.83)	(–2.44)	(–4.24)	(–6.26)
Observations	70	120	70	120	70	120
R-squared	0.485	0.369	0.288	0.326	0.630	0.397

In Table 5, green subsidies boosted green innovation in groups 1 and 2, with R&D investment serving as a mediator. Nevertheless, in models 1 and 2, the coefficient of GSUB for group 1 was greater than that for group 2. This suggests that the effect of green subsidies on green innovation and R&D investment is stronger in group 1 than in group 2. Moreover, in both models 1 and 2, the significance of the GSUB coefficient is greater in group 1 than in group 2, which does not meet the expectation of the paper. This may be because China's new environmental protection law enforces stronger environmental responsibility regulations, whereas corporations in less developed regions have historically prioritised economic expansion over environmental conservation. Under the regulation of the new environmental protection law, firms have raised their investment in environmental protection and vastly expanded their capacity for green innovation to avoid environmental liability for lawbreaking.

4.3 Test of moderating effect

The following three regressions in Table 6 examine the moderating influence of ER. Model 4 investigates the role of ER as a moderator between GSUB and GPAT. Model 5 investigates the moderating influence of ER on the relationship between GSUB and RD.

Model 6 analyses the moderating influence of ER on the relationship between RD and GPAT.

Table 6 Regression of moderating effect

Variables	*GPAT*	*RD*	*GPAT*
	Model 4	*Model 5*	*Model 6*
RD*ER			–2,041.767* (–1.91)
RD			6.891*** (5.06)
GSUB	2.988*** (3.70)	0.167*** (4.08)	1.896** (2.40)
ER	–124.193 (–0.08)	–21.374 (–0.29)	–126.659 (–0.09)
BOARD	–0.773 (–0.75)	–0.057 (–1.10)	–0.385 (–0.40)
RATE	0.397 (0.13)	–0.149 (–0.97)	0.957 (0.34)
SIZE	13.572*** (6.30)	0.351*** (3.21)	11.197*** (5.43)
ROA	67.660** (2.52)	3.211** (2.36)	49.175* (1.93)
STUD	0.020 (0.16)	–0.008 (–1.22)	0.074 (0.62)
GSUB*ER	–576.062 (–0.97)	33.806 (1.13)	
Constant	–320.333*** (–7.03)	–1.145 (–0.50)	–314.226*** (–7.40)
Observations	190	190	190
R-squared	0.374	0.273	0.462

Table 7 Regional heterogeneity test

	Model 1 (GPAT)		*Model 2 (RD)*		*Model 3 (GPAT)*	
	SOEs	*Non-SOEs*	*SOEs*	*Non-SOEs*	*SOEs*	*Non-SOEs*
RD					7.478***	5.932***
					(3.23)	(2.78)
GSUB	3.300**	1.906**	0.264***	0.099***	1.323	1.318
	(2.08)	(2.05)	(2.94)	(2.63)	(0.84)	(1.42)
BOARD	1.265	0.414	0.259***	–0.228***	–0.674	1.768
	(0.79)	(0.29)	(2.86)	(–3.89)	(–0.42)	(1.19)
RATE	–4.343	1.717	–0.469	–0.185	–0.833	2.815
	(–0.82)	(0.48)	(–1.56)	(–1.27)	(–0.17)	(0.80)
SIZE	10.549**	18.316***	–0.209	0.850***	12.112***	13.272***
	(2.55)	(7.24)	(–0.89)	(8.29)	(3.17)	(4.34)
ROA	49.745	79.800***	–1.544	4.709***	61.287	51.866*
	(0.80)	(2.72)	(–0.44)	(3.96)	(1.07)	(1.71)
STUD	–0.411*	0.125	–0.042***	0.005	–0.097	0.097
	(–1.77)	(0.84)	(–3.19)	(0.78)	(–0.41)	(0.67)
Constant	–267.532***	–421.158***	8.232	–10.340***	–329.086***	–359.817***
	(–2.88)	(–8.16)	(1.57)	(–4.94)	(–3.77)	(–6.55)
Obs	56	134	56	134	56	134
R-squared	0.351	0.443	0.365	0.509	0.467	0.475

In model 4, the coefficient on the cross term, GSUB*ER, for environmental regulation and green subsidies was –576.062. This suggests that environmental regulation can hinder the contribution of green subsidies to green innovation, but this effect is not significant. The moderating effect of environmental regulation on the relationship between them does not hold. GSUB*ER, the cross term between green subsidies and environmental regulation, had a coefficient of 33.806 in model 5. This coefficient fails the test for significance. This suggests that the influence of environmental regulation on the relationship between green subsidies and R&D inputs is negligible. In model 6, the cross term RD*ER coefficient between R&D inputs and environmental regulation was –2,041.767. This coefficient passes the 10% significance test. This suggests that environmental regulation impedes the contribution of R&D to green innovation. Environmental regulation acts as a negative moderator between these two factors.

According to the three preceding models, environmental regulation has a negative moderating effect. A high level of environmental regulation will impede the promotion of green innovation through R&D investment, which is not beneficial to the green development of environmental service firms.

Table 8 Substitution variable and Poisson regression

	Substitution variable		*Poisson regression*	
	APA	*APA*	*GPAT*	*GPAT*
	Model 1	*Model 3*	*Model 1*	*Model 3*
RD		6.671***		0.333***
		(7.19)		(19.66)
GSUB	2.253***	1.104**	0.174***	0.124***
	(3.93)	(2.08)	(19.20)	(13.04)
BOARD	–0.658	–0.222	–0.005	0.002
	(–0.90)	(–0.34)	(–0.47)	(0.15)
RATE	3.061	4.074**	–0.020	–0.011
	(1.42)	(2.14)	(–0.57)	(–0.33)
SIZE	11.313***	8.809***	0.520***	0.369***
	(7.72)	(6.56)	(29.59)	(18.30)
ROA	6.097	–14.607	3.271***	1.831***
	(0.32)	(–0.85)	(9.39)	(5.37)
STUD	0.086	0.130	–0.000	0.003**
	(0.96)	(1.64)	(–0.11)	(2.28)
Constant	–264.904***	–252.961***	–11.361***	–10.226***
	(–8.80)	(–9.48)	(–30.07)	(–26.42)
Observations	190	190	190	190
R-squared	0.429	0.555		

4.4 Robustness test

To demonstrate the dependability of the benchmark regression results presented in this study, robustness tests were done in three areas. First, there are substantial disparities in business management between state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). Although SOEs have a huge edge over private firms in terms of

innovation resources and possibilities, they are significantly less driven to innovate (Li et al., 2021). The sample was therefore separated into two groups, SOEs and non-SOEs, for separate regressions. Second, as the number of green patents held by firms is counted as data consistent with the Poisson distribution, the Poisson model for regression was used in this investigation. Lastly, the number of green patents granted by firms might also be an indicator of green innovation to some extent. In this work, the number of green patent applications was substituted by the number of green patent grants (APA) for regression purposes. The results are displayed in Tables 7 and 8.

In terms of significance level and coefficient size, the empirical findings differ marginally from those of the earlier study. However, the coefficients associated with this study pass the significance test, and the signs of the coefficients are the same as the results of the original model, thus confirming the results' resilience to some extent.

5 Discussion

The findings of this study indicate that green subsidies can encourage green innovation in environmental service firms. Furthermore, this effect is more potent in regions with less economic development. Therefore, when designing green subsidy policies, the government should consider the industry-specific nature of environmental service firms and the level of economic development in various regions. For instance, the business scope of environmental service firms includes repair of the environment, prevention and management of water contamination, and solid waste treatment. Currently, the forms of green subsidies are imperfect, with a concentration on environmental rehabilitation and a lack of scientific and technical assistance and development-model guidance subsidies. In addition, there is a lack of long-term, institutionalised support policies, for most green subsidy programs, which target specific regions and environmental issues. The application, implementation, and monitoring processes for green subsidy programs are also inadequate. These approaches disregard a firm's leading role in environmental protection and make it impossible to fully harness its enthusiasm. Therefore, in the framework of low-carbon growth, green subsidies should be made more accessible. This can be accomplished by accounting for the cost of environmental protection inputs by firms and rewarding those who develop green technology advances to minimise the cost of innovation. Consider placing a carbon tax on firms with excessive pollution emissions to increase the objective implementation effect of green subsidies. Administrative legislation could consolidate some best practice, in the form of rules and regulations, to ensure that green subsidies meet the needs of low-carbon development strategies in a timely manner.

Environmental regulation has a negative moderating effect on the relationship between green subsidies and green innovation. In the short-term, environmental regulation will necessitate the investment of large quantities of money by those firms and the incursion of huge treatment costs to achieve green production, which will limit the development of green technologies. However, after firms have improved their production efficiency through energy-saving and emission-reducing business models, they will obtain extra innovation benefits, encouraging them to engage in technological R&D (Shang et al., 2022). Despite the industry's rapid expansion in recent years due to government support, it still lags behind that of other developed economies. Consequently,

environmental rules have imposed stronger limits on firms' production technologies within the context of carbon neutrality, pushing them to innovate production technologies to reduce external pollution. Firms must achieve a balance between technical progress and environmental conservation. Meanwhile, the government should create environmental regulation laws using scientific methods and establish a reasonable range of green subsidies to encourage the complementary coupling of ecological regulation and green subsidies.

In addition to improving its duty of environmental preservation, China should also strengthen its green patent review system. As the supreme law of the new measures, the patent law should be amended to include patent promotion measures favourable to green technology innovation to set the legal groundwork for China to establish a rapid green patent review system. Concurrently, the quick-review-system implementation regulations for green technology patents should be produced quickly for the governance of review standards and procedures.

Lastly, from the firm's standpoint, the organisation should boost its R&D investment and R&D intensity. Environmental service firms might build green innovation technology roadmaps to increase the guidance and openness of technology development plans (Xu et al., 2022a). They can do so while simultaneously enhancing the interface between various segments. They should organically blend government and private funding to assist environmental technology R&D.

6 Conclusions

This study used the environmental service firms listed on the Shanghai and Shenzhen Stock Exchanges in China as its research subjects and analysed their balanced panel data from 2014 to 2020. Multiple linear regression was utilised to examine the impact of green subsidies on the green innovation of environmental service firms. Existing theoretical research on the effect of green subsidies on corporate green innovation is enriched by this study. There are numerous studies on government subsidies and corporate innovation, and most of them affirm the positive effect (Xu et al., 2021; Jung and Feng, 2020). Researchers also analysed green credit as an indication of firms' innovation in green technology (Tan et al., 2022). However, few scholars have conducted studies on the connection between green subsidies and green innovation. Fewer studies have investigated the role of green subsidies in accomplishing the 'two-carbon' objective. This study bolsters the empirical evidence about carbon trading markets in emerging nations. It makes recommendations commensurate with the dual-carbon strategy and can foster innovation in green technology, which is a favourable reference for firms seeking ecological sustainability and economic win-win.

The research perspective of this study is reflective of its originality. Most scholarly research on green innovation has been conducted at the provincial level, which is often excessively broad. Combining geographical and regulatory environmental variability, this research investigated environmental service firms from the perspective of publicly traded corporations. We attempted to blend macro and micro to compensate for the deficiencies of existing studies.

However, as there are numerous unobservable factors in implementing the pilot carbon market policy and numerous factors that influence the invention of green technologies, not all of them can be considered. Many provincial statistics are difficult to

locate, restricting the scope of this paper's investigation. Moreover, because the data on green subsidies were manually collected and retrieved by the authors, this article focused solely on environmental service firms and did not examine other industries with a significant focus on green innovation. These are the future improvements that can be made to this study.

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