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Empowering green innovation: The impact of green subsidies on Chinese firms

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ABSTRACT

As a form of targeted public expenditure, green subsidies play a crucial role during economic transformation. Their potential to foster green innovation, and ultimately support sustainable development, remains an important subject of empirical research. Drawing on panel data from Chinese A-share listed companies spanning 2007 to 2022, this research utilizes a three-way fixed effects framework to evaluate how green subsidies promote environmental progress. The empirical evidence suggests that, while green subsidies significantly enhance investment in innovation, their direct impact on innovation outputs is relatively limited. This trend is consistent across various types of firms, highlighting the initial success of green subsidy policies in motivating innovation investment, but also underscoring the necessity of further exploration and refinement to achieve a more sustainable impact on innovation outcomes. Notably, R&D outputs in technology-intensive firms paradoxically declined after receiving green subsidies, revealing limitations in the current policy framework's effectiveness. These findings emphasize the importance of tailoring subsidy policies to align with the heterogeneous demands of enterprises. Our research contributes to this discussion by emphasizing the need for a more nuanced policy approach that balances innovation incentives with long-term economic sustainability.

1. Introduction

The fossil fuel-based economy has posed severe challenges to the global environment. According to the International Energy Agency, carbon dioxide emissions resulting from global energy consumption rose by 6 % in 2021, hitting an unprecedented level of 36.3 billion tons, thereby threatening global sustainability [1]. Green innovation, as a vital strategy to promote both economic growth and environmental protection, mitigates emissions and enhances sustainability through technological advancements. Consequently, it has become a key priority for governments and enterprises alike [2].

Despite the robust momentum of green innovation, its development remains hindered by multiple factors. From a market perspective, consumer environmental awareness increases demand for eco-friendly products and allows firms to charge premium prices. Nevertheless, firms must also contend with substantial innovation costs [3]. From a strategic standpoint, engaging in eco-innovation projects can significantly strengthen corporations' competitiveness; however, external uncertainties pose risks to the stability of business operations [4]. Moreover, innovation activities exhibit significant positive externalities, meaning that societal benefits exceed the private returns to firms, which are often delayed or difficult to capture. Consequently, market mechanisms often fail to incentivize sufficient investment in eco-innovation [5]. Subsidies, as a policy instrument involving targeted allocation of additional public resources, aim to rectify market failures and improve the sustainability of production and consumption [6]. Therefore, green subsidies can substantially alleviate the financial burden associated with environmental technological advancement. These targeted policy interventions stimulate increased private engagement in sustainability-driven R&D, internalize externalities, and ultimately enhance social welfare [7,8].

As a major participant in the global economy, China has made substantial contributions toward promoting green technology innovation, facilitating economic transformation and achieving sustainable

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development. To fulfill its long-term decarbonization goals, China has progressively refined its green subsidy policies across various industries and established a National Green Development Fund to alleviate the financial pressures faced by traditional industries during their low-carbon transitions [9]. For instance, BYD Company Limited received nearly €2 billion in supplementary subsidies dedicated to technology research and development (R&D) between 2020 and 2022 [10]. However, substantial subsidy expenditures have also imposed fiscal burdens on China amid industrial transformation and policy adjustments [11]. Subsidies for certain industries, such as photovoltaics, have notably declined with the advent of the post-subsidy era [12]. This trend prompts several crucial research questions: Have existing subsidies effectively stimulated green innovation? How can subsidy policies be effectively designed to maximize their efficiency? Analyzing these questions is helpful for understanding whether green subsidies exert a meaningful impact on environmental innovation.

Although extensive research has explored how subsidies influence corporate innovation, most studies have not adequately differentiated between types of subsidies. Given that green subsidies specifically target environmental and sustainability objectives, overlooking distinctions between subsidy types may obscure their unique roles in facilitating green innovation. Furthermore, most existing studies suggest that subsidies unequivocally promote innovation, largely overlooking how industrial characteristics may affect firms' subsidy utilization rates. This oversight risks underestimating resource misallocation resulting from inefficient subsidy distribution. To address these gaps in existing research, this study adopts a three-way fixed effects model alongside heterogeneity analysis to thoroughly examine the relationship between green subsidies and innovation among Chinese listed firms.

The empirical strategy consists of three principal phases. At the initial stage, this paper distinguishes the uses of green subsidies and investigates how they influence the advancement of green innovation. Empirical findings suggest that while such subsidies play a significant role in enhancing enterprises' investment in innovation activities, their immediate contribution to tangible innovation outcomes appears to be comparatively modest. In the second stage, this paper conducts robustness checks and applies endogeneity correction methods, such as the instrumental variable (IV) approach and the Heckman two-stage method, to ensure consistent estimates and control for endogeneity. In the third stage, the research performs multiple heterogeneity analyses to identify which categories of firms benefit most from green subsidy interventions. The findings reveal that input structures, ownership types, and lifecycle stages all contribute to heterogeneous effects of green subsidies. For instance, green subsidies tend to have a stronger positive impact on labor-intensive firms, while they may exert a dampening effect on technology-intensive firms.

This paper offers multiple novel contributions. First, by emphasizing the distinct mechanisms through which green subsidies foster sustainability-oriented innovation, this study offers new perspectives on their direct effects, thereby enriching the theoretical understanding of subsidy policy design and addressing gaps in previous studies. Second, the study investigates heterogeneous impacts of green subsidies across multiple dimensions, including input structures, ownership structures, and lifecycle stages. Importantly, contrary to the predominantly positive effects documented in prior research [13,14], our findings indicate that although labor-intensive firms gain more from green subsidies, these subsidies hinder innovation when these firms are highly leveraged. A similar negative effect is also observed among technology-intensive firms. These findings suggest an alternative perspective on the applicability of green subsidies and highlight the necessity of tailoring the subsidy policy to specific industry characteristics.

The subsequent sections present the theoretical background and hypothesis formulation, followed by the research methodology, empirical findings, and concluding implications.

2. Literature review and research hypotheses

2.1. Literature review

As sustainability gains importance worldwide, eco-innovation has become crucial in determining corporate competitiveness. Nevertheless, given the high expenses and significant uncertainties linked to green technology R&D, market-based mechanisms are typically insufficient to motivate firms to pursue innovation aligned with sustainability goals [15]. Therefore, governments widely implement various forms of green subsidies, such as tax incentives, low-interest loans and financial grants, to mitigate market failures and promote coordinated progress in both economic performance and ecological responsibility [16,17].

Existing research presents divergent views on whether green subsidies effectively stimulate corporate green innovation and on the underlying mechanisms through which they operate. Some studies suggest that subsidies significantly reduce firms' R&D costs and, in turn, enhance operational efficiency while also mitigating risks inherent in green innovation and stimulating innovation activities [18–20]. Unlike general subsidies, green subsidies prioritize environmental benefits generated by enterprises, thereby contributing more significantly to firms' environmental innovation efforts, especially among smaller firms [21,22]. Moreover, green technological advancement enables firms to reduce ecological footprints, strengthen reputational capital, improve investor confidence, and support long-term financial and operational resilience [23–25]. Furthermore, sustained green subsidies can reinforce innovation incentives and facilitate the development of supporting industries [26–28]. From a governmental perspective, green subsidy policies represent a more cost-effective alternative to traditional financial instruments, thereby enabling sustained green development under fiscal constraints [29,30].

Nevertheless, some scholars hold opposing views. Certain studies argue that subsidies may induce a "crowding-out effect", reducing firms' intrinsic motivation for innovation [31,32]. Additionally, subsidies may even increase firms' dependency on financial aid, resulting in superficial innovation practices [33,34]. Furthermore, uncertainty in the external environment and improper subsidy allocation can lead to resource misallocation with benefits unevenly distributed across firms [35–37]. Technology-intensive firms are capable of achieving high innovation performance even without subsidies, implying that subsidies are not always a prerequisite for innovation [38,39]. Thus, subsidies may not guarantee enhanced green innovation outcomes for all firms.

Existing studies commonly employ econometric methods, such as moderation models, panel threshold regression, difference-in-differences (DID), and Tobit modeling, to investigate the effect of subsidies on environmental innovation [40–43]. Parametric analyses and game-theoretic models have also been adopted to explore optimal subsidy policies and corporate strategic responses [44,45]. Furthermore, Heckman two-stage method, IV methods, and propensity score matching (PSM) have been utilized to mitigate endogeneity issues in subsidy effectiveness research [46,47].

Regarding specific subsidy effects, prior research offers various perspectives. Studies indicate that direct subsidies and carbon taxes have limited impacts on social welfare, whereas green credit policies typically perform better [48,49]. Moreover, green subsidies are more effective than those targeting specific green products, particularly during the early stages of ecological transition [50]. Under budget constraints, innovation subsidies are more effective than product-based subsidies [51], with lump-sum subsidies outperforming discount-based subsidies in promoting innovation outcomes [52]. Additionally, supplier-oriented subsidies are often more effective in motivating sustainability-driven innovation [53].

With respect to firm and industry characteristics, enterprises with strong social responsibility and experienced R&D management teams effectively leverage subsidies to enhance green innovation performance [54,55]. Conversely, self-interested managerial behavior may reduce corporate innovation investments, exacerbating differences in subsidy effectiveness [56,57]. In particular, since green R&D activities often fail to generate sufficient returns to cover their initial costs in the short time, managers may reduce investment in such projects in pursuit of short-term performance goals [58,59]. In terms of firm size, governments typically prioritize large firms in subsidy allocation, potentially overlooking other entities within the supply chain [60]. However, the impact of subsidies on innovation in large firms often follows an inverted U-shaped relationship, wherein subsidies become less effective as firm size increases beyond a certain threshold [61–63]. Regarding ownership structure, state-owned enterprises (SOEs) tend to receive substantial subsidies; however, their actual innovation output remains modest, with a stronger emphasis on strategic objectives rather than technological breakthroughs [64,65]. In contrast, subsidies are more effectively translated into innovation outcomes in private enterprises [66].

To conclude, although the link between environmental subsidies and enterprise innovation has received considerable scholarly attention, notable gaps still remain. Although prior studies generally affirm the supportive impact of subsidies on innovation, the differences in impact across various subsidy types and heterogeneous firm characteristics remain unclear. Furthermore, empirical evidence on the specific mechanisms through which green subsidies influence innovation remains fragmented. This study emphasizes these neglected aspects, systematically analyzing how distinct subsidy forms and diverse firm-level characteristics affect the effectiveness of green subsidies. By addressing these gaps, this research offers valuable insights for refining subsidy policy design and advancing theoretical understanding of green innovation incentives.

2.2. Research hypotheses

Generally, the mechanisms through which green subsidies influence innovation may be conceptualized along two distinct dimensions: direct and indirect effects. On the one hand, green subsidies directly serve as a key contributor to research and development financing, helping firms alleviate financial constraints related to green innovation and enabling them to allocate more resources to research activities [67]. In addition, subsidies can enhance firms' confidence in innovation investment by reducing the perceived risks of R&D failure, thereby encouraging greater engagement in green technology development [68,69]. In contrast, the indirect effects of green subsidies often operate through a signaling mechanism. Subsidies can indirectly promote innovation investment by alleviating information asymmetries between firms and external stakeholders or government agencies. Given that this research centers on how green subsidies directly affect innovation inputs and performance outputs, we limit our analysis to the direct impact and explore whether such effects vary across different types of firms.

Drawing upon established theory and existing research, this study assumes that green subsidies received by firms in each year are invested in current-period innovation activities. Accordingly, we derive the hypothesis below:

H1. Green subsidies exert a direct positive effect on both firms' R&D investment and innovation performance.

3. Material and methods

3.1. Sample selection

This study collected financial statements from 5266 Chinese A-share listed firms over the 2007–2022 period to extract data on corporate subsidies, resulting in an initial sample of 841,491 records. While the aggregate volume of public subsidies is typically viewed as a reflection of governmental support [70], prior studies highlight the heterogeneous effects of different subsidy types [71]. Therefore, this study specifically identifies and extracts subsidy items explicitly labeled as "green subsidies" or "environmental subsidies" from the original dataset. To ensure data integrity, firms that did not disclose green subsidies or had missing key variables were excluded from the analysis. The final sample comprises 3869 firms across diverse industries, including technology and manufacturing. Subsequently, the disclosed green subsidies were categorized by type and aggregated annually, resulting in a total of 29,316 observations.

Furthermore, this study collected operational data, including firm size, ownership structure, profitability indicators, and information on green patent applications, to account for firm heterogeneity and innovation capabilities. These firm-level data were subsequently merged with subsidy data using stock codes as identifiers. The resulting balanced panel dataset consists of 13 variables with a total of 381,108 observations, facilitating rigorous empirical investigation into how green subsidies directly influence firm-level sustainability-oriented innovation. The primary source of sample data is the China Research Data Service Platform (CNRDS).

3.2. Definition of variables

Given the debate surrounding the relationship between innovation investment and applications [72], this study examines the dependent variables separately across two categories. Innovation input is measured by *R&D expenditure* and *R&D intensity*, which collectively reflect firms' R&D investments [73,74]. Innovation output, on the other hand, is measured using three indicators: *green patent applications, green invention patent applications*, and *green utility patent applications*. Specifically, *green patent applications* encompass all environmentally oriented patents, thus broadly reflecting firms' overall engagement in green technology development [75]. *Green invention patent applications* represent highly novel and complex innovations, thereby providing a more precise indication of a firm's substantive commitment to technological innovation [76]. Conversely, *green utility patent applications* typically capture firms' strategic innovation behaviors, which might be pursued primarily to secure subsidies or enhance corporate reputation [77]. Given that firms may not obtain new patent applications every year, resulting in a high frequency of zero observations in the dataset, this study follows existing practices by adding 1 to all values before performing logarithmic transformations [78].

The primary independent variable, *green subsidies*, is defined as the total amount of government grants for special funds and environmental protection received by firms. The natural logarithm of the variable is taken to address potential distortions caused by outliers and improve the stability of the empirical estimates.

To precisely capture the real effects of green subsidies on innovation performance, this study includes several control variables, such as *Scale, Tenure, Debt-to-Asset Ratio, Fixed Asset Ratio, Growth Capability*, and *Ownership Concentration*. Moreover, to strengthen the robustness of the findings, this study also employs *authorized green patents, authorized green invention patents*, and *authorized green utility patents* as alternative innovation indicators for robustness checks. Specifically, alternative indicators, such as *patent retention status*, are employed as independent variables within a Heckman two-stage selection model to reduce bias arising from endogeneity. Table 1 offers an overview of the definitions and construction of these variables.

3.3. Three-way fixed effects model

To capture unobserved heterogeneity in panel settings involving multiple dimensions, the fixed-effects framework was extended to accommodate multidimensional structures [79]. Specifically, the three-dimensional fixed-effects model employed in this study is structured as follows:

$$Y_{ijt} = \lambda + \alpha X_{ijt} + \mu_i + \xi_j + \tau_t + \varepsilon_{ijt} \quad (1)$$

Table 1
Variable descriptions and definitions.

Variable classification	Variable title	Abbreviations	Variable definition
Dependent variable	R&D expenditure	RDE	ln (Actual R&D investment amount (in RMB))
	R&D intensity	RDI	(R&D investment / operating revenue) × 100
	Green patent applications	GP	ln (Annual count of green patent applications + 1)
	Green invention patent applications	GIP	ln (Annual count of green innovation patent applications + 1)
	Green utility patent applications	GUP	ln (Annual count of applications for green utility patent applications + 1)
	Authorized green patents	AGP	ln (Annual count of authorized green patents + 1)
	Authorized green invention patents	AIP	ln (Annual count of authorized green invention patents + 1)
	Authorized green utility patents	AUP	ln (Annual count of authorized green utility model patents + 1)
Independent variable	Green subsidies	GS	ln (Total amount of green subsidies)
	Patent retention status	PRS	ln (Lagged count of authorized green patents + 1)
	Non-green subsidies	NGS	ln (Residual government subsidies after excluding green subsidies)
Control variable	Scale	SCA	ln (Total assets in financial statements)
	Tenure	TEN	Count of years a company has been in operation
	Debt-to-asset ratio	DAR	Ratio of total liabilities to total assets
	Fixed asset ratio	FAR	Ratio of net fixed assets to total assets
	Growth capability	GC	(Current revenue − Previous revenue) / Previous revenue × 100 %
	Ownership concentration	OC	Proportion of total shares held by the largest shareholder
	Compensation incentives	CI	ln (total compensation for management (Directors, Supervisors, and Executives))

Growth in patent applications may be shaped by a range of factors, such as spatial distribution, industrial structure, and time influences [22]. To address potential endogeneity and systematically control for variation due to policy shifts, macroeconomic fluctuations, and external shocks, our empirical specification includes region, industry, and time fixed effects. These controls mitigate biases resulting from unobserved variables and external disturbances, thus ensuring robust estimates. Considering that firms with stronger innovation capabilities tend to engage in continuous innovation activities [80], R&D expenditures are immediately recorded in financial statements, whereas innovation output often materialize with a delay. Therefore, this research adopts the approach of Wang and Hagedoorn [81], utilizing one-period-ahead innovation output as the dependent variable. This specification ensures the temporal precedence of green subsidies relative to innovation outcomes, thereby effectively mitigating concerns regarding reverse causality. The detailed specifications of the multidimensional fixed-effects models are as follows:

$$y_{ijt}\left(RDE_{ijt},\ RDI_{ijt}\right) = \alpha_0 + \alpha_1 GS_{ijt} + \sum \alpha_k \cdot controls_{ijt} + \mu_i + \xi_j + \tau_t + \varepsilon_{ijt} \tag{2}$$

$$y_{ij,t+1}\left(GP_{ij,t+1},\ GIP_{ij,t+1},\ GUP_{ij,t+1}\right) = \beta_0 + \beta_1 GS_{ijt} + \sum \beta_k \cdot controls_{ijt} + \mu_i + \xi_j + \tau_t + \varepsilon_{ijt} \tag{3}$$

In this model, RDE_{ijt} and RDI_{ijt} represent the R&D expenditure and R&D intensity of firms located in region i and operating in industry j during period t, respectively. GS_{ijt} denotes the green subsidies received by firms located in region i and operating in industry j during period t. $GP_{ij,t+1}$, $GIP_{ij,t+1}$ and $GUP_{ij,t+1}$ represent the number of green patent applications, green invention patent applications, and green utility patent applications submitted by firms in region i and industry j in the year of $t+1$, respectively. The term $controls_{ijt}$ refers to all control variables listed in Table 1. μ_i, ξ_j and τ_t denote the fixed effects for region, industry, and time, respectively.

3.4. Robustness checks

To verify the stability of our results, the model is re-estimated without time fixed effects, while region and industry fixed effects are maintained. This approach allows us to examine whether the benchmark findings remain consistent in the absence of year-specific shocks and to evaluate the sensitivity of the estimates to temporal heterogeneity. We further restrict the sample period to 2010–2019 to reinforce the robustness of our conclusions, which corresponds to China's 12th and 13th Five-Year Plans and represents a critical stage during the evolution of green subsidy policies.

Additionally, we conduct robustness checks by using alternative green innovation indicators to re-specify the dependent variables, while keeping the explanatory variables and the sample period unchanged. Specifically, *authorized green patents, authorized green invention patents*, and *authorized green utility patents* are employed as alternative measures of innovation output to verify the benchmark results. The specific model is specified as follows:

$$y_{ij,t+1}\left(AGP_{ij,t+1},\ AIP_{ij,t+1},\ AUP_{ij,t+1}\right) = \alpha_0 + \alpha_1 GS_{ijt} + \sum \alpha_k \cdot controls_{ijt} + \mu_i + \xi_j + \tau_t + \varepsilon_{ijt} \tag{4}$$

When governments allocate green subsidies, they may preferentially select firms based on specific criteria, such as higher technological capabilities, potentially resulting in sample selection bias [82]. Given potential endogeneity problems arising from such selection biases and unobserved variables, prior studies commonly utilize IV approaches to mitigate these concerns. However, IVs must satisfy stringent validity conditions, including relevance and exogeneity. This challenge is further exacerbated in the three-way fixed-effects model employed in this study, since locating a suitable instrument that remains valid across all three dimensions is especially difficult [83,84]. While PSM improves comparability between treatment and control groups by adjusting for observed covariates, it cannot adequately address biases caused by unobserved heterogeneity [85].

To overcome these limitations, this study adopts a more robust empirical framework by combining IV estimation and the Heckman two-stage method. We adopt an instrumental variable strategy using the mean green subsidy allocation to peer firms in the same industry and region [86], and conduct the estimation using two-stage least squares (2SLS). In addition, the Heckman model addresses potential sample selection bias by constructing a selection equation that corrects for non-random sample inclusion within the regression framework. A Probit model is first used to estimate the selection probability, from which the inverse Mills ratio (IMR) is derived. This term, calculated from the linear prediction component ηZ_{ijt}, reflects the conditional likelihood of being selected into the sample. It is subsequently included as an adjustment for selection endogeneity. The specific models are as follows:

$$\Pr(GS_{ijt}=1) = \Phi(\eta Z_{ijt}) = \gamma_0 + \gamma_1(GS_{ij,t-1}) + \gamma_2(PRS_{ijt}) + \sum \gamma_k \cdot controls_{ijt} + \mu_i + \xi_j + \tau_t + \varepsilon_{ijt} \tag{5}$$

$$\widehat{\lambda}(\eta Z_{ijt}) = \frac{\phi(\eta Z_{ijt})}{\Phi(\eta Z_{ijt})} \tag{6}$$

Here, the green subsidy received by a firm located in region i and operating in industry j during period $t-1$ is denoted by $GS_{ij,t-1}$, and the patent retention status of a firm in region i and industry j during period t is denoted by PRS_{ijt}. $\widehat{\lambda}(\eta Z_{ijt})$ denotes the inverse Mills ratio (IMR), where $\phi(\cdot)$ represents the standard normal probability density function, and $\Phi(\cdot)$ indicates its cumulative distribution function.

With the inclusion of the IMR, the second-stage regressions quantify how green subsidies influence both the input and output of green innovation at the firm level, thereby effectively mitigating endogeneity issues arising from sample selection bias. The models are specified as follows:

$$y_{ij,t}(RDE_{ijt},\ RDI_{ijt}) = \delta_0 + \delta_1 GS_{ijt} + \delta_2 NGS_{ijt} + \rho\sigma\widehat{\lambda}(\eta Z_{ijt}) + \sum \delta_k \cdot controls_{ijt} + \mu_i + \xi_j + \tau_t + \varepsilon_{ijt} \tag{7}$$

$$y_{ij,t+1}(GP_{ij,t+1},\ GIP_{ij,t+1}) = \delta_0 + \delta_1 GS_{ijt} + \delta_2 NGS_{ijt} + \rho\sigma\widehat{\lambda}(\eta Z_{ijt}) + \sum \delta_k \cdot controls_{ijt} + \mu_i + \xi_j + \tau_t + \varepsilon_{ijt} \tag{8}$$

Here, the non-green subsidies received by firms in region i and industry j during period t are denoted as NGS_{ijt}, and this variable is used to capture the impact of non-environmental or general-purpose subsidies.

In addition, to investigate variation in the effectiveness of green subsidies across firm categories and to improve the generalizability of the findings, this research conducts heterogeneity analyses. These tests evaluate whether the impacts of green subsidies remain consistent across firms with varying characteristics and contexts, thereby strengthening the robustness and applicability of the conclusions.

To summarize, Fig. 1 illustrates the overall empirical framework of this study, encompassing the benchmark regression and robustness check.

4. Empirical results

4.1. Descriptive statistics

According to the descriptive statistics in Table 2, R&D expenditure is relatively concentrated across firms. However, R&D intensity shows substantial variation, with some firms lagging in advancing green innovation during specific periods. Despite the active pursuit of green patents by most corporations, the overall number remains limited. The standard deviation of green subsidy amounts is 6.618, signifying considerable variability in the subsidies allocated to various firms. The minimal standard deviations for firm size, years of establishment, and remuneration incentives indicate that these attributes are reasonably uniform among the sample companies. Nonetheless, there is significant heterogeneity in firms' debt-to-asset ratios, fixed asset proportions, and growth potential.

Table 2
Descriptive statistics.

Variable	N	Mean	Std. Dev.	Min	Max
R&D expenditure	29,316	17.638	1.652	0	24.104
R&D intensity	29,316	4.608	5.447	0	137.45
Green patent applications	29,316	2.478	22.319	0	1166
Green invention patent applications	29,316	1.583	16.898	0	848
Green utility patent applications	29,316	0.896	6.927	0	436
Green subsidy	29,316	10.282	6.618	0	24.642
Scale	29,316	22.157	1.351	15.556	28.636
Tenure	29,316	17.965	5.737	2	30
Debt-to-asset ratio	29,316	0.448	0.22	0	1.997
Fixed asset ratio	29,316	0.225	0.168	0	0.971
Growth capability	29,316	0.235	1.219	−2.733	45.875
Ownership concentration	29,316	34.717	15.072	0.286	89.986
Compensation incentives	29,316	15.158	0.813	10.437	18.78

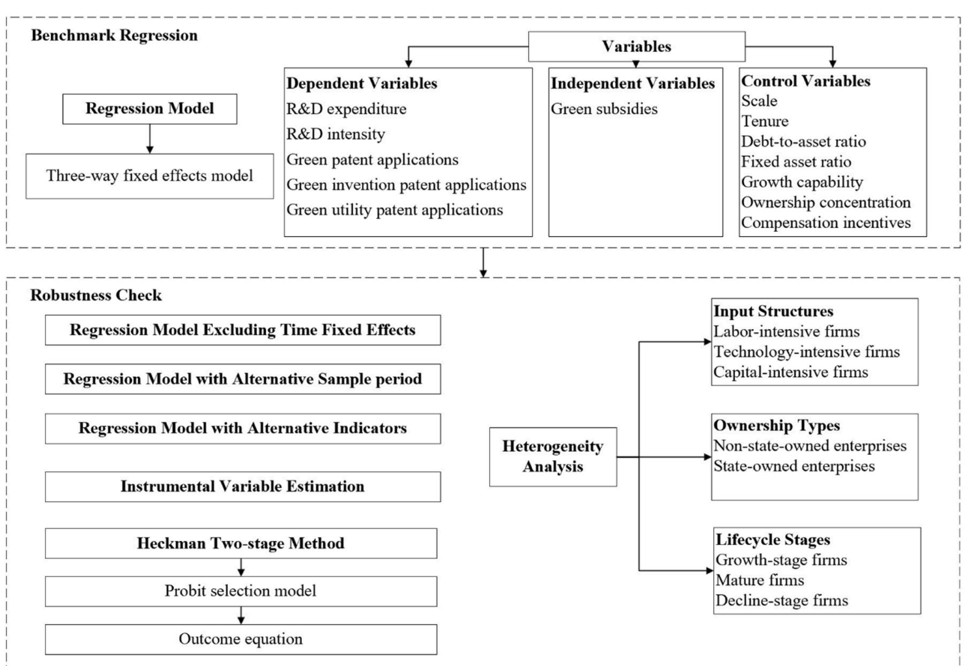

Fig. 1. Empirical framework.

4.2. Benchmark results

After confirming the absence of multicollinearity among the variables, regression analyses were conducted using the three-way fixed effects models. The empirical estimates, as reported in Table 3, reveal that green subsidies significantly increase both R&D expenditure (0.0155***) and R&D intensity (0.0368***), while the direct impact on innovation outcomes is relatively less significant, thereby supporting Hypothesis 1. Such discrepancy supports the idea that, while financial incentives, such as subsidies, can effectively alleviate R&D constraints and encourage firms to increase research investment, the transformation of such input into tangible innovation outcomes often involves a time lag. Factors such as long R&D cycles, organizational inefficiencies, or the lack of absorptive capacity may hinder the timely realization of innovation outcomes [87].

To visualize the divergence more effectively, we construct a forest plot of the independent variables (see Fig. 2). The horizontal axis represents the estimated coefficients, indicating how independent variables affect the dependent variables in terms of both direction and scale. The vertical axis lists the types of dependent variables. Each horizontal line depicts the 95 % confidence interval. Intervals fully positioned to the right or left of zero denote significant positive or negative effects, respectively. Confidence intervals that cross zero suggest that the variable's effect is considered statistically insignificant. As shown in the figure, innovation input exerts a significantly positive effect, whereas the effects of innovation output variables are relatively negligible.

To illustrate the impact of control variables more clearly, this paper also presents a bar plot (Fig. 3) based on the benchmark regression. In the plot, control variables are arranged on the x-axis, while the y-axis reflects their estimated effects. The color of each bar reflects the direction and magnitude of the effect. Bars shift toward red as the magnitude of positive effects increases, and toward blue as negative effects become more pronounced. The black lines represent the 95 % confidence intervals, and asterisks on the bars indicate that the corresponding coefficients are statistically significant.

Interestingly, larger organizations are more likely to use subsidies to advance green technologies (3.4996***) rather than solely pursuing strategic innovation (0.9449***). However, their spending intensity is declining (−0.7506***), suggesting a conservative approach to the allocation of R&D resources. These findings support the idea that larger firms often exhibit a preference for stability and efficiency over risk-taking. The presence of hierarchical decision-making and internal accountability mechanisms may lead firms to focus on incremental improvements and output maximization, rather than increasing high-risk investment [88].

In contrast to earlier research indicating that firms with elevated debt ratios depend on subsidies to enhance their operations as well as technological advancement [89], our results demonstrate that a rise in a company's debt-to-asset ratio constrains green innovation activities. Both green innovation input (−4.3494***) and innovation output (−4.9497***) exhibit a downward trend. This outcome may suggest that an elevated debt ratio amplifies financial strain on companies, thereby diminishing their participation in high-risk green innovation initiatives. Although profitability and ownership concentration have improved, R&D investment has not risen correspondingly; rather, it has diminished (growth capability −0.1641***, ownership concentration −0.0368***). This may be due to the preference of significant shareholders for consistent profitability, resulting in a tendency to avoid high-risk activities and long-term innovation endeavors. Despite a rise in revenue, allocating cash to innovation projects remains challenging.

4.3. Robust test

4.3.1. Excluding time fixed effects

In the benchmark regression, time fixed effects are incorporated to capture systematic temporal trends in green subsidy policies and to account for unobservable time-varying factors such as macroeconomic policy orientations and business cycles that may influence firms' engagement in eco-innovation. To evaluate whether policy changes over time moderate the effect of green subsidies, we further estimate a model that includes only industry and region fixed effects (see Table 4). The findings confirm a consistently significant positive association between green subsidies and innovation input, while their effect on output remains non-significant. Although the direction of the coefficients reflects a similar pattern to that found in the baseline specification, the magnitude of the effects is notably reduced. This suggests that green subsidies serve as incentives, to some extent, reinforced by the broader temporal policy environment, underscoring the importance of controlling for year fixed effects in the empirical specification.

Table 3
Results of the three-way fixed effects model.

	(1) R&D expenditure	(2) R&D intensity	(3) Green patent applications	(4) Green invention patent applications	(5) Green utility patent applications
Green subsidy	0.0155***	0.0368***	0.0356*	0.0275*	0.0082
	(0.0017)	(0.0066)	(0.0212)	(0.0161)	(0.0066)
Scale	0.5929***	−0.7506***	3.4996***	2.5547***	0.9449***
	(0.0108)	(0.0434)	(0.1356)	(0.1029)	(0.0423)
Tenure	−0.0356***	−0.0960***	−0.0441	−0.0117	−0.0323***
	(0.0021)	(0.0081)	(0.0271)	(0.0206)	(0.0085)
Debt-to-asset ratio	−0.7890***	−4.3494***	−4.9497***	−4.0802***	−0.8695***
	(0.0557)	(0.2244)	(0.6761)	(0.5129)	(0.2106)
Fixed asset ratio	−0.7082***	−4.5684***	0.9028	0.5641	0.3387
	(0.0672)	(0.2699)	(0.8037)	(0.6098)	(0.2504)
Growth capability	0.0022	−0.1641***	−0.1673	−0.1173	−0.0500
	(0.0097)	(0.0412)	(0.1053)	(0.0799)	(0.0328)
Ownership concentration	−0.0042***	−0.0368***	−0.0097	−0.0032	−0.0065**
	(0.0007)	(0.0027)	(0.0090)	(0.0068)	(0.0028)
Compensation incentives	0.3914***	0.7787***	−0.0916	−0.2123	0.1207*
	(0.0167)	(0.0665)	(0.2127)	(0.1614)	(0.0663)
Constant	−0.3316	14.6867***	−70.8595***	−50.0371***	−20.8224***
	(0.2369)	(0.9518)	(2.9429)	(2.2327)	(0.9167)
N	18,611	17,080	29,316	29,316	29,316
R-squared	0.3698	0.1732	0.0451	0.0411	0.0380
Year FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes

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

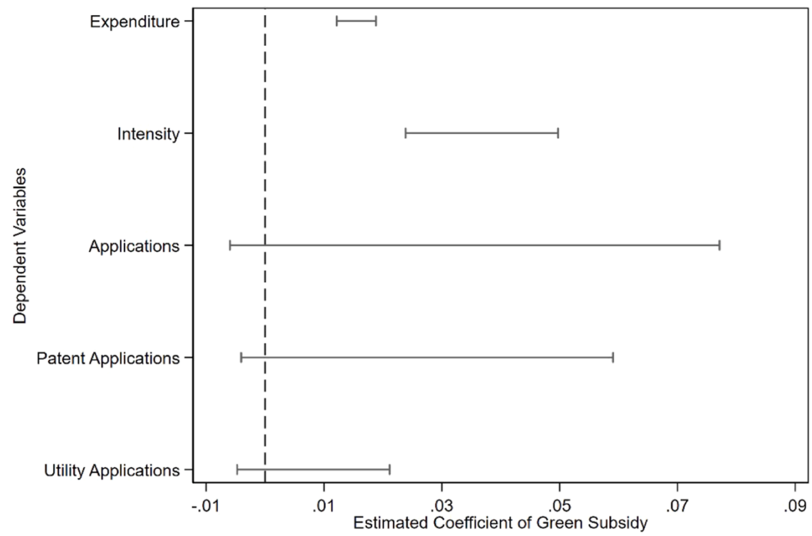

Fig. 2. Estimated effects of green subsidy.

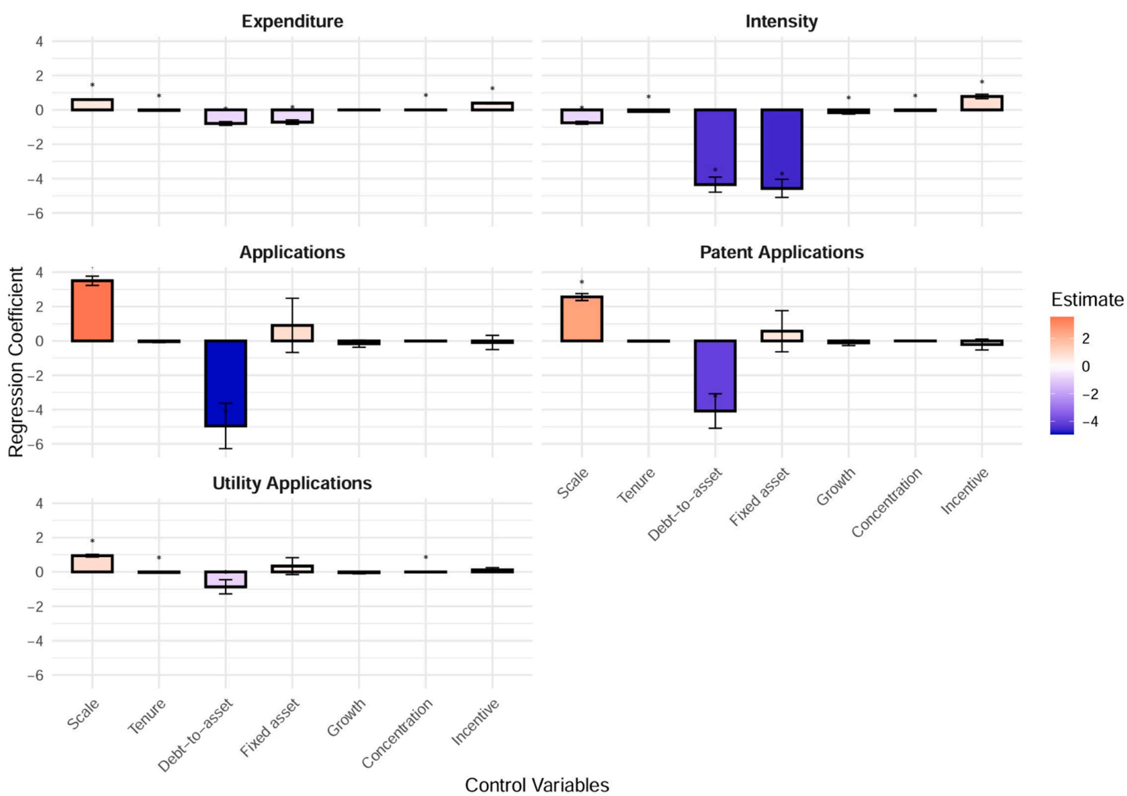

Fig. 3. Bar plot of effects of control variable.

4.3.2. *Alternative sample period*

Given that China's green development policies were actively promoted during the 12th and 13th Five-Year Plans, with the green subsidy system gradually established and refined, we restrict the sample period to 2010–2019 to capture this critical phase of concentrated policy implementation (see Table 5). Empirical findings suggest that, within this timeframe, the estimated effects of green subsidies on firms' environmental innovation efforts and their results remain consistent with the benchmark regression, with only minor differences in coefficient magnitudes. These observations uphold the robustness of the results and suggest that green subsidies continued to play a stable and positive role in promoting corporate innovation under a more proactive green policy environment.

4.3.3. *Alternative measure of green innovation*

When examining innovation quality, some scholars use the count of patent citations as a metric to reflect the significance and value of technological patents [90]. However, patent citations are strongly influenced by the time since the patent's publication, and citation data from public firms can be affected by the size of their patent portfolio [91]. In contrast, authorized green patents are granted more promptly due to the fast-track process for green patents, making them a timely indicator of eco-technology innovation [92]. Thus, this study substitutes indicators of authorized green patents as alternative dependent

Table 4
Results of the two-way fixed effects model.

	(1) R&D expenditure	(2) R&D intensity	(3) Green patent applications	(4) Green invention patent applications	(5) Green utility patent applications
Green subsidy	0.0085***	0.0194***	0.0312	0.0239	0.0073
	(0.0029)	(0.0074)	(0.0580)	(0.0434)	(0.0154)
Controls	Yes	Yes	Yes	Yes	Yes
Constant	−1.8694	11.7024***	−70.6463***	−49.4191***	−21.2272***
	(1.1378)	(1.7758)	(24.6051)	(17.8878)	(7.2927)
N	18,608	17,079	29,312	29,312	29,312
R-squared	0.3547	0.1675	0.0445	0.0405	0.0375
Province FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes

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

Table 5
Results based on an alternative sample period (2010–2019).

	(1) R&D expenditure	(2) R&D intensity	(3) Green patent applications	(4) Green invention patent applications	(5) Green utility patent applications
Green subsidy	0.0150***	0.0347***	0.0540	0.0408	0.0133
	(0.0040)	(0.0096)	(0.0569)	(0.0433)	(0.0142)
Controls	Yes	Yes	Yes	Yes	Yes
Constant	−0.2348	14.3954***	−70.9795***	−49.6803**	−21.2992***
	(1.2324)	(1.5994)	(26.7405)	(19.5269)	(7.8097)
N	16,212	15,202	20,835	20,835	20,835
R-squared	0.3545	0.1689	0.0466	0.0409	0.0417
Year FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes

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

variables in robustness checks, while maintaining the same control variables and fixed effects to ensure comparability. The findings are presented in Table 6.

The results indicate that green subsidies positively influence the authorization of green patents, particularly by increasing the number of authorized patents, a trend that surpasses the effect observed for green patent applications. When patents lack formal protection, companies often encounter competitive and financial disadvantages, which can dampen their enthusiasm for further green patent R&D [93]. Conversely, authorized patents provide stable and sustained economic benefits, encouraging companies to leverage green subsidies for green patent development. According to the China 2024 Green Low-Carbon Patent Statistical Analysis Report, authorized green technology patents in China grew at an average annual rate of 9.7 % from 2016 to 2023, with more than half of the patent holders being publicly listed companies. Hence, the robustness checks confirm that subsidies consistently foster corporate innovation, regardless of the innovation output indicator employed. These findings confirm the strong incentive that green subsidies provide for corporate innovation investment, underscoring the credibility and wide applicability of the research results.

Table 6
Results based on alternative indicators.

	(1) Authorized Green Patents	(2) Authorized Green Invention Patents	(3) Authorized Green Utility Patents
Green subsidy	0.1052***	0.0599***	0.0453***
	(0.0241)	(0.0132)	(0.0147)
Controls	Yes	Yes	Yes
Constant	−95.8640***	−38.6506***	−57.2134***
	(3.3448)	(1.8392)	(2.0379)
N	29,316	29,316	29,316
R-squared	0.1025	0.0550	0.1040
Year FE	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

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

4.3.4. *Instrumental variable approach*

Although the benchmark results already demonstrate that green subsidies exert a positive and significant influence on corporate green innovation efforts, the IV regression (Table 7) further enhances the identification of the causal relationship by addressing potential endogeneity concerns. Specifically, the instrumental variable is constructed as the average green subsidy granted to other enterprises within the same industry and location. Both the under identification and weak identification tests yield statistically significant results, verifying the instrument's relevance and the consistency of the estimation results. Moreover, after controlling for endogeneity, green subsidies' contribution to improved innovation output becomes even more pronounced, suggesting that the benchmark estimates may have understated the true impact. Given the potential systematic differences in how firms convert subsidies into innovation outcomes, we further conduct a heterogeneity analysis to explore how the effectiveness of green subsidies varies across firms with different characteristics.

4.3.5. *Heckman two-stage method*

As reported in Table 8, the Heckman two-stage estimation reveals that the IMR is negative and statistically significant, suggesting potential bias arising from non-random sample selection. Due to the non-random nature of subsidy distribution, the results may obscure the true innovation-enhancing effects of green subsidies. The Heckman method addresses this bias, thereby improving estimation accuracy and revealing a significant direct effect on innovation output. In the selection model, the coefficients for green subsidies are positive and significant, which aligns with expectations that the government favors certain firms in subsidy allocation. Additionally, the presence of existing patents significantly increases the likelihood of subsidy receipt, further supporting that innovation-driven firms tend to receive larger allocations of

Table 7
Results of IV estimation.

	(1) R&D expenditure	(2) R&D intensity	(3) Green patent applications	(4) Green invention patent applications	(5) Green utility patent applications
Green subsidy (IV)	0.1372***	0.4146***	0.8846**	0.6484**	0.2362**
	(0.0269)	(0.1449)	(0.4310)	(0.3279)	(0.1094)
Controls	Yes	Yes	Yes	Yes	Yes
Constant	−0.0017	21.5548***	−64.6657***	−45.2594***	−19.4062***
	(1.1881)	(3.6135)	(22.3676)	(16.0279)	(6.8852)
N	18,364	16,919	28,719	28,719	28,719
R-squared	0.1900	0.0194	−0.0057	−0.0061	−0.0003
Year FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Under identification test (p-value)	0.000	0.000	0.000	0.000	0.000
Weak identification test (Cragg-Donald Wald F statistic)	502.699	352.174	1018.544	1018.544	1018.544

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

Table 8
Heckman two-stage regression results.

	(1) R&D expenditure	(2) R&D intensity	(3) Green patent applications	(4) Green invention patent applications
Green subsidy	0.1561***	0.1829***	1.2248***	0.6063***
	(0.0060)	(0.0222)	(0.0842)	(0.0475)
Non-green subsidy	−0.0010	0.0099	−0.2453***	−0.1291***
	(0.0023)	(0.0088)	(0.0295)	(0.0167)
Constant	16.4433***	10.9619***	2.5113	−0.7995
	(0.1231)	(0.4591)	(1.8584)	(1.0258)
IMR	−1.7219***	−6.5019***	−28.2738***	−10.6847***
	(0.1275)	(0.4708)	(2.4848)	(1.3234)
Selection model results				
Green subsidy	0.1961***	0.1942***	0.1745***	0.1745***
	(0.0037)	(0.0037)	(0.0027)	(0.0027)
Patent retention status	0.1023***	0.1198***	0.0365***	0.0365***
	(0.0115)	(0.0116)	(0.0102)	(0.0102)
Controls	Yes	Yes	Yes	Yes
N	22,109	20,880	29,316	29,316
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

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

subsidies. By incorporating the Heckman method, this study offers a thorough assessment of the contribution of green subsidy policies to advancing corporate innovation, as reflected in both specific and broader innovation outcomes.

4.4. Heterogeneity analysis

Moreover, to account for potential firm-level heterogeneity and enhance understanding of the pathways through which firm characteristics influence the effect of green subsidies, this study adopts the approach of Guo [94] and conducts heterogeneity analyses across three dimensions: input structures (labor-intensive, technology-intensive, and capital-intensive), ownership types (non-state-owned enterprises and state-owned enterprises), and lifecycle stages (growth, mature, and

Table 10
Heterogeneity analysis (2): by ownership types.

	Non-state-owned enterprises		State-owned enterprises	
	(1) R&D expenditure	(2) Green patent applications	(3) R&D expenditure	(4) Green patent applications
Green subsidy	0.0111***	0.0551***	0.0244***	0.0542
	(0.0018)	(0.0136)	(0.0035)	(0.0421)
Controls	Yes	Yes	Yes	Yes
Constant	−0.4678*	−38.1549***	−0.3669	−90.3437***
	(0.2730)	(2.0172)	(0.5073)	(6.2152)
N	12,031	16,892	6360	12,070
R-squared	0.3810	0.0403	0.3784	0.0613
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

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

Table 9
Heterogeneity analysis (1): by input structures.

	Labor-intensive firms		Technology-intensive firms		Capital-intensive firms	
	(1) R&D expenditure	(2) Green patent applications	(3) R&D expenditure	(4) Green patent applications	(5) R&D expenditure	(6) Green patent applications
Green subsidy	0.0217***	0.1733***	0.0080***	−0.1159***	0.0115***	0.0253**
	(0.0043)	(0.0534)	(0.0014)	(0.0419)	(0.0035)	(0.0099)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.8996	−77.6276***	−5.3624***	−147.6271***	1.1439**	−9.6418***
	(0.6379)	(7.8507)	(0.2067)	(6.1096)	(0.4950)	(1.3787)
N	3931	7859	8588	10,530	4357	6702
R-squared	0.3609	0.0736	0.7039	0.0836	0.3417	0.0641
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes

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

decline). The corresponding results are presented in Tables 9–11. These analyses furnish policymakers with a novel perspective, contesting the conventional belief that "adequate funding ensures corporate innovation" and presenting empirical data for the examination of diverse policies customized for various sorts of organizations.

4.4.1. Heterogeneity analysis: input structures

Table 9 reveals substantial differences in innovation responses to green financial support, with variation linked to firms' input structures. In labor-intensive enterprises, subsidies markedly enhance both the R&D input (0.0217***) and output (0.1733***). Labor-intensive enterprises, due to their unique resource integration capabilities, can maintain a cost advantage in production and innovation, thereby reducing their reliance on subsidies [95]. Labor productivity does not inherently diminish with an expanding workforce, and subsidies assist labor-intensive enterprises in mitigating budgetary limitations [96]. The straightforward manufacturing procedures of these enterprises enable them to rapidly transform subsidies into inputs for innovation. Thus, providing subsidies for the labor expenses of green firms is a highly effective approach to both pollution reduction and the promotion of green industry growth [97].

For technology-intensive enterprises, the influence of subsidies on the R&D input is negligible (0.0080***); more notably, subsidies appear to significantly hinder innovation output (−0.1159***). Technology-intensive companies encounter prolonged R&D cycles and substantial capital requirements, rendering subsidies inadequate to offset the elevated R&D expenses. This results in a misallocation of resources, as companies redirect funding intended for innovation into alternative pursuits (such as short-term profit projects), thus stifling innovation output. In capital-intensive enterprises, the contribution of subsidy policies to green innovation input is limited (0.0115***), although the effect on output is considerably greater (0.0253**). The marginal expense of undertaking green innovation for capital-intensive enterprises declines with increased innovation output, allowing green subsidies to have a stronger impact.

To illustrate the effects separately, this paper presents a forest plot (see Fig. 4), while appendix A reports the regression outcomes for the control variables. Fig. 4 shows that green subsidies contribute significantly and positively to both R&D investment and patent output for labor-intensive firms. In contrast, they exhibit a significant negative effect on green output for technology-intensive firms, suggesting heterogeneous incentive effects of subsidies across different types of enterprises.

4.4.2. Heterogeneity analysis: ownership types

The findings in Table 10 show that green subsidies substantially enhance both R&D investment (0.0111***) and patent output (0.0551***) in non-state-owned enterprises (non-SOEs). These firms typically possess more transparent ownership structures and, due to market competition, their owners are more focused on the efficient allocation of resources. Consequently, following the receipt of subsidies, they are more predisposed to augment R&D expenditure to garner increased investment interest and social resources.

Although prior research suggests that SOEs face lower financial constraints due to implicit government backing, which is thought to enhance their green innovation capabilities [98], this study finds a contrasting outcome. To facilitate comparison, we present the results in a forest plot. As shown in Fig. 5, the effect of green subsidies on SOEs is clearly less pronounced. Under the influence of green subsidies, SOEs exhibit a slight increase in R&D investment (0.0244***); however, there is no significant improvement in patent output (0.0542). This outcome is consistent with agency theory, which posits that while the operational aims of SOEs are closely aligned with societal objectives, the absence of competitive pressure diminishes management's incentives for innovation. Consequently, resource allocation is inefficient, hindering the effective conversion of R&D investment into innovative output.

4.4.3. Heterogeneity analysis: lifecycle stages

This study follows Dickinson [99] in classifying firms into growth, mature, and decline phases, based on the net cash flows from core financial activities. The findings in Table 11 indicate that although green subsidies do not significantly increase R&D expenditure for mature firms (0.0079***), their patent output (0.1232***) far exceeds that of firms in the growth and decline stages. Growth-stage firms, while characterized by dynamic innovation potential and rapid expansion [100], also face greater risks stemming from technological and market uncertainties. These risks make it more difficult for such firms to consistently translate innovation efforts into stable patent outputs. However, mature enterprises, characterized by substantial cash flow and considerable market expertise, help alleviate innovation-related uncertainty for firms at varying points in their life cycle [101]. In this process, subsidies act as a catalyst, helping mature enterprises convert accumulated knowledge and technological resources into tangible green innovation outcomes. Companies in the decline stage, limited by obsolete technology and competitive market forces, find it challenging to adapt to rapidly changing markets. The opportunity cost of innovative activities is elevated for these enterprises, resulting in constrained innovation output despite the availability of green subsidies.

As presented in the forest plot of coefficient estimates (Fig. 6), the coefficient for patent applications in mature firms exhibits the notable positive effect among all subgroups. Additionally, green subsidies have significantly increased R&D expenditure among firms at all stages of the life cycle.

5. Conclusion and discussion

Drawing on panel data covering Chinese A-share listed firms from 2007 to 2022, this study explores how green subsidies affect green

Table 11
Heterogeneity analysis (3): by lifecycle stages.

	Growth-stage firms		Mature firms		Decline-stage firms	
	(1) R&D expenditure	(2) Green patent applications	(3) R&D expenditure	(4) Green patent applications	(5) R&D expenditure	(6) Green patent applications
Green subsidy	0.0148***	0.0232	0.0079***	0.1232***	0.0311***	−0.0805*
	(0.0025)	(0.0266)	(0.0027)	(0.0431)	(0.0042)	(0.0414)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.2847	−61.1520***	−0.4503	−98.6756***	0.0809	−45.6965***
	(0.3520)	(3.6930)	(0.3837)	(6.1040)	(0.6216)	(6.0509)
N	8441	12,768	6771	10,614	3367	5853
R-squared	0.3634	0.0397	0.3940	0.0748	0.3605	0.0228
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes

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

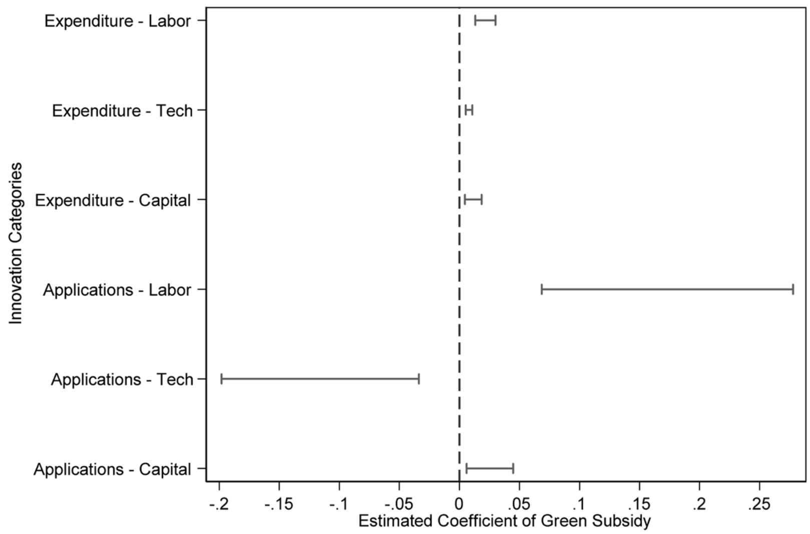

Fig. 4. Forest plot of the effects by input structures.

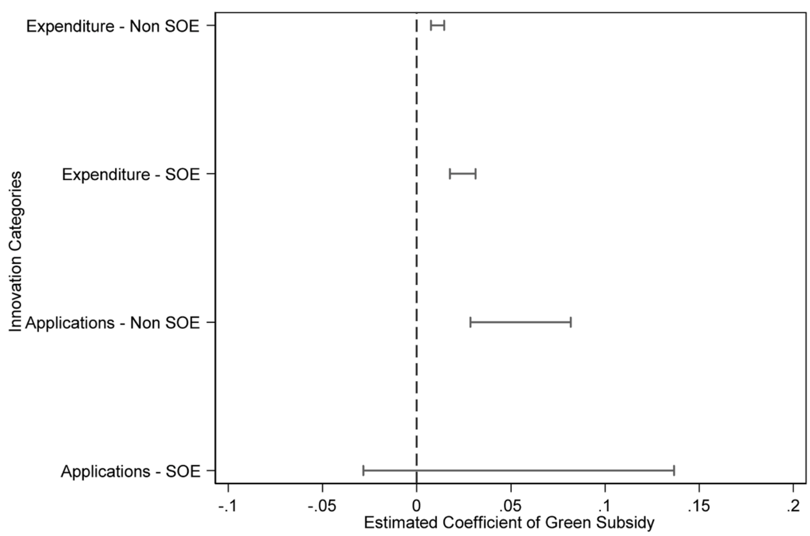

Fig. 5. Forest plot of the effects by ownership types.

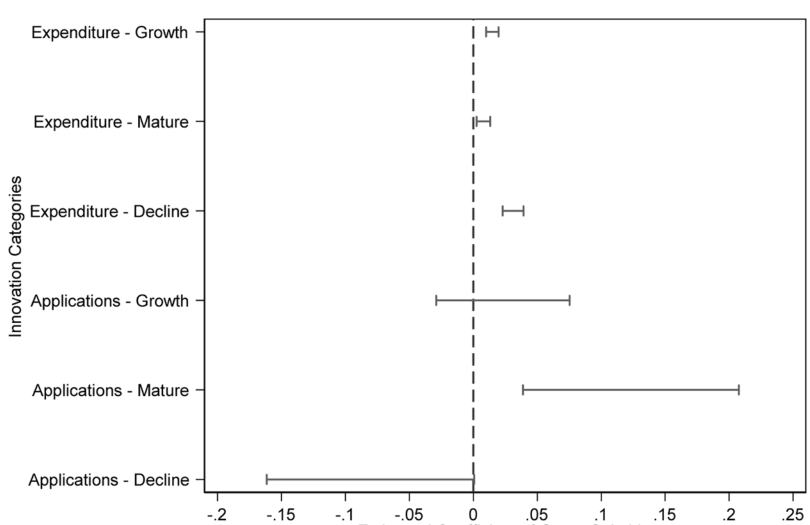

Fig. 6. Forest plot of the effects by lifecycle stages.

innovation. A three-way fixed effects model and heterogeneity analysis are employed, and several methods are incorporated to strengthen the robustness of the findings.

The findings indicate that green subsidies substantially promote firms' R&D investment, while their direct impact on innovation output remains relatively limited. Further heterogeneity analysis shows that green subsidies have a stronger positive effect on innovation output in labor-intensive firms, whereas a negative effect is observed in technology-intensive firms. Non-SOEs derive more benefit from green subsidies than SOEs. In terms of firm lifecycle, green subsidies significantly stimulate R&D input in growth-stage and declining firms, while mature firms exhibit greater efficiency in converting R&D into green patent output. This study contributes by identifying the heterogeneous influence of green subsidies depending on firm-level features, particularly the adverse effects observed in highly leveraged or technology-intensive firms. The results not only highlight the positive role of green subsidies in encouraging sustainable innovation but also underscore the limitations of a uniform policy design, suggesting the need for more tailored and adaptive policy frameworks.

Drawing on the empirical findings, several recommendations are suggested: (1) The government should establish a specialized review committee to assess firms' R&D capabilities and innovation potential to ensure subsidies target firms with genuine innovation potential. (2) A responsive oversight mechanism should be implemented, considering firm-level operational realities. After subsidies are distributed, the government should conduct periodic evaluations of enterprises' operational and financial conditions and monitor R&D progress to ensure the efficient use of subsidy resources. (3) Green subsidy schemes should be tailored to the demonstrated innovation performance of firms. Companies with high innovation conversion rates should receive increased subsidy intensity upon meeting industry standards or performance criteria. For firms with significant technical complexity and high R&D expenditures, flexible subsidy strategies, including tax incentives and R&D support initiatives, should be considered. (4) Finally, the government should enhance oversight mechanisms to ensure the effective allocation and utilization of green subsidies by companies. Those that use subsidies effectively should be rewarded with enhanced support, while firms that misuse subsidies or provide fraudulent claims should face reduced funding. This would ensure fairness and effectiveness in policy implementation.

Although this study offers significant empirical insights into how green subsidies influence green innovation, it has its limitations. Relying solely on green subsidies may be insufficient to drive green innovation effectively, as changes in the external environment could also influence corporate development strategies and innovation investments. Future research should consider external factors and explore the synergistic effects of green subsidies with other policy tools, such as tax incentives and green finance. Furthermore, if data on the timing of specific policy implementation becomes available, applying a DID methodology would provide stronger causal inferences regarding corporate innovation responses to green subsidy policies.

CRediT authorship contribution statement

Shuyi Liu: Writing – original draft, Validation, Investigation, Formal analysis, Conceptualization, Writing – review & editing. **Ning Ba:** Writing – original draft, Visualization, Software, Resources, Methodology, Data curation, Writing – review & editing. **Yu Hao:** Writing – original draft, Supervision, Project administration, Funding acquisition, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Building upon the heterogeneity analysis of the selected control variables, several key patterns emerge across different firms. As shown in Fig. A.1, firm size consistently exhibits a positive effect on green innovation, particularly in technology-intensive firms, where its impact on innovation output is most pronounced. This suggests that larger firms possess superior capabilities in resource integration and allocation, enabling them to effectively convert green subsidies into R&D investment and technological breakthroughs. In contrast, leverage and the fixed asset ratio generally exert negative effects, indicating that heavier financial structures may reduce firms' operational flexibility and hinder green innovation. However, for capital-intensive firms, both leverage and fixed asset intensity positively contribute to green innovation. This may reflect the inherent dependence of such firms on physical capital, coupled with their greater demand for external financing. When leverage is high, their marginal reliance on external funding increases, making them more responsive to policy incentives, such as green subsidies, as a means to ease financial constraints and improve capital efficiency. These patterns are not fully captured in the benchmark regression, underscoring the value of heterogeneity analysis in revealing differentiated policy effects across firm types. Other control variables, such as firm age and revenue growth, although showing relatively small coefficients, remain statistically significant, suggesting their relevance in shaping firms' long-term resilience and innovation capacity.

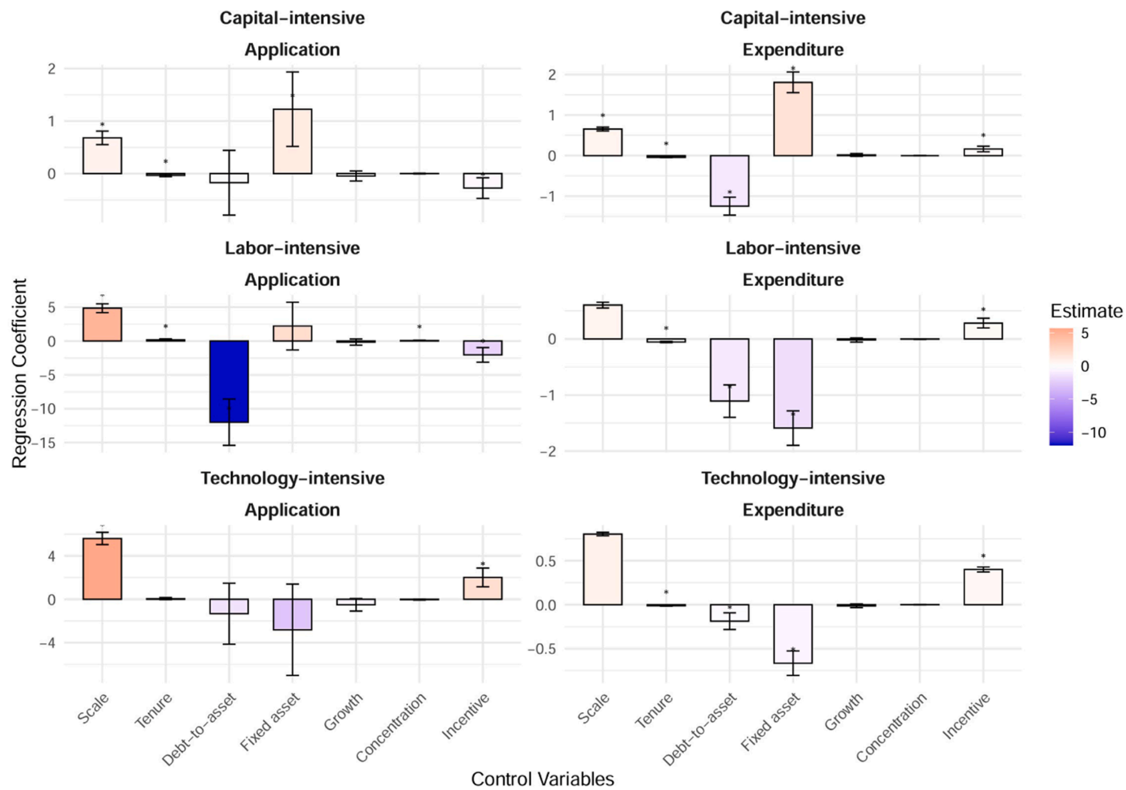

Fig. A.1. Bar plot of control variable effects by input structure.

Regarding ownership types (see Fig. A.2), firm size demonstrates a positive impact again. Notably, performance incentives demonstrate greater effectiveness in promoting green R&D input and output among non-SOEs. Compared to SOEs, non-SOEs are typically governed by stronger incentive contracts and performance-driven mechanisms, which increase managerial responsiveness to subsidies and improve resource allocation efficiency. While leverage and fixed assets mostly exert negative effects, moderate levels of leverage under manageable risk may still facilitate green innovation output in non-SOEs by alleviating funding constraints.

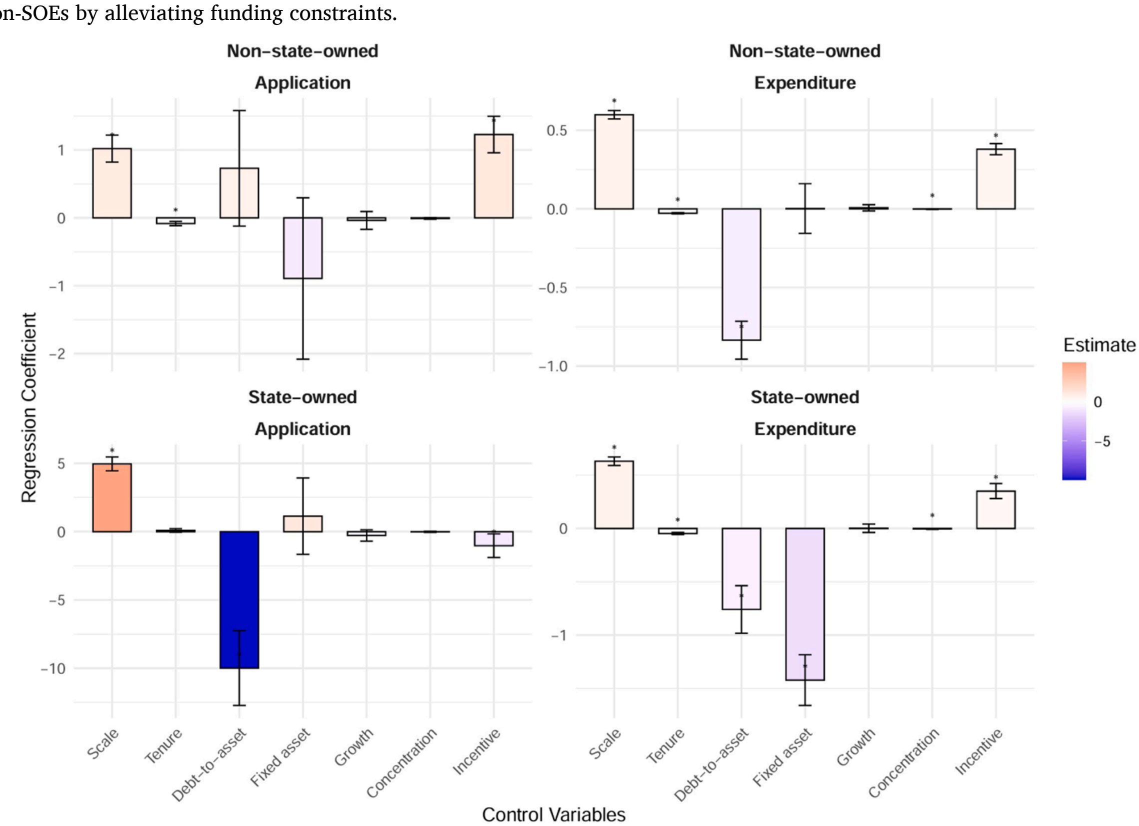

Fig. A.2. Bar plot of control variable effects by ownership types.

Across different stages of the life cycle (see Fig. A.3), firm size continues to contribute positively to the advancement of green innovation, reaffirming the advantage of scale in resource accumulation and organizational capability regardless of the development stage. Leverage and fixed asset ratios generally serve as inhibiting factors, suggesting that heavy financial burdens may reduce the flexibility needed for green technological transformation. Nevertheless, for firms in growth and decline phases, higher fixed asset ratio may be associated with increased green innovation output. This could be due to a motivation to recover sunk costs or pursue breakthrough strategies to extend the firm's operational lifespan. Performance incentives consistently encourage green R&D investment across stages, but may suppress innovation output in mature firms, possibly reflecting a more risk-averse posture during stable development periods.

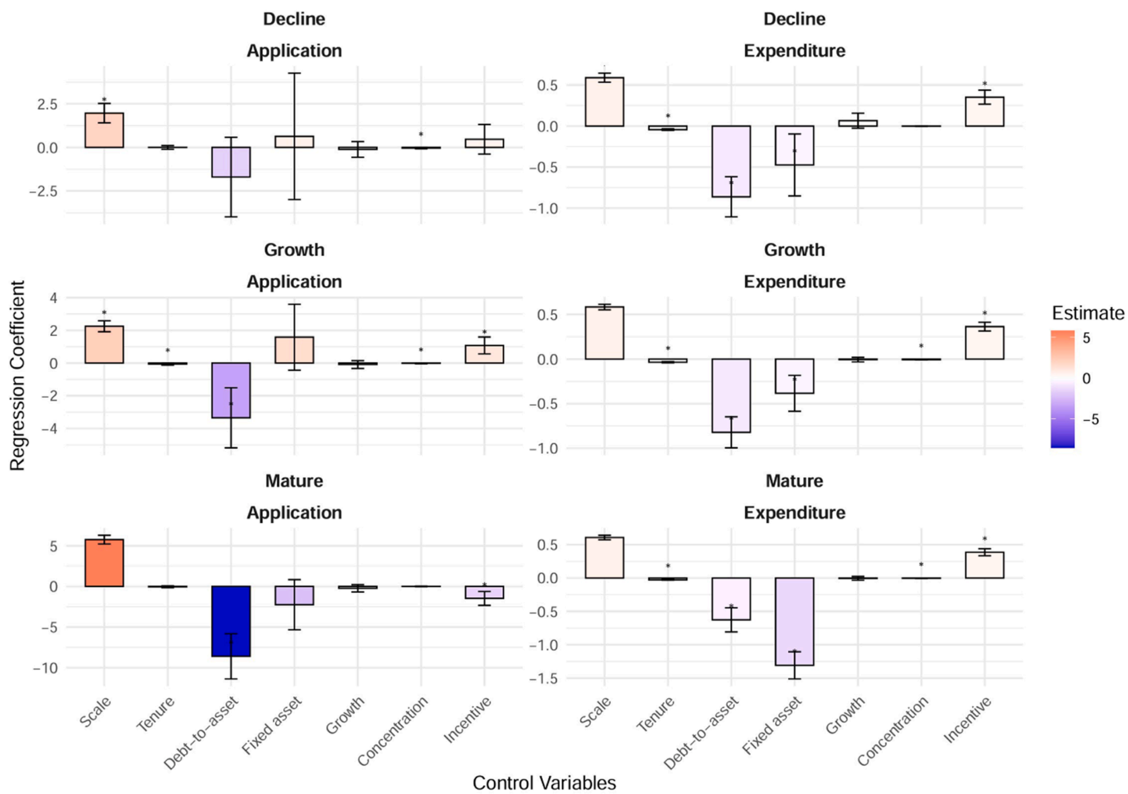

Fig. A.3. Bar plot of control variable effects by lifecycle stages.

Data availability

Data will be made available on reasonable request.

References

[1] R. De Haas, A. Popov, Finance and green growth, Econ. J. 133 (650) (2023) 637–668.
[2] Y. Chen, C.C. Lee, Does technological innovation reduce CO2 emissions? Cross-country evidence, J. Clean. Prod. 263 (2020) 121550.
[3] Y. Yu, X. Han, G. Hu, Optimal production for manufacturers considering consumer environmental awareness and green subsidies, Int. J. Prod. Econ. 182 (2016) 397–408.
[4] S. Roper, E. Tapinos, Taking risks in the face of uncertainty: an exploratory analysis of green innovation, Technol. Forecast. Soc. Change 112 (2016) 357–363.
[5] K. Bi, P. Huang, X. Wang, Innovation performance and influencing factors of low-carbon technological innovation under the global value chain: a case of Chinese manufacturing industry, Technol. Forecast. Soc. Change 111 (2016) 275–284.
[6] S. Charnovitz, Green Subsidies and the WTO. Robert Schuman Centre for Advanced Studies Research Paper No, RSCAS, 2014, p. 93.
[7] S. Ruidas, M.R. Seikh, P.K. Nayak, A production inventory model for green products with emission reduction technology investment and green subsidy, Process Integr. Optim. Sustain. 6 (4) (2022) 863–882.
[8] M.P. Singh, A. Chakraborty, M. Roy, The link among innovation drivers, green innovation and business performance: empirical evidence from a developing economy, World Rev. Sci., Technol. Sustain. Dev. 12 (4) (2016) 316–334.
[9] China Briefing. (2023). China's environmental policy: new fiscal support for green development. Retrieved from https://www.china-briefing.com/news/chinas-environmental-policy-new-fiscal-support-for-green-development/.
[10] Kiel Institute for the World Economy. (2024). China's Massive Subsidies for Green Technologies. Retrieved from https://www.ifw-kiel.de/publications/news/chinas-massive-subsidies-for-green-technologies/.
[11] X. Zhu, L. Ding, H. Zhu, Y. Guo, The dual-credit policy model, a production strategy decision-making algorithm and application to Chinese automakers, Neural Comput. Appl. 37 (2025) 8165–8179.
[12] D. Liu, H. Zou, Y. Qiu, H. Du, Consumer reaction to green subsidy phase-out in China: evidence from the household photovoltaic industry, Energy Econ. 129 (2024) 107270.
[13] Y. Shao, Z. Chen, Can government subsidies promote the green technology innovation transformation? Evidence from Chinese listed companies, Econ. Anal. Policy 74 (2022) 716–727.
[14] X. Sun, J. Tang, S. Li, Promote green innovation in manufacturing enterprises in the aspect of government subsidies in China, Int. J. Env. Res. Public Health 19 (13) (2022) 7864.
[15] Z. Li, G. Liao, Z. Wang, Z. Huang, Green loan and subsidy for promoting clean production innovation, J. Clean. Prod. 187 (2018) 421–431.
[16] X. Han, M. Khouja, X. Liu, A dynamic model considering consumer green awareness and environmental subsidy, Int. J. Prod. Econ. 260 (2023) 108840.
[17] H. Wu, J. Weng, G. Li, H. Zheng, Green subsidy strategies and fairness concern in a capital-constrained supply chain, Transp. Res. E: Logist. Transp. Rev. 192 (2024) 103693.
[18] M. Almus, D. Czarnitzki, The effects of public R&D subsidies on firms' innovation activities: the case of Eastern Germany, J. Bus. Econ. Stat. 21 (2) (2003) 226–236.
[19] D. Hu, L. Qiu, M. She, Y. Wang, Sustaining the sustainable development: how do firms turn government green subsidies into financial performance through green innovation? Bus. Strategy Environ. 30 (5) (2021) 2271–2292.

[20] W. Shao, K. Yang, X. Bai, Impact of financial subsidies on the R&D intensity of new energy vehicles: a case study of 88 listed enterprises in China, Energy Strategy Rev. 33 (2021) 100580.
[21] G. Bi, M. Jin, L. Ling, F. Yang, Environmental subsidy and the choice of green technology in the presence of green consumers, Ann. Oper. Res. 255 (2017) 547–568.
[22] R. Bronzini, P. Piselli, The impact of R&D subsidies on firm innovation, Res. Policy 45 (2) (2016) 442–457.
[23] Z. Jiang, C. Xu, J. Zhou, Government environmental protection subsidies, environmental tax collection, and green innovation: evidence from listed enterprises in China, Environ. Sci. Pollut. Res. 30 (2) (2023) 4627–4641.
[24] H. Lyu, C. Ma, F. Arash, Government innovation subsidies, green technology innovation and carbon intensity of industrial firms, J. Env. Manag. 369 (2024) 122274.
[25] X. Xie, Q. Zhu, R. Wang, Turning green subsidies into sustainability: how green process innovation improves firms' green image, Bus. Strategy Environ. 28 (7) (2019) 1416–1433.
[26] Y. Duan, B. Xi, X. Xu, S. Xuan, The impact of government subsidies on green innovation performance in new energy enterprises: a digital transformation perspective, Int. Rev. Econ. Financ. 94 (2024) 103414.
[27] L. Liu, X. Xu, The effect of government subsidies on firms' innovation performance: does subsidy continuity matter? Appl. Econ. (2024) 1–17.
[28] X. Zhang, X. Bai, Incentive policies from 2006 to 2016 and new energy vehicle adoption in 2010–2020 in China, Renew. Sustain. Energy Rev. 70 (2017) 24–43.
[29] S. Chen, J. Su, Y. Wu, F. Zhou, Optimal production and subsidy rate considering dynamic consumer green perception under different government subsidy orientations, Comput. Ind. Eng. 168 (2022) 108073.
[30] X. Xiang, C. Liu, M. Yang, Who is financing corporate green innovation? Int. Rev. Econ. Financ. 78 (2022) 321–337.
[31] V. Květoň, P. Horák, The effect of public R&D subsidies on firms' competitiveness: regional and sectoral specifics in emerging innovation systems, Appl. Geogr. 94 (2018) 119–129.
[32] Z. Wu, X. Fan, B. Zhu, J. Xia, L. Zhang, P. Wang, Do government subsidies improve innovation investment for new energy firms: a quasi-natural experiment of China's listed companies, Technol. Forecast. Soc. Change 175 (2022) 121418.
[33] Z. Jiang, Z. Liu, Policies and exploitative and exploratory innovations of the wind power industry in China: the role of technological path dependence, Technol. Forecast. Soc. Change 177 (2022) 121519.
[34] Y. Liu, H. Xu, X. Wang, Government subsidy, asymmetric information and green innovation, Kybernetes 51 (12) (2022) 3681–3703.
[35] L. Fang, S. Zhao, On the green subsidies in a differentiated market, Int. J. Prod. Econ. 257 (2023) 108758.
[36] A. Howell, Picking 'winners' in China: do subsidies matter for indigenous innovation and firm productivity? China Econ. Rev. 44 (2017) 154–165.
[37] H. Wen, C.C. Lee, F. Zhou, How does fiscal policy uncertainty affect corporate innovation investment? Evidence from China's new energy industry, Energy Econ. 105 (2022) 105767.
[38] M. Shoaeinaeini, K. Govindan, D. Rahmani, Pricing policy in green supply chain design: the impact of consumer environmental awareness and green subsidies, Oper. Res. 22 (2022) 1–40.
[39] H. Wu, Y. Qu, How do firms promote green innovation through international mergers and acquisitions: the moderating role of green image and green subsidy, Int. J. Env. Res. Public Health 18 (14) (2021) 7333.
[40] Y. Bai, C. Hua, J. Jiao, M. Yang, F. Li, Green efficiency and environmental subsidy: evidence from thermal power firms in China, J. Clean. Prod. 188 (2018) 49–61.
[41] Z. Jiang, C. Xu, Policy incentives, government subsidies, and technological innovation in new energy vehicle enterprises: evidence from China, Energy Policy 177 (2023) 113527.
[42] J. Liu, M. Zhao, Y. Wang, Impacts of government subsidies and environmental regulations on green process innovation: a nonlinear approach, Technol. Soc. 63 (2020) 101417.
[43] H. Peng, Y. Liu, How government subsidies promote the growth of entrepreneurial companies in clean energy industry: an empirical study in China, J. Clean. Prod. 188 (2018) 508–520.
[44] X. Li, Y. Li, On green market segmentation under subsidy regulation, Supply Chain Manag.: Int. J. 22 (3) (2017) 284–294.
[45] S. Ruidas, M.R. Seikh, P.K. Nayak, M.L. Tseng, An interval-valued green production inventory model under controllable carbon emissions and green subsidy via particle swarm optimization, Soft Comput. 27 (14) (2023) 9709–9733.
[46] Y. Bai, S. Song, J. Jiao, R. Yang, The impacts of government R&D subsidies on green innovation: evidence from Chinese energy-intensive firms, J. Clean. Prod. 233 (2019) 819–829.
[47] X. Liu, X. Li, H. Li, R&D subsidies and business R&D: evidence from high-tech manufacturing firms in Jiangsu, China Econ. Rev. 41 (2016) 1–22.
[48] S. Huang, Z.P. Fan, N. Wang, Green subsidy modes and pricing strategy in a capital-constrained supply chain, Transp. Res. E: Logist. Transp. Rev. 136 (2020) 101885.
[49] C. Xu, C. Wang, R. Huang, Impacts of horizontal integration on social welfare under the interaction of carbon tax and green subsidies, Int. J. Prod. Econ. 222 (2020) 107506.
[50] Z. Li, C. Zheng, A. Liu, Y. Yang, X. Yuan, Environmental taxes, green subsidies, and cleaner production willingness: evidence from China's publicly traded companies, Technol. Forecast. Soc. Change 183 (2022) 121906.
[51] Y. Li, Y. Tong, F. Ye, J. Song, The choice of the government green subsidy scheme: innovation subsidy vs. product subsidy, Int. J. Prod. Res. 58 (16) (2020) 4932–4946.
[52] L. Zhang, B. Xue, K.W. Li, Assessing subsidy policies for green products: operational and environmental perspectives, Int. Trans. Oper. Res. 29 (5) (2022) 3081–3106.
[53] Y. Xing, L. Zhao, R. Huang, Y. Qian, Green energy subsidy structure design under the impact of conventional energy price uncertainty, Comput. Ind. Eng. 174 (2022) 108798.
[54] C. Na, Z. Ni, Q. Shu, H. Zhang, Can government subsidies improve corporate ESG performance? Evidence from listed enterprises in China, Financ. Res. Lett. 64 (2024) 105427.
[55] H. Wang, J. Li, Professional experience of CEOs in industry associations and corporate green innovation-empirical evidence from China, Pac.-Basin Financ. J. 85 (2024) 102383.
[56] M.D. Amore, M. Bennedsen, Corporate governance and green innovation, J. Env. Econ. Manag. 75 (2016) 54–72.
[57] L. Xia, S. Gao, J. Wei, Q. Ding, Government subsidy and corporate green innovation-does board governance play a role? Energy Policy 161 (2022) 112720.
[58] J.Y. Tong, F.F. Zhang, Do capital markets punish managerial myopia? Evidence from myopic research and development cuts, J. Financ. Quant. Anal. 59 (2) (2024) 596–625.
[59] X. Xie, Y. Gong, L. Cheng, Managerial myopia and carbon emission: evidence from China, Pac.-Basin Financ. J. 90 (2025) 102614.
[60] Q. Meng, Y. Wang, Z. Zhang, Y. He, Supply chain green innovation subsidy strategy considering consumer heterogeneity, J. Clean. Prod. 281 (2021) 125199.
[61] B. Lin, Y. Xie, Positive or negative? R&D subsidies and green technology innovation: evidence from China's renewable energy industry, Renew. Energy 213 (2023) 148–156.
[62] J. Plank, C. Doblinger, The firm-level innovation impact of public R&D funding: evidence from the German renewable energy sector, Energy Policy 113 (2018) 430–438.
[63] R. Xu, Y. Shen, M. Liu, L. Li, X. Xia, K. Luo, Can government subsidies improve innovation performance? Evidence from Chinese listed companies, Econ. Model. 120 (2023) 106151.
[64] J. Yi, J. Hong, W. chung Hsu, C. Wang, The role of state ownership and institutions in the innovation performance of emerging market enterprises: evidence from China, Technovation 62 (2017) 4–13.
[65] Z. Zhang, X. Luo, J. Du, B. Xu, Substantive or strategic: government R&D subsidies and green innovation, Financ. Res. Lett. 67 (2024) 105796.
[66] Z. Wang, X. Li, X. Xue, Y. Liu, More government subsidies, more green innovation? The evidence from Chinese new energy vehicle enterprises, Renew. Energy 197 (2022) 11–21.
[67] V. Costantini, F. Crespi, C. Martini, L. Pennacchio, Demand-pull and technology-push public support for eco-innovation: the case of the biofuels sector, Res. Policy 44 (3) (2015) 577–595.
[68] D. Czarnitzki, C. Lopes-Bento, Innovation subsidies: does the funding source matter for innovation intensity and performance? Empir. Evid. Ger. Ind. Innov. 21 (5) (2014) 380–409.
[69] C. Ghisetti, K. Rennings, Environmental innovations and profitability: how does it pay to be green? An empirical analysis on the German innovation survey, J. Clean. Prod. 75 (2014) 106–117.
[70] X. Qi, Y. Guo, P. Guo, X. Yao, X. Liu, Do subsidies and R&D investment boost energy transition performance? Evidence from Chinese renewable energy firms, Energy Policy 164 (2022) 112909.
[71] F. Yu, L. Wang, X. Li, The effects of government subsidies on new energy vehicle enterprises: the moderating role of intelligent transformation, Energy Policy 141 (2020) 111463.
[72] B. Yuan, Q. Xiang, Environmental regulation, industrial innovation and green development of Chinese manufacturing: based on an extended CDM model, J. Clean. Prod. 176 (2018) 895–908.
[73] M. Dahmani, Environmental quality and sustainability: exploring the role of environmental taxes, environment-related technologies, and R&D expenditure, Environ. Econ. Policy Stud. 26 (2) (2024) 449–477.
[74] L. Shi, B. Lin, The dual-credit policy effectively replaces subsidy from the perspective of R&D intensity, Env. Impact Assess Rev. 102 (2023) 107160.
[75] W. Li, M. Zheng, Is it substantive innovation or strategic innovation? Impact of macroeconomic policies on micro-enterprises' innovation, Econ. Res. J. 51 (4) (2016) 60–73, in Chinese.
[76] L. Xu, M. Fan, L. Yang, S. Shao, Heterogeneous green innovations and carbon emission performance: evidence at China's city level, Energy Econ. 99 (2021) 105269.
[77] H. Mao, Z. Yin, J. Zhang, Could China's innovation get rid of the trap of utility model system, China Ind. Econ. 3 (2018) 98–115, in Chinese.
[78] B. Wang, Y. Wu, P. Yan, Environmental efficiency and Environmental total factor productivity growth in China's regional economies, Econ. Res. J. 45 (5) (2010) 95–109. In Chinese.
[79] L. Matyas, Proper econometric specification of the gravity model, World Econ. 20 (1997) 363–369.
[80] Q. Li, M. Wang, L. Xiangli, Do government subsidies promote new-energy firms' innovation? Evidence from dynamic and threshold models, J. Clean. Prod. 286 (2021) 124992.
[81] N. Wang, J. Hagedoorn, The lag structure of the relationship between patenting and internal R&D revisited, Res. Policy 43 (8) (2014) 1275–1285.

[82] M. Yang, How government green subsidies motivate green innovation of corporations——Exposition and evidence from Strategic response perspective, J. Cent. China Norm. Univ. (Humanit. Soc. Sci.) 63 (01) (2024) 61–74, in Chinese.
[83] J.D. Angrist, J.S. Pischke, Mostly Harmless econometrics: An empiricist's Companion, Princeton university press, 2009.
[84] J.M. Wooldridge, Econometric Analysis of Cross Section and Panel Data, MIT press, 2010.
[85] J.A. Smith, P.E. Todd, Does matching overcome LaLonde's critique of nonexperimental estimators? J. Econ. 125 (1–2) (2005) 305–353.
[86] W. Wu, T. Zhang, The asymmetric influence of Non-R&D subsidies and R&D subsidies on innovation output of new ventures, J. Manag. World 37 (03) (2021) 137–160. +10. (in Chinese).
[87] W.M. Cohen, D.A. Levinthal, Absorptive capacity: a new perspective on learning and innovation, Adm. Sci. Q. 35 (1) (1990) 128–152.
[88] M.C. Jensen, W.H. Meckling, Theory of the firm: managerial behavior, agency costs and ownership structure, J. Financ. Econ. 3 (4) (1976) 305–360.
[89] Y. Tian, W. Song, M. Liu, Assessment of how environmental policy affects urban innovation: evidence from China's low-carbon pilot cities program, Econ. Anal. Policy 71 (2021) 41–56.
[90] P. Moser, J. Ohmstedt, P.W. Rhode, Patent Citations and the Size of the Inventive Step-Evidence from Hybrid Corn, National Bureau of Economic Research, 2015. No. w21443.
[91] Y. Cheng, K. Du, X. Yao, Stringent environmental regulation and inconsistent green innovation behavior: evidence from air pollution prevention and control action plan in China, Energy Econ. 120 (2023) 106571.
[92] A. Xu, M. Song, S. Xu, W. Wang, Accelerated green patent examination and innovation benefits: an analysis of private economic value and public environmental benefits, Technol. Forecast. Soc. Change 200 (2024) 123105.
[93] E.L. Lane, Building the global green patent highway: a proposal for international harmonization of green technology fast track programs, Berkeley Technol. Law J. 27 (2) (2012) 1119–1170.
[94] Y. Guo, Signaling mechanism of government innovation subsidies and firms' innovation, China Ind. Econ. 9 (2018) 98–116, in Chinese.
[95] L. Li, G. Qian, How do Chinese firms sustain their cost advantage in labour-intensive industries? J. Gen. Manag. 34 (4) (2009) 1–14.
[96] Y. Xie, J. Jiang, D. Wang, Green finance policy and labor demand: evidence from China, Pac.-Basin Financ. J. 86 (2024) 102434.
[97] M.T. Benkhodja, V. Fromentin, X. Ma, Macroeconomic effects of green subsidies, J. Clean. Prod. 410 (2023) 137166.
[98] X. Zhou, M. Dai, L. Liu, Green credit, carbon emission trading and corporate green innovation: evidence from China, Pac.-Basin Financ. J. 86 (2024) 102445.
[99] V. Dickinson, Cash flow patterns as a proxy for firm life cycle, Account. Rev. 86 (6) (2011) 1969–1994.
[100] E. Huergo, The role of technological management as a source of innovation: evidence from Spanish manufacturing firms, Res. Policy 35 (9) (2006) 1377–1388.
[101] A. Coad, A. Segarra, M. Teruel, Innovation and firm growth: does firm age play a role? Res. Policy 45 (2) (2016) 387–400.

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