Financial Economics Research; Vol.3, No.4; 2026
E-ISSN: 3006-3663 P-ISSN: 3006-3655
DOI: https://doi.org/10.70267/fer.v3n4.129142
Published by: Zeus Press

# The Study of the Impact Mechanism of R&D Expense Super-deduction on Green Innovation of High-tech Enterprises in the Context of the Digital Economy

**Ting Wang***

*School of Public Finance and Taxation, Southwestern University of Finance and Economics, Chengdu 610000, China*

**Corresponding author: Ting Wang.*

## Abstract

As the digital economy improves by leaps and bounds, new factor conditions are provided for corporate green innovation. In the meantime, the R&D expense super-deduction policy has become a vital fiscal and tax instrument for incentivizing high-tech enterprises to conduct low-carbon technology R&D. Nevertheless, existing research rarely places the digital economy, the super-deduction policy, as well as corporate green innovation within the same framework, and analyses of transmission paths and differentiated policy effects still need improvement. Against this background, this research selects panel data of A-share listed high-tech enterprises from 2019 to 2023 as the sample, and then constructs two-way fixed effects and mediation effect models, and empirically examines the impact of the R&D expense super-deduction on green innovation of high-tech enterprises and its internal transmission mechanism. Further, Heterogeneity analysis is conducted from three dimensions: ownership nature, regional distribution, and firm size. The results suggest that the R&D expense super-deduction reinforces green innovation in high-tech enterprises, R&D intensity plays a partial mediating role in this process, and the policy incentive effect is heterogeneous, being more significant in non-state-owned, eastern-region, and small-scale high-tech enterprises. This paper supplements micro-level evidence on the intersection of fiscal and tax incentives and corporate green innovation, and provides references for the government, in order to implement differentiated tax policies and for enterprises to conduct green R&D.

### Keywords

digital economy, R&D expense super-deduction, high-tech enterprises, green innovation, R&D intensity

## 1. Introduction

With the perspective of high-quality development and the "dual carbon" goal, the digital economy is undergoing quick iteration, and the R&D expense super-deduction policy has been put into effect in full by high-tech companies, which has become a crucial fiscal and taxation measure to ease business R&D tax loads, as well as promote green and low-carbon technologies. Both digital technologies and tax policies have an impact on the process of corporate innovation, however, in reality, the outcomes of policy implementation are not uniform.

According to the available statistics and the information in the CSMAR database, the size of R&D spending in high-tech industries has increased over time, but the share of green patents in total patents is still small, and innovation assets are located in the east, whereas low-carbon R&D of high-tech companies in the middle and west are somewhat weak. Due to the long duration and high risk involved in green innovation, businesses tend to be financially constrained. Following the benefit of super deduction, there are some companies that have not used tax saving money into green R&D and digitalization has not been integrated with low carbon R&D effectively.

In the area of three fundamental facets of R&D expenses super-deduction, digital economy, and green innovations in business, both local and foreign scholars have developed a fairly abundant scholarly literature. Under the dual carbon objectives and policy coverage growth, more and more domestic scholars are starting to focus on the real incentives of policies to green innovations.

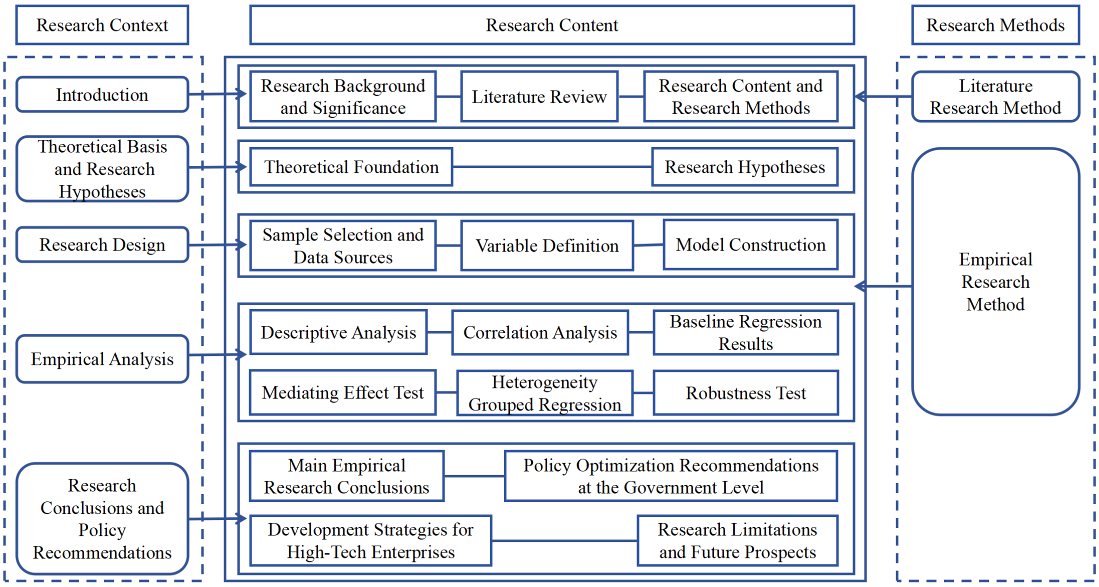
When it comes to the study of tax incentives and corporate innovation, the current literature has shown that R&D tax incentives are capable of encouraging businesses to invest more in R&D by removing financing constraints and freeing up internal cash flows; consequently, it would have an impact on the level of innovation output [1,2]. Other studies have also performed mediation and heterogeneity tests in which they examine the variations in policy effects based on factors like ownership and the corporate life cycle. Nevertheless, much of the empirical literature simply measures the overall number of corporate patents as an indicator of innovation level without any distinction between green and low-carbon patents, and it becomes hard to identify the particular influence of tax policies on green innovation [3]. A number of studies develop indicators based on combining various forms of tax incentive testing, but only a small portion focuses on examining the impact of the R&D expense super-deduction in a separate manner as a special policy towards green innovation [4]. Only a few studies use case analysis to examine the effects of policy implementation, however, due to the single-sample limitation of studies, their findings cannot be generalized. Early works, limited in time by the sample size, were unable to adequately consider the realistic context of the high rate of growth of the digital economy [5]. The practical literature is primarily concerned with institutional issues, including R&D cost collection and ledger management, and it generally takes the form of qualitative discussion, with no large-sample micro-level empirical work being conducted on the topic of green innovation [6,7].

One of the other significant areas of research in this regard is the impact of the digital economy on corporate innovation and green innovation. Previous studies have shown that at the urban macro level, the digital economy could optimize the distribution of regional innovation factors and enhance the pattern of spatial distribution of innovation resources [8]. Other sources, based on the point of view of digital finance, claim that digitalization may help to ease information asymmetry, minimize external financing expenses, and contribute to the empowerment of corporate R&D efforts indirectly [9]. There are some studies that suggest that digitalization also has two-fold effects of reducing costs and investing heavily, i.e., the digital innovation paradox [10]. Nevertheless, the current body of research has its shortcomings: most works consider the topic of the digital economy and fiscal and tax policies individually, but few of them explore how the variations in the levels of digital economy development across regions affect the incentive effects of taxes on innovations; many studies are still conducted at the urban macro level with no attempts made to test the mediating transmission mechanisms at the firm micro level [11].

An overall review of all domestic and foreign literature shows that three main research gaps exist in the current body of work. The paper in particular contributes to the improvement of the current analytical framework so as to correct such shortcomings. Firstly, most literature uses total corporate patents to measure innovation output in general terms, but empirical evidence that specifically employs green patents to differentiate low-carbon innovation and develops fine-grained econometric models of A-share listed high-tech companies is rare. To pin down green innovation behavior accurately, this paper uses the logarithm of green patent applications as the independent variable. Secondly, the current studies divide the macro environment of the digital economy, the fiscal and tax policy of R&D super-deduction, and corporate green innovation, without testing the mediating transmission chain completely. This paper brings R&D intensity as an intervening variable and applies the three-step approach by Wen Zhonglin to systematically test the transmission process of R&D expense super-deduction-R&D intensity-green innovation, explaining in detail the inner mechanism through which the policy impacts green innovation and addressing the discontinuity of previous mechanism analysis. Thirdly, the presence of heterogeneity tests in the existing literature is disjointed and singular and lacks a coherent layered interpretation of differentiated policy impact incorporating both the dual aspects of ownership and region and does not explain the reason behind heterogeneity in light of the reality of the division of the domestic digital economy on the basis of region. This paper eliminates tests dimensions with no significant statistical support and keeps three groups of grouped regressions: ownership, region, and firm size. It examines differences in policy responses between state-owned and private enterprises, eastern and central-western regions, and large and small enterprises, and offers explanations of the results of grouped regressions based on regional disparities in the development of digital economies, thus enhancing the layered research framework of fiscal and tax incentives to green innovation. On the theoretical front, it could add to the body of micro-level empirical evidence in the area of fiscal and tax incentives and corporate green innovation. On the practical front, the empirical findings of this paper may not only serve as empirical guidelines to the government in terms of formulating layered and differentiated tax policies toward green innovation, but also assist high-tech enterprises in making more effective use of the super-deduction policy in conducting green R&D, which will allow advancing the dual carbon objectives and industrial digitalization simultaneously.

Moreover, preliminary non-empirical findings indicate that the digital economy interaction coefficient is insignificant. No moderating effect model is proposed in the paper, since the digital economy is only included in the theoretical framework as part of the macro context, which corresponds to the objective features of the sample data and is more rigorous.

*Figure 1: Research Framework Diagram*




The paper is essentially based on two research approaches. The first approach is known as the literature review method whereby related domestic and foreign literature is reviewed, the available research findings and limitations are summarized and the theoretical basis of the paper is developed. The other approach is empirical research where panel data of A-share high-tech firms are chosen, and two-way fixed effects and mediating effect models are created and empirical analysis is done using Stata software. At the same time, heterogeneous regressions are performed to contrast how policies affect various ownership types, areas and company sizes.

## 2. Theoretical Basis and Research Hypotheses

### 2.1 Tax Incentive Theory

The tax incentive theory indicates that green innovation has important positive externalities. If the market were purely competitive, then business low-carbon R&D spending would be less than the socially optimal amount, causing market failure. To address this discrepancy the government can use tax-base preference tools to alter the cost-benefit structure of corporate R&D. The R&D spending super-deduction policy is an average tax-base preference that permits businesses to make additional deductions of R&D expenditures prior to taxation with a particular rate. The mechanism is reducing the marginal cost of green innovation directly, reducing the enterprise tax burden on low-carbon R&D, and thus fundamentally changing the enterprise attitudes towards conducting green patent R&D.

In line with the theoretical reasoning stated above, it can be concluded that the greater the extent of the super-deduction preference received by an enterprise, the more abundant are the funds accessible to low-carbon technology R&D, and the higher the level of green innovation output correspondingly. Meanwhile, the digital economy can open up cross-regional circulation channels for innovation factors, which in turn will lower the trial-and-error costs of low-carbon R&D and become an external environmental condition for enterprises conducting green innovation. Therefore, this paper suggests the research hypothesis of the main effect:

H1: The amount of R&D expense super-deduction has a significant positive promoting effect on green innovation of high-tech enterprises.

## 2.2 Financing Constraint Theory

Green innovation is characterized by a protracted R&D process and a greater level of information asymmetry. It is subject to more stringent internal and external financing conditions than traditional innovation. Poor internal cash flow, as well as external green credit premiums, will have a direct impact on the inability of low-carbon R&D activities to take place. The R&D expense super-deduction would relieve financial challenges along two routes: firstly, by decreasing corporate income tax spending and increasing internal operating cash flow; secondly, the history of enterprises that benefit from the tax preference will send a message of high-quality R&D to the capital market, reducing the barrier to external financing. Nevertheless, the additional funds created by tax savings cannot be immediately turned into green patent production, they need to go through an intermediary step of investing in R&D resources in order to make the innovation results effectively implemented. This transmission logic is used as a theoretical framework behind the further mediating effect test.

## 2.3 R&D Investment Mediation Theory

Mediation theory of R&D investment suggests that different fiscal, tax, and industrial policies cannot directly produce innovation output. R&D resource investment intensity is one major intermediate vehicle for converting policy dividends into innovation results. R&D expenditure as a proportion of operating revenue may be used as an objective indicator of the extent to which resources are inclined towards innovation efforts within an enterprise. Together with the capital transmission mechanism underlying the theory of financial constraints, the cash flow generated by the super-deduction policy will initially increase the total R&D budget of the enterprise and thus increase R&D intensity. Adequate R&D resources will keep on enabling low-carbon process development and environmental protection product updates until they eventually become green patent output. This creates a full chain of transmission between fiscal and tax policy and R&D investment leading to green innovation, which is also the main theoretical framework of the mediation logic in this paper. Thereby, the next hypothesis is formulated:

H2: R&D intensity plays a mediating role between the R&D expense super-deduction and green innovation of high-tech enterprises.

## 2.4 Enterprise Heterogeneity Theory

The theory of enterprise heterogeneity implies that various enterprises have organized differences in terms of ownership goals, location assets, and size of operations and will result in varied output impacts when the same fiscal and tax policies are applied. In regard to the ownership perspective, private companies consider market outcomes as their core operating aim, and green innovation is one of the effective approaches to the development of market competition, whereas state-owned companies have to strike a balance between various non-profit goals, including labor safety and supply chain stability, and therefore there are not many strict limitations on low-carbon R&D evaluation. In terms of the regional aspect, eastern cities have a strong presence of digital infrastructure, green industrial chains, and advanced scientific and technological innovation talent, whereas the central and western regions have significant deficiencies in digital auxiliary devices and innovation components. As per the classification of the National Bureau of Statistics, this paper has classified the regions to which the enterprises belong into the eastern region (13 provinces and municipalities): Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, Liaoning, Jilin, and

Heilongjiang, and the central and western regions (the rest of the provinces). The eastern region has a high concentration of the digital economy and scientific and technological innovation factors, and the central and western regions have severe weaknesses in innovation support facilities; it is anticipated that the policy effects will differ by region. On the scale dimension, the aggregate amount of R&D resources of large-scale enterprises is very large and the marginal amount of tax reduction is small, whereas the R&D base of small-scale enterprises is relatively low and the same tax-saving resources can be more effective in making them invest in low-carbon activities. According to these three types of endowment differences, the layered heterogeneity model of policy incentive effects can be inferred. Therefore, the hypotheses below are formulated:

H3: Compared with state-owned enterprises, the R&D expense super-deduction has a more significant promoting effect on green innovation of non-state-owned enterprises.

H4: Compared to companies in the central and western parts of the country, the R&D expenditure super-deduction is more influential in promoting green innovation of companies in the eastern part of the country.

H5: Compared to large-scale enterprises, R&D expense super deduction is a much more encouraging factor in green innovation of small-scale enterprises.

## 3. Research Design

### 3.1 Sample Selection and Data Sources

The present paper chooses listed companies that are identified as high-tech companies on the Shanghai and Shenzhen A-share markets during 2019-23 as the starting research sample. The screening of the sample is based on the principles of mainstream domestic empirical research: financial and real estate sectors are not included in the screening process; enterprises with financial irregularities (ST and *ST) are not included; and missing core variables are excluded with significant missing data.

Following repeated screenings and proper panel balancing, there is the final sample of 14,246 firm-year panel observations. The CSMAR (China Stock Market & Accounting Research) database provides firm-level micro financial indicators, green patent application data, R&D expense super-deduction amounts, and R&D expenditure data. The empirical regression coefficients are not affected by extreme outliers as two-sided winsorization is used in all continuous variables at 1% and 99%. The data processing and regression analysis were done using Stata 17.0 econometric software.

### 3.2 Variable Definition

#### 3.2.1 Dependent Variable

The measure is the natural logarithm of the sum of the total number of green patent applications in the present year, including green invention patents and green utility model patents. The calculation formula is $LnGrePatent_{it}=ln(GrePatent_{it}+1)$.

The number of patent applications is taken instead of granted patents in this paper to prevent the problem of approval time lag; green patents are differentiated so as to be relevant to the topic of research in this paper; adding one and taking a logarithm solves the problem of too many values with zero patents in the sample and reduces right-skewness in the data.

#### 3.2.2 Independent Variable

The paper picks the practical value of R&D expense super-deduction tax relief that the enterprise is using in a given year as the main independent variable, which is actually assessed as the ratio between the R&D super-deduction tax relief and the nominal income tax rate of the enterprise.

This continuous indicator may indicate the real magnitude of policy preference achieved by the enterprise. It is more sophisticated than a 0-1 dummy variable. The information is based on the income tax schedule of the CSMAR database, which has a uniform measurement scale and is able to evaluate the decrease in R&D expenses due to the policy.

#### 3.2.3 Mediating Variable

The measure is the ratio of enterprise R&D expenditure to operating revenue, the intensity of overall R&D resource investment by the enterprise.

The measure of R&D intensity refers to the division of R&D expenditure by operating revenue. It could remove the influence of the scale of a firm and enable the horizontal comparison of the investment in R&D resources of enterprises. The variable constitutes the central part of the mediating path in the present paper. Equivalent domestic research on mediating mechanisms usually uses this indicator [12] with enough literature support and makes sure that results of empirical investigations are consistent and reproducible.

#### 3.2.4 Control Variables

With reference to the existing literature, this paper chooses the following variables: size of the firm (*Lnsize*), age of the firm (*LnAge*), ratio between assets and liabilities (*Lev*) and operating cash flow (*CFS*). Besides, it controls for both the firm-specific fixed effects and year fixed effects simultaneously to minimize the effect of omitted variables.

*Table 1: Variable Definitions*

| Category | Variable Name | Variable Definition |
|---|---|---|
| Dependent Variable | *LnGrePatent* | ln (Number of green patent applications + 1) |
| Independent Variable | *Deductamt* | Tax relief amount from R&D expense super-deduction / Enterprise's nominal income tax rate |
| Mediating Variable | *RD* | R&D expenditure / Operating revenue |
| Control Variables | *Lnsize* | ln (Total assets + 1) |
| | *LnAge* | ln (Observation year − Year of firm establishment + 1) |
| | *Lev* | Total liabilities / Total assets |
| | *CFS* | Net cash flow from operating activities / Total operating revenue |

### 3.3 Model Construction

#### 3.3.1 Baseline Regression Model

In order to test the main effect hypothesis H1, the following two-way fixed effects panel baseline regression model is designed:

$$LnGrePatent_{it}=\alpha_0+\alpha_1 Deductamt_{it}+\alpha_2 Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \tag{1}$$

In which, $LnGrePatent_{it}$ is the green innovation output level of the *i*-th high-tech enterprise at the end of the period *t*; $Deductamt_{it}$ is the amount of R&D expense super-deduction of an enterprise in the current period; $Controls_{it}$ is the set of all control variables; $\mu_i$ is the firm individual fixed effect; $\lambda_t$ is the year time fixed effect; $\varepsilon_{it}$ is the random disturbance term of the model. The support of Hypothesis H1 is given when the key coefficient $\alpha_1$ is significantly larger than 0.

#### 3.3.2 Mediating Effect Model

Based on the stepwise regression test method of Wen Zhonglin and Ye Baojuan [13] three progressive regression model sets are formed:

Model 1 (Baseline Total Effect Regression):

$$LnGrePatent_{it}=\alpha_0+\alpha_1 Deductamt_{it}+\alpha_2 Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \tag{1}$$

Model 2 (Independent Variable Regressed on Mediating Variable):

$$RD_{it}=\beta_0+\beta_1 Deductamt_{it}+\beta_2 Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \tag{2}$$

Model 3 (Simultaneously Incorporating Independent Variable and Mediating Variable):

$$LnGrePatent_{it}=\gamma_0+\gamma_1 Deductamt_{it}+\gamma_2 RD_{it}+\gamma_3 Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \tag{3}$$

When the coefficients α1 in Model 1, β1 in Model 2 and γ2 in Model 3 are statistically significant, and the coefficient γ1 of the core independent variable in Model 3 decreases in value or becomes less significant than α1 in Model 1, then R&D intensity acts as a partially mediating transmission factor, and Hypothesis H2 is confirmed.

### 3.3.3 Heterogeneity Grouped Regression Model

The three subsamples are sorted by the type of ownership, location of registration, and industry median of total assets, and individual regression models are fitted to test hypotheses H3, H4 and H5.

## 4. Empirical Analysis

### 4.1 Descriptive Statistics

*Table 2: Descriptive Statistics Results*

| Variable | Observations | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| *LnGrePatent* | 14246 | 0.568 | 0.940 | 0 | 4.025 |
| *Deductamt* | 14246 | 7.12e+07 | 1.50e+08 | 0 | 1.01e+09 |
| *RD* | 14246 | 7.5288 | 7.229 | 0.410 | 44.960 |
| *Lnsize* | 14246 | 8.175 | 1.108 | 6.079 | 11.581 |
| *LnAge* | 14246 | 3.005 | 0.283 | 2.197 | 3.611 |
| *Lev* | 14246 | 0.370 | 0.191 | 0.049 | 0.865 |
| *CFS* | 14246 | 0.099 | 0.158 | -0.473 | 0.569 |

Descriptive statistics findings of all variables are presented in Table 2. The analysis indicates that the output of green innovation in high-tech enterprises is distinctly differentiated in the sample. Over half of the enterprises did not apply for any green patents this year, which suggests inadequate overall green innovation enthusiasm and modest results, as well as an uneven structure of low-carbon technology R&D. Such a feature corresponds to the result of critical disparity among the levels of enterprise innovation by Wang Huixin et al. (2025) [12] findings. Super-deduction preferences enjoyed by various enterprises differ significantly: small and medium high-tech enterprises have a small amount of R&D basis and a small size of tax savings, whereas the most prominent big enterprises can benefit from significant tax relief. High-tech enterprise internal R&D allocation is also not even, and many enterprises have invested less in R&D compared to the industry average. Control variable distribution is reasonable, and the sample represents high-tech companies of varying sizes and at various stages of operation, which is indicative of a high quality of sample representativeness.

### 4.2 Correlation Analysis

*Table 3: Correlation analysis results*

| Variable | *LnGrePatent* |
|---|---|
| *Deductamt* | $0.218^{***}$ |
| *RD* | $0.0146^{*}$ |
| *Lnsize* | $0.334^{***}$ |
| *LnAge* | 0.0108 |
| *Lev* | $0.222^{***}$ |
| *CFS* | $-0.0561^{***}$ |
| Observations | 14246 |

*Note:* $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$.

The Pearson correlation outcomes indicate that the core explanatory variable has a significant positive relationship with the dependent variable as expected by the theory. All the correlation coefficient absolute values between any two variables are smaller than 0.4 which preliminarily confirms that there is no serious multicollinearity and that the variables can be used in regression analysis.

### 4.3 Baseline Regression Results

The reduction in the size of the baseline regression sample originates from the deletion of single-period firm observations through two-way fixed effects and the elimination of missing values on variables. The actual effective number of observations is 13,667, which does not alter the conclusions.

The value of the core explanatory variable, namely the R&D expense additional deduction amount (*Deductamt*) coefficient, is 0.000 and statistically significant at a 10 percent level, which means that the growth of the R&D expense additional deduction amount is positively correlated with the increase in the green innovation output of high-tech enterprises, which confirms H1.

*Table 4: Baseline Regression Results*

| Variable | *LnGrePatent* |
|---|---|
| *Deductamt* | 0.000* |
| | (0.000) |
| *Lnsize* | 0.118*** |
| | (0.027) |
| *LnAge* | 0.453* |
| | (0.274) |
| *Lev* | 0.041 |
| | (0.079) |
| *CFS* | -0.085* |
| | (0.047) |
| Year fixed effects | Controlled |
| Individual fixed effects | Controlled |
| Constant | -1.665** |
| | (0.813) |
| Observations | 13667 |

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01; standard errors are given in parentheses.*

The extra deduction reduces the marginal cost of corporate green R&D by lowering the tax base, adds more internal operating cash flow, relieves long-term and massive funding pressures on green innovation, encourages companies to invest in low-carbon process and environmental protection product R&D, and eventually brings up more green patent applications.

The coefficient of the control variable, firm size (*Lnsize*), is 0.118 and statistically significant at the 1% level, which implies that big firms are likely to be more successful in the establishment of a well-developed R&D system and having adequate capital resources; the coefficient of operating cash flow (*CFS*) is statistically negative, implying that companies with excess cash flow can invest their money into short-term lucrative opportunities, leaving less space to invest in green R&D with long payback periods and low yields; there are no statistically significant effects of firm age (*LnAge*) and asset-liability ratio (*Lev*).

## 4.4 Mediation Effect Test

In accordance with the three-stage mediation process of Wen Zhonglin, three successive regression models are built. Model (1) is the baseline total effect test; Model (2) takes R&D intensity (RD) as the dependent variable; and Model (3) takes both Deductamt and the mediator RD. The findings are given in Table 5.

Regression findings of Model 1 in Table 5 indicate that the R&D expense super-deduction amount coefficient (*Deductamt*) is statistically significantly positive, which means that the R&D expense super-deduction has a general promoting impact on corporate green innovation. In Model 2, R&D intensity (RD) is taken as the dependent variable, and the core explanatory variable, the R&D expense super-deduction amount (*Deductamt*), is highly significant at the 1 percent level. Tax relief savings could be used to directly increase corporate R&D expenditure and make the share of R&D spending in operating revenue significantly larger. This model includes both the core explanatory variable (*Deductamt*) and the mediator (RD). The R&D expense super-deduction amount (*Deductamt*) coefficient is slightly less than with Model 1, but its significance remains the same; the regression coefficient of RD is positive, which is consistent with the partial mediator criterion, thus Hypothesis H2 is confirmed. It can then be inferred that, apart from directly enhancing green innovation in high-tech companies, the R&D expense super-deduction also has an indirect transmission path: tax benefits lower corporate tax payments; companies use the extra money to fund R&D efforts, which leads to increased overall R&D intensity; adequate R&D capacity enables repetitive development of low-carbon technologies; and finally, the amount of green patent filings rises. R&D intensity partially mediates between these two.

*Table 5: Mediation Effect Test Results*

| Variable | *LnGrePatent* Total Effect | *RD* Mediator | *LnGrePatent* Direct Effect |
|---|---|---|---|
| *Deductamt* | 0.000* | 0.000*** | 0.000* |
| | (0.000) | (0.000) | (0.000) |
| *RD* | - | - | 0.003* |
| | | | (0.002) |
| *Lnsize* | 0.118*** | -1.424*** | 0.122*** |
| | (0.027) | (0.159) | (0.027) |
| *LnAge* | 0.453* | 10.460*** | 0.426 |
| | (0.274) | (1.832) | (0.274) |
| *Lev* | 0.041 | -0.755 | 0.043 |
| | (0.079) | (0.590) | (0.079) |
| *CFS* | -0.085* | -3.990*** | -0.075 |
| | (0.047) | (0.474) | (0.048) |
| Year/Individual fixed effects | Controlled | Controlled | Controlled |
| Constant | -1.665** | -11.306** | -1.635** |
| | (0.813) | (5.223) | (0.813) |
| Observations | 13667 | 13667 | 13667 |

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01; standard errors in parentheses.*

## 4.5 Grouped Regression for Heterogeneity Analysis

In order to test two sets of heterogeneity hypotheses (H3, H4, and H5), the sample is split into three categories based on ownership nature, region of registration, and size of the firm to perform two-way fixed effects regressions between groups to determine how much the policy incentive effects differ among groups.

### 4.5.1 Heterogeneity Analysis by Ownership Nature

*Table 6: Heterogeneity Test Results by Ownership Nature*

| Variable | *LnGrePatent* (State-owned Enterprises) | *LnGrePatent* (Non-state-owned Enterprises) |
|---|---|---|
| *Deductamt* | -0.000 | 0.000** |
| | (0.000) | (0.000) |
| *Lnsize* | 0.075 | 0.120*** |
| | (0.059) | (0.031) |
| *LnAge* | 0.943 | 0.397 |
| | (0.767) | (0.302) |
| *Lev* | 0.147 | -0.003 |
| | (0.212) | (0.081) |
| *CFS* | -0.099 | -0.098** |
| | (0.128) | (0.049) |
| Year/Individual fixed effects | Controlled | Controlled |
| Constant | -2.702 | -1.534* |
| | (2.324) | (0.899) |
| Observations | 2708 | 10959 |

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01; standard errors in parentheses.*

The research also separates the sample by state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) based on the characteristics of the actual controller. The grouped regression results are given in Table 6. These results indicate that the regression coefficient of the R&D expense super-deduction amount does not have a significant value in the SOE subsample, but it is significantly positive at the 5 percent level in the non-SOE subsample, thus confirming Hypothesis H3.

Non-SOEs compete under a highly competitive market setting and green innovation has a direct relationship to their market competitiveness. On the other hand, these companies are limited in their internal capital and have more stringent external finance restrictions, which means that the additional cash flow associated with tax relief may be used to invest in low-carbon R&D. By comparison, SOEs have diverse business goals. Besides revenues generated through operations, SOEs have to take on social mandates including employment and industry safety. They are less restricted in their performance evaluation of green R&D. Furthermore, SOEs are able to have greater access to credit facilities and experience lower financial pressures. The cash flow due to tax incentives is a marginal increase in the amount of money saved on taxes and will not significantly alter the initial course of corporate fund allocation. Thus, the super-deduction is not likely to increase their green patent production.

### 4.5.2 Regional Heterogeneity

*Table 7: Regional Heterogeneity Test Results*

| Variable | *LnGrePatent* (Eastern Enterprises) | *LnGrePatent* (Central and Western Enterprises) |
|---|---|---|
| *Deductamt* | 0.000** | -0.000 |
| | (0.000) | (0.000) |
| *Lnsize* | 0.124*** | 0.079* |
| | (0.032) | (0.046) |
| *LnAge* | 0.491 | 0.382 |
| | (0.311) | (0.585) |
| *Lev* | -0.003 | 0.148 |
| | (0.088) | (0.153) |
| *CFS* | -0.088 | -0.074 |
| | (0.055) | (0.099) |
| Year/Individual fixed effects | Controlled | Controlled |
| Constant | -1.799* | -1.202 |
| | (0.929) | (1.694) |
| Observations | 10497 | 3170 |

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01; standard errors in parentheses.*

The sample is split into two categories by the location of the registered enterprise, which are the eastern region and the central and western regions. The outcomes of regional grouped regression analysis are given in Table 7. It is found that the coefficient of the main explanatory variable for high-tech enterprises in the eastern region is highly significant at the 5 percent level, but the regression coefficient of the same variable for enterprises in the central and western regions fails to be significant. Thus, Hypothesis H4 is supported by empirical evidence.

The identical tax policy causes disparate results in different regions as it is directly connected with regional innovation resources and the favourable environment of the digital economy. The eastern region has intensive digital infrastructure, green industrial chains, and leading scientific and technological innovation talent. Once companies have secured tax-saving money, they will be able to convert these assets into green patents through supportive R&D systems and industrial conditions. In comparison, the central and western regions have weaknesses in the provision of factors concerning green innovation. Although enterprises may get the same tax stimuli, they do not have digital R&D carriers, talent, and industrial chain support, so that the funds can easily be directed towards conventional technological iterations and are hard to convert into green innovation output. It also explains theoretically why the digital economy interaction term is insignificant in the sample: the influence of tax incentives is extremely sensitive to local real innovation conditions. The eastern region can provide policy dividends, whereas the central and western regions can balance the policy impact through the factor deficiencies. A single tax incentive can never make up for the systemic gap in regional innovation factors; both fiscal and tax policies and regional public supporting facilities should be synergized.

### 4.5.3 Heterogeneity by Enterprise Size

The sample is segmented into two categories, which are large-scale and small-scale companies, depending on the industry median of annual total assets. Table 8 contains the regression findings of the heterogeneity of enterprise sizes. As indicated by the results of the grouped regression by size, the regression coefficient of the R&D expense super-deduction amount does not matter statistically in large-scale enterprises, but the relevant coefficient in small-scale enterprises is highly significant at the 5 percent level. Thus, Hypothesis H5 is confirmed. This disparity has a fundamental cause, which is the varying marginal effects of tax-saving funds. In large-scale high-technology enterprises, there exists a large R&D fund pool of overall spending, and the savings brought by the super deduction represent a relatively small fraction of total R&D investment, therefore, incremental funds play a minimal role in the overall R&D plan. Moreover, large companies operate in diverse fields, and tax-saving gains do not necessarily go towards green R&D but rather spread across various lines of production and operations. On the other hand, small high-tech enterprises have a lower R&D investment base, and the same amount of tax relief may result in much larger increases in the share of R&D investment. Meanwhile, small and medium businesses have constrained sources of financing, and tax benefits become an inexpensive way to finance internal R&D activities. They are more responsive to policy, and tax-saving funds could be used to achieve green patent output successfully.

*Table 8: Heterogeneity Test Results by Enterprise Size*

| Variable | *LnGrePatent (Large-scale Enterprises)* | *LnGrePatent (Small-scale Enterprises)* |
|---|---|---|
| *Deductamt* | 0.000 | $0.000^{**}$ |
| | (0.000) | (0.000) |
| *Lnsize* | $0.158^{***}$ | $0.080^{**}$ |
| | (0.044) | (0.039) |
| *LnAge* | 0.637 | 0.349 |
| | (0.466) | (0.360) |
| *Lev* | 0.160 | 0.006 |
| | (0.139) | (0.107) |
| *CFS* | -0.086 | -0.023 |
| | (0.081) | (0.061) |
| Year/Individual fixed effects | Controlled | Controlled |
| Constant | $-2.529^{*}$ | -1.180 |
| | (1.387) | (1.051) |
| Observations | 6929 | 6738 |

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01; standard errors in parentheses.*

## 4.6 Robustness Test

*Table 9: Robustness Test Results*

| Variable | *LnGrePatent* |
|---|---|
| *L_Deductamt_w* | $0.000^{*}$ |
| | (0.000) |
| *Lnsize* | $0.107^{***}$ |
| | (0.033) |
| *LnAge* | 0.106 |
| | (0.354) |
| *Lev* | -0.061 |
| | (0.095) |
| *CFS* | -0.080 |
| | (0.054) |
| Year/Individual fixed effects | Controlled |
| Constant | -0.481 |
| | (1.059) |
| Observations | 10518 |

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01; standard errors in parentheses.*

Due to the presence of reverse causality as a possibility, this paper regresses the primary explanatory variable with a one-period lag. The findings in Table 9 indicate that the coefficient of the lagged term is still statistically significantly positive at 10 percent, and the sign is the same. It means that the main conclusion is strong even after removing the influence of bidirectional causality. Funds to tax policies have a time lag, and even though the amount saved on taxes in any given year will continue to affect R&D in future years, this is also supported by the regression findings.

# 5. Research Conclusions and Policy Recommendations

## 5.1 Main Empirical Research Conclusions

The paper uses 14,246 firm-years of panel data of A-share listed high-tech companies for the period between 2019 and 2023 and runs the entire battery of empirical tests. Two-way fixed-effects baseline regression confirms that R&D expense super deduction will help to boost corporate green innovation output significantly, which means, H1 is corroborated. The three-stage mediation test of Wen Zhonglin indicates that R&D intensity has a mediating effect, which generates a full transmission process of the form R&D expense super deduction-increase in R&D intensity-green innovation promotion, and thus H2 is supported. The regroupings into ownership, regions and sizes show strong stratified differences in policy incentives. Just non-state-owned enterprises, eastern region enterprises and small scale high-tech enterprises can efficiently release policy dividends; the incentive impact on state-owned enterprises, central and western regions enterprises and large enterprises is insignificant. All these hypotheses, H3, H4 and H5, are empirically confirmed. The findings of the robustness test based on the one-period lagged core variable are also similar to the baseline regression, and they indicate that the main findings of the present study cannot be altered by the endogeneity issue of bidirectional causality and that the findings are reliable and credible.

## 5.2 Government-Level Policy Optimization Recommendations

According to the baseline regression, mediation effect test and heterogeneity findings depending on ownership, region, and size, the paper suggests differentiated fiscal and tax policy and optimisation of the use of public services recommendations.

Concerning the ownership aspect, it is possible to integrate green R&D investment and green patent output into the performance evaluation system of state-owned enterprises, as the policy incentive impact on state-owned enterprises was minimal; such integration will direct tax-saving resources to green innovations. On top of that, the procedures for collecting and declaring R&D expenses of privately owned and foreign-invested companies need to be constantly optimized, which will lower the institutional transaction costs and completely unleash the green innovation energy of the market-oriented entities.

On the regional scale, it is necessary to provide proper green R&D super deduction preferences to the high-tech companies in the middle and western regions, which should be backed up by low-carbon digital government services and enhanced efforts to attract science-based and innovative talent to make up the gap in regional innovation determinants. In the eastern region, it may use its strength in the digital industry to concentrate on incentives for high-value green invention patent production and further encourage frontier low-carbon technology studies.

At the level of the size of firms, there is a need to increase the specific tax incentives for the green R&D of small enterprises. In big high-tech companies, companies should be encouraged to enhance restrictions on green R&D funding investments and refrain from diverting too much of the tax dividends into regular business operations.

Based on the transmission mechanism, tax and science and technology departments could work together to enhance the detailed regulations of independent green R&D accounting, to facilitate the efficient conversion of super deduction benefits into enterprise R&D spending, to create low-carbon digital carriers of public services, to introduce green credit products based on tax credits, to relieve financial constraints, and to release the transmission channel of the R&D expense super deduction-R&D intensity-green innovation.

## 5.3 Development Countermeasures for High-Tech Enterprises

The policy dividends of the R&D expense super deduction should be well utilized by high-tech enterprises, and the internal path between policy dividends and green innovation transformation should be opened up. Companies may form dedicated funds to green R&D, have separate control over the tax savings created by the super deduction, and increase the pace of growth in green patents by increasing the level of R&D.

Lightweight low-carbon process improvements can be undertaken by small-scale enterprises depending on their available resources, whereas large-scale enterprises may set up specialized green R&D departments, define the amount of low-carbon R&D spending, and decrease the degree of fund scattering. State-owned enterprises must enhance internal green R&D incentives and reinforce internal evaluation of innovations. Regional digital innovation platforms should be actively connected to private and foreign-funded enterprises in order to enhance efficiency in R&D transformation.

Eastern regional enterprises may also depend on the local digital industry chains to create a synergistic effect between digitalization and green R&D. The central and western enterprises are advised to interact with the government measures to digitalize and support talents to compensate the inadequacy of innovation resources. All types of enterprises must have standardized green R&D financial registers, correct classification and aggregation of R&D expenditures, as well as guarantee the authenticity and reliability of R&D expenditure accounting.

## 5.4 Research Limitations and Future Prospects

The present study has these limitations. Firstly, the sample is limited to high-tech companies listed in the A-share market, and the findings cannot be simply extrapolated to other unlisted science and innovation organizations. Secondly, only the overall quantity of green patents is considered, without splitting invention patents (utility model patents) to determine how the policy affected innovation quality. Thirdly, the digital economy is viewed solely as a macro background, and its sub-indicators are not broken down to test moderation. Thirdly, the endogeneity remedy relies on the lagged independent variable only, and no remedies like DID or instrumental variables are used. Future studies may increase the sample size to non-listed enterprises, differentiate green patent types to investigate the quality of innovation, break down digital economy sub-indicators, apply DID and instrumental variables to further control endogeneity, and add variables to the extension research, including environmental regulation and state grants.

## References

[1] Qiqi Yan. (2025). Research on the impact of R&D expense deduction policy on the innovation ability of high-tech enterprises. Master’s thesis. Chinese Academy of Fiscal Sciences.

[2] Shaowei Jia. (2025). A study on the impact of the R&D expense super-deduction on technological innovation of high-tech enterprises: An analysis from the perspective of enterprise life cycle. Master’s thesis. Shanxi University of Finance and Economics.

[3] Zhaochang Ma. (2024). Research on the Impact of R&D Expense Deduction on the Innovation Output of High-tech Enterprises. Master’s thesis. Shandong University of Finance and Economics.

[4] Wang, H., Yang, J., & Zhu, N. (2024). Does tax incentives matter to enterprises' green technology innovation? The mediating role on R&D investment. Sustainability, 16 (14), 5902. https://doi.org/10.3390/su16145902.

[5] Wansi He. (2022). A study on the impact of the R&D expense super-deduction on innovation of high-tech enterprises: A dual perspective of financing constraints and ownership attributes [Master's thesis]. Zhejiang University of Finance and Economics.

[6] Liling Yang. (2026). Research on financial risk management in the R&D expense super-deduction of enterprises. Modern Marketing, (1), 67–69.

[7] Zejian Yang. (2025). A study on strategies of high-tech enterprises in response to the R&D expense super-deduction policy. Management & Technology of SME, (19), 163–165.

[8] Tao Zhao, Zhi Zhang, & Shangkun Liang. (2020). Digital economy, entrepreneurship, and high-quality economic development: Empirical evidence from urban China. Journal of Management World, 36(10), 65–75.

[9] Kong, T., Sun, R., Sun, G., & Song, Y. (2022). Effects of digital finance on green innovation considering information asymmetry: An empirical study based on Chinese listed firms. Emerging Markets Finance and Trade, 58(15), 4399–4411. https://doi.org/10.1080/1540496X.2022.2083953.

[10] Ruizhi Pang, Dongge Liu. (2022). The paradox of digitalization and innovation: Does digitalization promote enterprise innovation? An explanation based on open innovation theory. South China Journal of Economics, (9), 97–117.

[11] Jiang, J. (2025). A configurational pathway analysis of digital economy and green technology innovation. Modern Economy, 16(2), 284–299.

[12] Huixin Wang & Ping Kuang. (2025). Can additional deduction of R&D expenses enhance the innovation vitality of high-tech enterprises? Science Technology and Industry, 25(14), 235–239.

[13] Zhonglin Wen & Baojuan Ye. (2014). Analyses of mediating effects: The development of methods and models. Advances in Psychological Science, 22(5), 731–745. https://doi.org/10.3724/SP.J.1042.2014.00731.

## Funding

This research received no external funding.

## Conflicts of Interest

The authors declare no conflict of interest.

## Acknowledgment

This paper is an output of the science project.