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# The Impact of Green Technology Research and Development (R&D) Investment on Performance: A Case Study of Listed Energy Companies in Beijing, China

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**Abstract:** The aim of this study is to investigate the relationship between green technology R&D investment and corporate performance (ROA) of 44 Beijing-listed energy companies from 2016 to 2021 using a threshold regression model. The results show that there is an inverse W-shaped nonlinear relationship between green technology R&D investment and firm performance. This means that green technology R&D investments only have a positive effect on firm performance within an appropriate green technology R&D investment interval, and a negative effect occurs outside this interval. Additionally, the study analyses the influence of three threshold variables (firm size, capital structure and capital density) on the relationship between green technology R&D investment and firm performance. The results show that firm size has an inversely- U-shaped relationship, the capital structure has a negative nonlinear relationship and the capital density has an inversely N-shaped relationship. Optimal intervals are observed for all three threshold variables. Moreover, the study shows that the green technology R&D investment intensity has a lagged effect on firm performance. The positive influence weakens over time, and the negative influence becomes more pronounced. The findings of the study can help energy companies to develop green technology R&D innovation strategies, such as differentiating green technology R&D expenditures for companies in different development situations. It can also exploit the driving effect of green technology R&D investment on firm performance in the context of China's energy sector restructuring.

**Keywords:** green technology R&D investment; firm performance; hysteresis effect; threshold effect



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## 1. Introduction

The International Energy Agency recently published the report "Net Zero Emissions 2050: A Roadmap for the Global Energy Sector" to respond to the increasing diversification, decarbonisation, intelligence and distribution of global energy development. This roadmap aims to foster international cooperation on green energy and calls on governments to accelerate the transition to a more sustainable energy system. As we move towards this unprecedented energy system, energy policy, innovative technologies and international cooperation will be crucial to global energy development. China has also taken important steps towards sustainability by proposing a vision of development, which is both peak carbon and carbon neutral. This means no further increase in $CO_2$ emissions by 2030 (peak carbon) and relatively "zero" $CO_2$ emissions from human activities by 2060 (carbon neutrality). To achieve these ambitious dual-carbon targets and effectively address the challenges of climate change, it is imperative that China makes comprehensive and profound economic and social systemic changes. Among the various sectors, the energy sector will play a central role in driving the transition to a greener and low-carbon future. Transforming and modernising the energy sector will be a crucial way for China to successfully achieve its "dual carbon" goals. The energy transition will undoubtedly pave the way for a more resilient, greener and prosperous future and promote a low-carbon society that benefits both current and future generations.

Against the backdrop of the global transformation of the energy industry from traditional to green energy, scientific and technological innovations are key for Chinese energy companies to overcome various challenges and generate economic returns. However, there is still a technological gap between China and developed countries in the energy sector. As the development of energy technologies is characterised by high investment in green technology R&D and technical design with long green technology R&D and development cycles, a forward-looking and innovation-driven approach is essential [1]. As one of the key players in the implementation of the "double carbon" target, China is placing new demands on the energy sector. Revolutionary technological advances, rapid regulatory changes and constraints on carbon emission targets are required. Changes in the industry, technological bottlenecks and the behaviour of customers and competitors pose major challenges for energy companies. Therefore, the energy industry in China urgently needs to invest in innovation and complete industrial transformation by optimising processes, adopting low-carbon technologies and adjusting industrial layouts to reduce carbon emissions. Overall, Chinese energy companies need to be more innovative and forward-looking, and the government needs to support technological innovation, talent training and industrial development to improve the competitiveness of China's energy industry [2].

Optimising green technology R&D investments in the energy sector is critical to improving investment and research efficiency, as green technology R&D investments have different impacts on the firm performance of different types of corporations and phases. First, green technology R&D investment exhibits significant heterogeneity across different types of firms. For example, for business and finance companies, green technology R&D investments may use more accurate economic models to obtain an optimal investment and financing structure. In manufacturing, green technology R&D investment can improve total factor productivity by developing new equipment [3]. To investigate the external role of green technology R&D investment in the energy sector, an industry-specific analysis with different companies as a separate research object is required. Second, the economic benefits obtained at different stages of green technology R&D investment are also heterogeneous. For example, the return on green technology R&D investment is lower for start-up companies than for mature companies, as the mature companies can effectively use the scale effect and learning effect of green technology R&D investment to increase the success rate of green technology R&D [4]. As China pursues its "double carbon" goal, green technology R&D investment in the energy sector is increasing year by year. Therefore, considering the role of green technology R&D in corporate governance in the energy industry is both theoretically and practically important, as the example of China shows. Overall, optimising green technology R&D investment in the energy sector should consider the unique characteristics of the industry, such as long green technology R&D cycles, high investment in green technology R&D and other complex external factors. Moreover, the government should also support green technology R&D investment and encourage companies to improve their green technology R&D capabilities to promote sustainable development.

Given the unique characteristics of China's energy sector, it is noteworthy that state-owned enterprises account for more than 90% of the China Energy 500 list (2021). Moreover, of the 51 top state-run enterprises in the China National Resources Commission system, 34 are headquartered in Beijing, making Beijing the city with the largest number of such enterprises. As a model city for China's transition to clean energy, Beijing is consistently among the leading provinces when it comes to energy use efficiency, and the number of listed energy companies is one of the highest in China. These factors underscore the great importance and value of studying the energy sector in Beijing. Figure 1 illustrates the important role Beijing plays in the spatial distribution of green technology R&D investment by listed energy companies in China. As Beijing serves as a hub for the energy sector, green technology R&D investments by listed energy companies in Beijing can not only improve their own performance but also facilitate the transformation and modernisation of their economic and energy structures. Moreover, these investments have the potential to influence energy companies across the country. Against this backdrop, this study seeks to refine the circle of energy companies and explore the impact of green technology R&D investment on the corporate performance of Beijing-based energy companies.

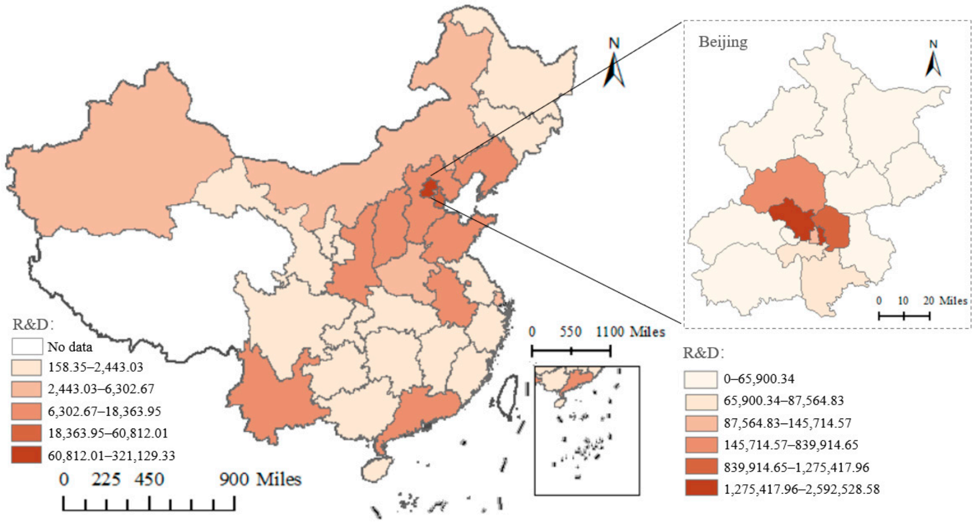


**Figure 1.** Spatial distribution of average green technology R&D investment (RMB million) of listed energy companies in Beijing, China. According to the two-digit industry classification of the China Securities Regulatory Commission's "Industry Classification Guidelines for Listed Companies (2012 Revision)", listed energy companies include, in particular, Coal Mining and Washing (B06), Oil and Gas Mining (B07), Petroleum Refining, Coking and Nuclear Fuel Processing (C25), Electricity, Heat Generation and Supply (D44), Gas Generation and Supply (D44), etc.

Most previous studies have focused on technology and innovation industries [5–7], while research on R&D investment in green technologies energy firms is limited. The relationship between R&D investment in green technologies and firm performance varies across different mediation mechanisms, but there are limited articles discussing this. The contribution of this study lies in two main aspects. First, although the relationship between corporate innovation and performance has been widely studied, the results and research methods are inconsistent and influenced by other variables. To decrease this gap, we use a threshold regression model to examine the relationship between green technology R&D investment and firm performance among listed energy firms in Beijing, using firm size, capital structure and capital density as threshold variables. Second, given the long green technology R&D cycles and slow implementation of innovation investment in the energy sector, we examine the lag effect and action cycle of green technology R&D investment on firm performance. The results of this study provide valuable insights for energy companies in developing green technology R&D innovation strategies and maximising the positive impact of green technology R&D investments on firm performance.

The rest of this paper is structured as follows. Section 2 provides a literature review on the impact of green technology R&D investment on the firm performance of Beijing-listed energy firms. Section 3 describes the hypothesis, model design and variables used in the study. Section 4 presents descriptive statistics and tests. Section 5 presents the empirical analysis, examining the relationship between green technology R&D investment and firm performance and the effects of threshold and control variables. Finally, Section 6 draws the experimental conclusion and discusses the influence mechanism and specific sector change of listed energy companies in Beijing.

## 2. Literature Review

### *2.1. Correlation between Green Technology R&D Investment and Firm Performance*

Green technology R&D investment is critical to a firm's performance because it improves the firm's ability to use available information effectively [7]. The relationship between green technology R&D investment and firm performance has been widely studied in the literature, with often conflicting empirical results [8–10]. Scholars have applied empirical methods to assess the efficiency of green technology R&D investment, as numerous attributes are required to measure green technology R&D performance [11–13]. The literature has mainly focused on the following aspects regarding the correlation between green technology R&D investment and firm performance.

First, green technology R&D expenditure has been found to be positively related to a firm's future performance [14,15], with green technology R&D investment as an important determinant of firm performance [16]. Second, according to technological innovation theory, the technological outcomes of green technology R&D development activities contribute to economic growth and productivity at the firm level and generate additional revenues for the firm [17]. Third, green technology R&D investment at the competitive level serves as the basis for improving the firm's competitive advantage, long-term economic growth and technological progress, which ultimately improves firm performance [18–20]. In other words, firms use their green technology R&D investments to develop and bring innovative products and technologies to market, thereby improving the firm's competitiveness and performance [21]. Although a positive correlation between future firm performance and future green technology R&D investment is widely recognised, the literature suggests that this relationship is not always positive. Factors such as reverse causality [22] and the attenuating role of mediating variables that influence the effect of green technology R&D intensity on the knowledge creation process and new product performance [23–25] may undermine the positive correlation between green technology R&D investment and firm performance.

Several scholars have argued that green technology R&D intensity has a significant negative impact on profitability. On the one hand, green technology R&D investments are associated with inherent risks and uncertainties [26], and overinvestment may occur, leading to insufficient returns to compensate for green technology R&D expenditures [27]. Companies often face high costs for uncertain future returns, and the time lag between green technology R&D investments and their innovation output can negatively affect current financial performance [28]. On the other hand, managers may prefer short-term gains over long-term, uncertain technological innovations [29], leading to risk-averse tendencies among managers with higher green technology R&D spending [30]. Green technology R&D funding may be perceived as a hidden cost that carries significant risks and can weaken firm performance. Managers may even forego long-term economic gains from green technology R&D investments to meet current earnings targets and choose to reduce current green technology R&D investments to meet short-term goals [31,32].

In contrast, some scholars have suggested that the relationship between green technology R&D investment and firm performance may not be significant [33,34]. These scholars have used various models to measure firm performance and concluded that an increase in green technology R&D investment in the current period may not create enough value for the firm because the newly developed technologies and products are not recognised by the market. They, therefore, concluded that there is no significant relationship between green technology R&D investment and firm performance [35]. Additionally, other scholars have conducted empirical studies suggesting that the impact of green technology R&D investment on firm performance may be offset by a combination of other factors [36], implying that the innovation output of green technology R&D investment may not be significant for the market effect. A considerable body of literature shows that firms can improve their innovation output as well as their innovation absorption capacity by imitating existing innovations [29]. When new technologies are brought to market for profit, some of them become public knowledge and are imitated or copied by other competitors. This means that the innovator does not have exclusive access to the benefits of the innovation, which results in the benefits from the company's green technology R&D activities being much lower than expected [37,38].

Moreover, a growing number of studies confirm the complex and nonlinear nature of the relationship between green technology R&D investment and firm performance. On the one hand, the impact of market uncertainty on investment may vary, and the risk associated with green technology R&D investment may increase with green technology R&D intensity [39]. Moreover, firms' innovation performance appears to be bought by significant green technology R&D costs, and firms with higher green technology R&D intensity may have poorer operating performance in the short run but higher value potential in the long run. On the other hand, green technology R&D investment is influenced by other variables, resulting in a complex relationship between green technology R&D investment and profitability, where country-level factors attenuate the relationship between green technology R&D and firm performance [20]. Therefore, the relationship is subject to constant fluctuations. Although the intensity of green technology R&D investment has a negative impact on the profitability aspect of short-term financial performance, investments in green technology R&D innovations and new technologies have a positive impact on long-term performance [40]. Additionally, there are also some studies that provide a theoretical framework for analysing the impact of dynamic changes in the knowledge base on green innovation from the perspective of technological knowledge coupling, which confirms the existence of an optimal value for green technology R&D investment and the inversely-U-shaped nonlinear relationship between firms' technological innovation and firm performance [41].

### *2.2. Determinants of Variability in the Relationship between Green Technology R&D Investment and Firm Performance*

The differences in the correlation between green technology R&D investment and firm performance are due to the different selection of indicators in the existing studies [42–44]. Most studies have quantified green technology R&D inputs and expenditures using green technology R&D intensity [45–48]. The selection of business performance indicators is controversial. Some scholars use absolute variables such as the gross operating profit or the [49] net present value, while others have chosen relative variables such as the return on assets (ROA) [19,50], the return on net assets (ROE) or Tobin's Q [17,26,33,40].

Diversity in the measurement of green technology R&D performance contributes to the variability in the correlation between green technology R&D investment and firm performance [51]. Various methods have been used, ranging from simple procedures to complex mathematical models [52]. First, some studies analysing the innovation performance of green technology R&D inputs and their role in firms have used multi-criteria decision models to evaluate the weights of green technology R&D inputs and outputs [53]. For example, some scholars have used the analytic hierarchy process (AHP) to create a hierarchical structure and analyse the priority of green technology R&D inputs using relative weights [54]. Others have used the best–worst method to determine the optimal weighting of green technology R&D inputs and efficiently allocate limited resources [13]. Some have applied real option models and the option pricing theory in economic models to evaluate investment uncertainty and analyse the optimal strategies for firms after making irreversible green technology R&D investments [49]. Second, some articles argue that the data envelopment analysis (DEA) approach is more suitable than other methods such as AHP and integrative fuzzy analysis (fuzzy AHP) because it does not require the assumption of multiple relationships between input and output functions. Dynamic network DEA models can measure the efficiency of green technology R&D inputs at different stages and time periods [55–57]. Moreover, green technology R&D investments are not randomly distributed across firms but are determined by firm decisions, which raises the problem of selection bias [58]. Common econometric approaches to dealing with selection bias include propensity score matching, generalised propensity score matching methods, endogenous switching regression, treatment effect models, various types of sample selection models (e.g., the two-stage Heckman model), instrumental variable methods, correlated random effects, fixed-effects models and difference-in-differences methods.

A review of the existing literature shows that the relationship between green technology R&D investment and firm performance varies across industries and countries, different time periods, mediation mechanisms and research methods. Moreover, most of the previous studies have focused on technology and innovation industries, while research on green technology R&D investment in energy firms is limited. Against this background, this study examines the nonlinear relationship between green technology R&D investment and firm performance among listed energy firms in Beijing using data from 44 firms over the period of 2016–2021.

## 3. Research Design

### 3.1. Hypotheses

After reviewing the existing literature, we found that there was an inversely-U-shaped threshold effect of green technology R&D investment on firm performance, where green technology R&D expenditure above a certain rate could have a negative impact on profitability [59]. Moreover, the threshold effect of green technology R&D spending is significant, and there is an optimal green technology R&D interval [60]. However, the effectiveness of green technology R&D investment on firm performance decreases significantly after the optimal green technology R&D investment interval is exceeded [61]. Given the different effects observed in the literature due to different levels of green technology R&D investment, we hypothesise the following three hypotheses.

Many studies have shown that investing in the R&D of green technologies has a significant positive impact on the performance growth of energy companies. By adopting green technologies, energy companies can reduce resource consumption and pollution, which in turn leads to higher production efficiency and product quality, thereby improving performance levels [9]. Several studies show that green investments can lead to nonlinear growth in a company's financial performance, and especially above a certain level of investment, the company's performance can improve significantly [62]. This means that in the early stages of technology research and development, high investment may be required, and the return on investment is relatively low [63]. However, once the technology is mature, there can be a significant positive growth effect on firm performance, as shown in Hypothesis 1.

**Hypothesis 1.** *There is a nonlinear positive correlation between R&D investment in green technologies and firm performance in the energy sector.*

The impact of green technology R&D activities can vary greatly depending on the category of a company, which underlines the heterogeneity of the companies under study [64]. Recent studies have found that the size of a firm is an important determinant of the impact of green technology R&D investment on firm performance, with effects varying across firms of different sizes [65]. Large firms tend to have more resources and a stronger market presence, allowing them to make significant green technology R&D investments to gain a competitive advantage, which can lead to high performance. In contrast, small- and medium-sized enterprises (SMEs) may have a stronger motivation to innovate and be able to achieve some technological breakthroughs better [66]. Based on the resource-based theory, the resource allocation of small enterprises plays a crucial role in their sustainable development. Compared to large enterprises, SMEs are less likely to allocate extensive resources to green technology R&D and promotional activities. Therefore, the effective use and allocation of limited resources have become a critical issue for small enterprises [67]. The impact of firm size on green technology R&D investment and firm performance may also vary across industries. For example, larger firms in high-tech industries typically invest more green technology R&D resources and personnel to achieve better performance, while in traditional industries, the impact of firm size on green technology R&D investment and performance may be smaller. Since large and small firms spend differently on green technology R&D, we hypothesise that firm size has an impact on the relationship between green technology R&D investment and firm performance (Hypothesis 2a).

The capital structure of a company reflects its financial flexibility and indicates whether the company has pursued a conservative or aggressive strategy. A balanced capital structure is crucial for the short- and long-term development of the company [17]. Since green technology R&D investments are subject to greater uncertainty than investments in fixed assets, a stable capital structure makes it easier for companies to raise additional funds to fully expand their innovation activities. However, if a company's capital structure is insufficient to fund its green technology R&D activities, this can increase future uncertainty for investors [68]. This means that equity financing can provide additional financial support to make the company more competitive in green technology R&D and thus improve its performance. Nevertheless, too high a leverage ratio can increase the financial risk for companies, which can have a negative impact on their green technology R&D investment and performance. Therefore, capital structure plays a threshold role in the relationship between green technology R&D investment and firm performance (Hypothesis 2b).

Furthermore, the degree of liquidity of a company can be measured by its capital intensity, which represents its ability to adapt to market changes and maintain its operations [69]. High liquidity, characterised by higher retained earnings and lower debt and interest expenses, can improve a firm's ability to raise capital and take on debt, leading to higher green technology R&D investment and better performance. Conversely, low liquidity can limit a company's ability to fund green technology R&D activities, which negatively impacts performance [36]. However, excessive liquidity can lead to the abnormal dispersion of corporate assets and a potential endogenous crisis [70]. Therefore, it is hypothesised that the relationship between R&D investment in green technologies and firm performance differs at different stages of capital intensity. (Hypothesis 2c).

In summary, we put forward three hypotheses related to the threshold effects of different firm-level variables on the relationship between green technology R&D investment and firm performance:

**Hypothesis 2.** *At different stages of firm size, capital structure and capital intensity, there are characteristics of the threshold effect between R&D investment in green technologies and firm performance.*

**Hypothesis 2a.** *At different stages of firm size, there are characteristics of the threshold effect between R&D investment in green technologies and firm performance.*

**Hypothesis 2b.** *At different stages of capital structure, there are characteristics of the threshold effect between R&D investment in green technologies and firm performance.*

**Hypothesis 2c.** *At different stages of capital intensity, there are characteristics of the threshold effect between R&D investment in green technologies and firm performance.*

In the course of research, it has been shown that firm performance is not only affected by green technology R&D investment in the current period but also by its lagged effect that extends into the long run [71]. First, some scholars argue that green technology R&D activities in products span a long cycle, and it takes time for green technology R&D innovations to lead to business revenues. Green technology R&D investments have a cumulative effect, meaning that their impact on performance is felt gradually over time [35]. Second, the costs of green technology R&D investment in the present are offset by the benefits in the future, and the negative effect of green technology R&D spending diminishes over time [72], leading to a positive effect of technological innovation on firm performance that is more pronounced over different time periods [73]. In other words, green technology R&D investments have different effects on firm performance over different time horizons [30,74,75]. While they have a positive impact on firm innovation and long-term financial performance, they have a negative impact on short-term financial performance [11,25]. Therefore, we assume that there is a lagged effect between green technology R&D investments and firm performance.

**Hypothesis 3.** *There is a lagged effect relationship between green technology R&D investment and firm performance. In the short run, green technology R&D expenditure and financial performance are negatively correlated, while in the long run, they are positively correlated.*

### *3.2. Model Settings*

Based on the above hypotheses, the research framework of this study is presented in Figure 2, which mainly tests the impact of green technology R&D investment itself, firm size, capital structure and capital density on the correlation between green technology R&D investment and firm performance and discusses the lag of the impact of green technology R&D investment on firm performance on this basis.

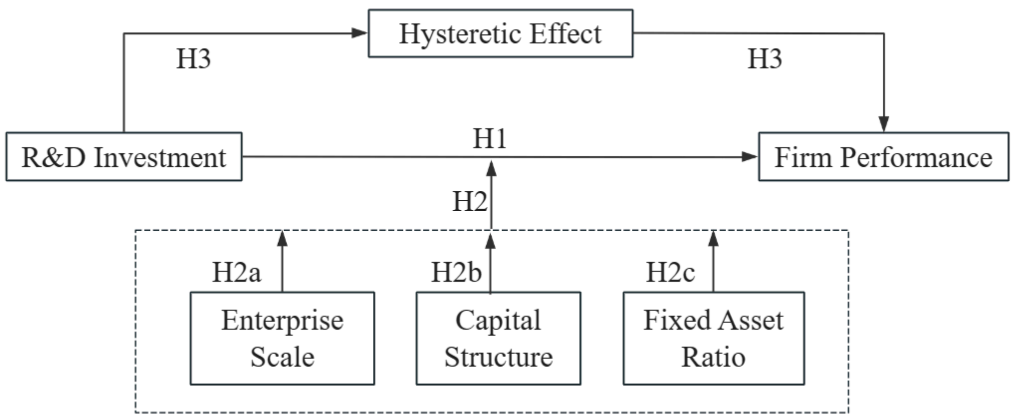


**Figure 2.** Research path diagram of the relationship between green technology R&D investment and firm performance.

This study uses a threshold model based on the previous literature [50,76] with an advanced panel threshold regression model that extends the traditional least squares estimation method. This model uses a simulated likelihood ratio test to derive the asymptotic distribution of the threshold test statistic. The panel threshold model is estimated using a two-stage OLS approach. In the first stage, the threshold is determined, and the significance of the threshold effect is tested. In the second stage, the coefficients within each interval are determined. To examine the impact of green technology R&D investment on firm performance in the presence of other factors in the firm, we optimised the multi-panel regression model using the threshold regression model shown below.
Model I:

$$ROA_{it} = \beta_1 * RD_{it} + \beta_2 * {RD_{it}}^2 + \gamma_1 OPC_{it} + \gamma_2 RQ_{it} + \delta_i \delta_t + \epsilon \tag{1}$$

$$\begin{aligned} ROA_{it} = I(RD_{it} &< \alpha_1)\beta_1 * RD_{it} + I(\alpha_1 \le RD_{it} < \alpha_2)\beta_2 * RD_{it} + \cdots \\ &+ I(RD_{it} > \alpha_r)\beta_{r+1} * RD_{it} + \gamma_1 OPC_{it} + \gamma_2 RQ_{it} + \delta_i \delta_t + \epsilon \end{aligned} \tag{2}$$

Model II:

$$ROA_{it} = I(FS_{it} < \alpha_1)\beta_1 * RD_{it} + I(\alpha_1 \leq FS_{it} < \alpha_2)\beta_2 * RD + \cdots + I(FS_{it} > \alpha_r)\beta_{r+1} * RD_{it} + \gamma_1 OPC_{it} + \gamma_2 RQ_{it} + \delta_i\delta_t + \epsilon \quad (3)$$

$$ROA_{it} = I(LEV_{it} < \alpha_1)\beta_1 * RD + I(\alpha_1 \leq LEV_{it} < \alpha_2)\beta_2 * RD + \cdots + I(LEV_{it} > \alpha_r)\beta_{r+1} * RD_{it} + \gamma_1 OPC_{it} + \gamma_2 RQ_{it} + \delta_i\delta_t + \epsilon \quad (4)$$

$$ROA_{it} = I(FAR_{it} < \alpha_1)\beta_1 * RD + I(\alpha_1 \leq FAR_{it} < \alpha_2)\beta_2 * RD + \cdots + I(FAR_{it} > \alpha_r)\beta_{r+1} * RD_{it} + \gamma_1 OPC_{it} + \gamma_2 RQ_{it} + \delta_i\delta_t + \epsilon \quad (5)$$

Model III:

$$ROA_{it} = I(RD_{i,t-1} < \alpha_1)\beta_1 * RD_{it} + I(\alpha_1 \leq RD_{i,t-1} < \alpha_2)\beta_2 * RD_{it} + \cdots + I(RD_{i,t-1} > \alpha_r)\beta_{r+1} * RD_{it} + \gamma_1 OPC_{it} + \gamma_2 RQ_{it} + \delta_i\delta_t + \epsilon \quad (6)$$

where $\alpha_1, \ldots, \alpha_r$ are the estimated thresholds and $I(\ldots)$ is the indicator function that takes the value 1 if the conditions in parentheses are satisfied and takes the value 0 otherwise. $\beta_1, \ldots, \beta_{r+1}$ are the coefficient estimates of the green technology R&D inputs, $\gamma_1, \gamma_2$ are the coefficient estimates of the control variables, $\epsilon$ is the residual term, $\delta_i\delta_t$ are the cross-multiplier terms for individual and time fixed effects, respectively, and the specific variables are as defined in Table 1. Table 1 lists the variables in the model: The performance of enterprise me in year t is the dependent variable $ROA_{it}$, and the independent variable $RD_{it}$ is green technology R&D investment. The threshold variables are enterprise size $FS_{it}$, asset structure $LEV_{it}$ and capital intensity $FAR_{it}$. The control variables are operating capacity $OPC_{it}$ and earnings quality $RQ_{it}$.

**Table 1.** Variable Definition Table.

| Category | Name | Symbol | Definition | References Source |
|---|---|---|---|---|
| Dependent Variable | Firm performance | *ROA* | The profit growth of the enterprise | [18,20,77,78] |
| Independent Variable | green technology R&D investment | *RD* | Total green technology R&D expense | [13,34,45,47,77] |
| Threshold Variable | Enterprise scale | *SIZE* | Logarithm of fixed assets | [18,45,73] |
| | Capital structure | *LEV* | Asset–liability ratio | [34,35,45,48,79] |
| | Fixed Asset Ratio | *FAR* | Ratio of fixed assets to total assets | [26,35,73] |
| Control Variables | Operating Capacity | *OPC* | Enterprise operation capability | [48,63,73] |
| | Quality of earnings | *RQ* | Enterprise value reliable information | [4,17] |

Note: The data are mainly from the database of listed companies' financial indicators in the China Stock Market & Accounting Research Database (CSMAR) and Wind Database. The main software used for data processing is Stata 17 and Python 3.7.

In this study, we use firm performance as the explanatory variable and choose ROA, a financial indicator that reflects the firm's operating performance, as the measure of firm performance [18,35,77]. ROE provides a comprehensive measure of the operating efficiency of both the debt and equity investments of a firm. The main explanatory variable of interest is research investment intensity, which is defined as the ratio of the net research expenditures to the total operating revenues. We use the green technology R&D investment intensity as the primary measure for evaluating research investment.

The relationship between green technology R&D activities and performance is influenced by various internal and external factors that may have direct or indirect effects. To investigate whether there is a nonlinear relationship between green technology R&D investment and firm performance among Beijing-listed energy firms, we first choose green technology R&D investment intensity as the threshold variable. We also consider the constraining effects of factors such as firm size, equity structure and capital density on green technology R&D investment. To this end, we use three threshold variables in our analysis: firm size, capital structure and capital density.

- The impact of green technology R&D investment on firm performance is moderated by firm size [61], and the resource advantages of firms of different sizes can have a significant impact on firm performance [4]. In this study, firm size ($SIZE$) is defined as the logarithm of fixed assets. The use of the logarithmic index of fixed assets not only reflects the size of the enterprise but also effectively prevents errors in statistical analysis due to differences in the fixed assets of the enterprise.
- The capital structure refers to the combination of the value of all of the assets of the company and the debt–equity ratio. The company's gearing ratio ($LEV$) is a measure of the relationship between the company's total liabilities and its total assets. This ratio reflects the asset structure of the company and the effectiveness of debt control. A reasonable and adequate asset structure can not only reduce a company's total cost of capital ratio but also increase the profit from debt and further enhance the value of the company [77,79]. In this study, $LEV$ is chosen as a threshold variable that helps to measure corporate risk.
- Finally, capital density ($FAR$) is chosen in this study as a threshold variable for the share of fixed assets in the total assets of energy companies [35].

To obtain more accurate results, this study controls for other variables that may affect firm performance. Operating capacity and earnings quality are defined as control variables. Operating capacity ($OPC$) reflects the level of a firm's operations, and we choose the total capital turnover ratio (the ratio of the firm's operating income to total assets in a given period) to reflect the effectiveness of the firm's use of all assets, which ultimately affects the firm's profitability and performance level. Earnings quality primarily considers the relationship between the net income from operating activities and the total profit.

### *3.3. Descriptive Statistics*

This study primarily uses data from the Wind Database, supplemented by information from the annual reports of listed companies and the National Bureau of Statistics. Our sample consists of 44 Beijing-listed energy companies for the period from 2016 to 2021, including various types of energy companies such as coal, oil, natural gas, thermal power, wind power, tidal power, new energy vehicles, batteries and others, covering both traditional and new energy sectors. The data collected at the company level include various indicators such as total operating revenue, net profit, total assets of a company, total liabilities of the company, net income from operations, green technology R&D expenditure and total asset turnover. To ensure the quality of the data, we excluded samples with missing data and variables and some abnormal values.

Table 2 presents the descriptive statistics for each variable in its raw data, normalised by using the formula $(X - mean(X))\ /\ sd(X)$, since the ranges of values vary and there are outliers in some variables. Figure 3 shows the statistical boxplots of the normalised variables and explains the observed negative values. Table 2 and Figure 3 show the approximate range, variance and median of the variables. We find that earnings quality, firm performance and firm size have large standard deviations, indicating significant differences across energy firms. The other variables have changed standard deviations. In addition, the medians of firm size and earnings quality deviate significantly from their means, indicating a skewed distribution in which the majority of firms have a smaller firm size. These results suggest the presence of unicorns with a larger firm size that inflate the overall mean and underscore the importance of examining variables such as firm size and capital structure as threshold variables in this study.

**Table 2.** Descriptive Statistics of the Variables.

| | Min | Max | Median | Mean | S.D |
|---|---|---|---|---|---|
| *RD* | 0.00003 | 0.7570 | 0.033 | 0.051 | 0.0780 |
| *ROA* | −228.2580 | 23.5500 | 2.4020 | 0.362 | 17.6790 |
| *FS* * | 0.6600 | 27000 | 100 | 1900 | 4700 |
| *LEV* | 0.002847 | 0.8758 | 0.1806 | 0.2623 | 0.6600 |
| *FAR* | 0.06181 | 30.6750 | 0.5473 | 0.6789 | 2.1294 |
| *OPC* | 0.0060 | 3.2152 | 0.4593 | 0.5542 | 0.4691 |
| *RQ* | −6546.8100 | 901.7400 | 80.1800 | −12.2400 | 562.8929 |

Note: * Represents enterprise size in billions.

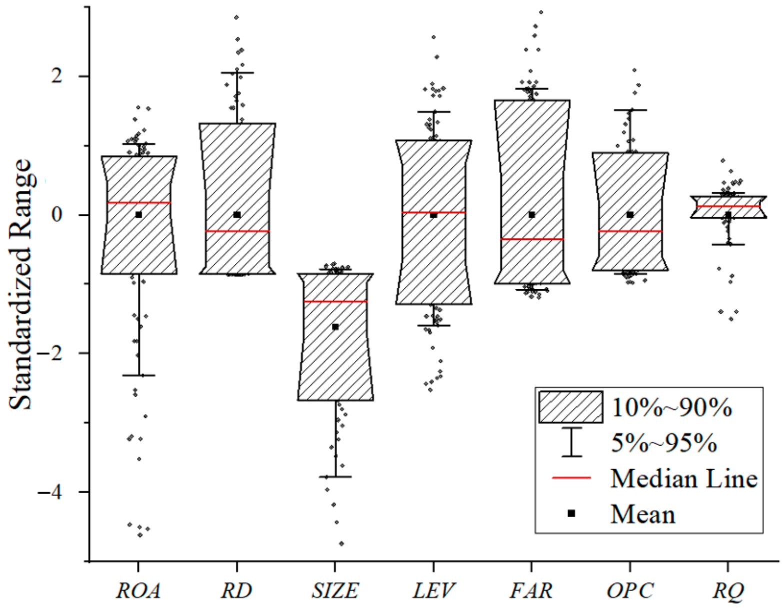


**Figure 3.** Statistical Box Plot of Standardised Variables.

## 4. Empirical Analysis

### *4.1. Discussion of Nonlinear Correlations*

#### 4.1.1. Correlation Analysis

To examine the correlation between the variables, we first performed a Pearson correlation analysis. This method is used to evaluate the linear correlation between two continuous variables [2]. Let $x_1, \ldots, x_n$ be the data sample for variable 1 and $y_1, \ldots, y_n$ be the data sample for variable 2. The Pearson correlation coefficient is defined as shown in Equation (7), where $\overline{x}$ is the average of $x_1, \ldots, x_n$ and $\overline{y}$ is the average of $y_1, \ldots, y_n$.

$$r = \frac{\sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \overline{x})^2 \sum_{i=1}^{n} (y_i - \overline{y})^2}} \tag{7}$$

The results of the Pearson correlation coefficient test are shown in the following Figure 4. It can be seen that green technology R&D investment has a significant linear correlation with all variables except earnings quality, operating capacity and firm performance. This confirms that there is no correlation between green technology R&D investment and the control variables. It also suggests that the three threshold variables have an impact on green technology R&D investment, leading to a change in the relationship between green technology R&D investment and firm performance. Furthermore, the scatter plot of the standardised firm performance (ROA) and standardised green technology R&D investment intensity shows that there is no obvious linear relationship between the two variables.

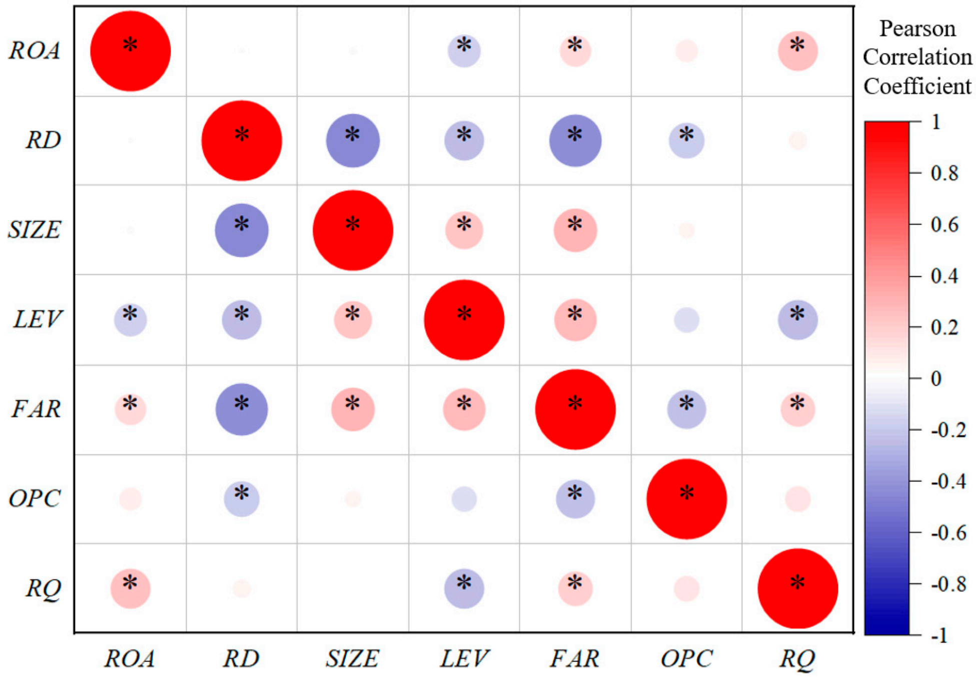


**Figure 4.** The Pearson correlation coefficient figure. The colours in Figure 4 represent the magnitude of the correlation coefficients between different variables, while "*" indicates a $p$-value less than or equal to 0.05.

### 4.1.2. Threshold Effect Model

We then investigate whether there is a threshold effect in green technology R&D investment. Green technology R&D investment is used as a threshold variable while controlling for operating capacity (total sales) and earnings quality (net profit from operating activities/total profit). Table 3 shows the overall sample model with a lag of one period, using the bootstrap method proposed by Hansen to estimate the corresponding bootstrap $p$-value by overlapping the simulated likelihood ratio test statistic 300 times.

As the results in Table 3 show, the estimate has a threshold effect for green technology R&D investment, and the $p$-values, which are all below 0.05, indicate that the model passes the single, double and triple threshold tests, dividing the range into four segments. The threshold estimates in the figure are the main threshold nodes, and the numbers in parentheses represent the corresponding T-statistic values estimated by this coefficient. Table 4 shows that there is a positive relationship between green technology R&D investment and firm performance when green technology R&D investment intensity is less than −0.368. When the green technology R&D investment intensity is in the range of (−0.368, 1.247), there is a significant negative relationship between green technology R&D investment and firm performance in this threshold range. When the intensity of green technology R&D investment is in the range of (1.247, 1.918), there is a positive relationship between green technology R&D investment and firm performance. However, if the value of green technology R&D investment intensity exceeds 1.918, the relationship between green technology R&D investment and firm performance changes to negative.

From this, we can conclude that the relationship between green technology R&D investment and firm performance has an inverse-W-shaped nonlinear relationship that can be modified by other variables such as firm size, capital structure and capital density. In the next section of this paper, we will discuss the threshold effect of these variables on the correlation between green technology R&D investment and firm performance.

**Table 3.** Test Estimation Results when green technology R&D Investment is the Threshold Condition.

| Threshold Test | Models | Threshold Estimates | LR Statistical Quantities | Bootstrap *p*-Value | BS Times |
|---|---|---|---|---|---|
| Overall sample testing | Single Threshold | −0.368 | 14.06066 | 0.0030 | 300 |
| | Double Threshold | 1.247 | 14.2050 | 0.0030 | 300 |
| | Three thresholds | 1.918 | 15.7590 | 0.0000 | 300 |

Note: The main software for the model regression is Stata 17 and Python 3.7; the following tables are the same.

**Table 4.** Correlation between green technology R&D Investment and Firm Performance when green technology R&D Investment is the Threshold Condition.

| Test | *RD 1* | *RD 2* | *RD 3* | *RD 4* | *OPC* | *RQ* |
|---|---|---|---|---|---|---|
| Overall sample test | 0.5244 * | −0.1524 * | 0.0926 ** | −0.6912 * | 0.0701 ** | −0.0171 |
| | (1.8234) | (−1.7616) | (2.1634) | (−1.6935) | (2.4272) | (−0.7443) |

Note: RD1, RD2, RD3, RD4 corresponds to each threshold interval. ** and * represent significance at the 5% and 10% levels respectively.

### *4.2. Impact Study of Threshold Variables*

#### 4.2.1. Threshold Effect Model Results

Based on the nonlinear relationship between green technology R&D investment and firm performance, in this section, we will build threshold regression models for the three threshold variables of firm size, capital structure and capital intensity and conduct tests for single, double and triple thresholds, selecting the appropriate number of thresholds for model estimation. To test whether the identified threshold effects are significant, we use the statistic LR to test for the presence or absence of threshold effects. The initial hypothesis is H0: $\alpha_1 = \alpha_2$, and the alternative hypothesis is H1: $\alpha_1 \neq \alpha_2$. The constructed likelihood ratio statistic is shown in Equation (8), where $SSE_1$ is the sum of squared errors in regression with $\alpha_1$, $\hat{\alpha}$ is the estimation result of $\alpha_1$, and $\hat{\sigma}^2$ is the predicted variance in the regression model.

$$LR(\alpha) = \frac{SSE_1(\alpha) - SSE_1(\hat{\alpha})}{\hat{\sigma}^2} \tag{8}$$

Under the null hypothesis, the asymptotic distribution of the statistic LR satisfies the condition $c(k) = -2\ln\left(1 - \sqrt{k}\right)$, where $k$ is the significance level. The original hypothesis is rejected if the value of the LR statistic is less than c(k), which means that the threshold regression model is not significant. To further investigate the threshold effect of green technology R&D investment on firm performance, this study uses firm size, capital structure and capital density as threshold variables and operational capacity and earnings quality as control variables.

Table 5 shows the model estimates, model fit results and significance test results for different threshold variables and the number of thresholds. Table 5 shows that when $FS$ (firm size) and $FAR$ (capital density) are used as threshold variables, the *p*-values for single, double and triple thresholds are all below 0.05, indicating that the data all pass the threshold tests and have three thresholds simultaneously. In contrast, when examining capital structure as a threshold variable, only the *p*-value for the single threshold is less than 0.05, while the *p*-values for the double and triple thresholds are greater than 0.05 and only pass the single threshold test. Therefore, the triple threshold model is used to examine the nonlinear effects of green technology R&D investment on firm performance when capital density and firm size are used as threshold variables, while a single threshold model is more appropriate when the capital structure is used as the threshold variable.

**Table 5.** Tests for the Existence of Threshold Effects and Threshold Estimates for Firm Size, Capital Structure and Density.

| Threshold Vars | Models | Threshold Estimates | LR Statistical Quazntities | Bootstrap *p*-Value | BS Times |
|---|---|---|---|---|---|
| *FS* | Single Threshold | −0.3985 | 798.4822 | 0.0000 | 300 |
| | Double Threshold | −0.3965 | 473.4431 | 0.0000 | 300 |
| | Three thresholds | −0.3923 | 402.2496 | 0.0000 | 300 |
| *LEV* | Single Threshold | −0.1024 | 4.6556 | 0.0167 | 300 |
| | Double Threshold | 0.0906 | 3.8229 | 0.4767 | 300 |
| | Three thresholds | 0.0990 | 39.5859 | 0.3167 | 300 |
| *FAR* | Single Threshold | −1.1516 | 663.8746 | 0.0000 | 300 |
| | Double Threshold | −1.1446 | 40.6406 | 0.0033 | 300 |
| | Three thresholds | −0.6700 | 719.5633 | 0.0000 | 300 |

Table 6 shows the estimation results of the three-threshold model with firm size and capital density as threshold variables and the one-threshold model with capital structure as threshold variable while controlling for operating capacity and earnings quality. Values in parentheses correspond to the t-test statistics marked *, ** and ***, indicating significance levels of 1%, 5% and 10%, respectively. Green technology R&D investment 1, 2, 3 and 4 are coefficients representing the four intervals, and the numbers in parentheses are the t-statistics estimated by these coefficients.

**Table 6.** Correlation between green technology R&D Investment and Firm Performance under the Conditions of Firm Size, Capital Structure and Density Threshold.

| Constraints | *RD 1* | *RD 2* | *RD 3* | *RD 4* | *OPC* | *RQ* |
|---|---|---|---|---|---|---|
| *FS* | 2.1002 **<br>(2.3109) | 0.1269 **<br>(2.0340) | −0.2147 **<br>(−1.6975) | −0.0658 *<br>(−1.6486) | 0.0538 **<br>(2.2021) | 0.0091<br>(1.1245) |
| *LEV* | −0.0508 **<br>(2.1581) | −0.7921 *<br>(−1.7242) | | | 0.0627 **<br>(2.1538) | 0.0003<br>(0.0234) |
| *FAR* | −0.2030 ***<br>(−3.7599) | −2.0919 *<br>(−1.9488) | 0.1610 **<br>(2.2878) | −0.1661 **<br>(−2.5611) | 0.0615 **<br>(2.6960) | 0.0124<br>(1.5184) |

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels respectively.

#### 4.2.2. Discussion of Threshold Effect

(1) The Threshold Effect of Firm Size on the Relationship between green technology R&D Investment and Firm Performance

Based on Tables 5 and 6, the results for firm size show that, first, the coefficient of the green technology R&D investment intensity is 2.1002 when the firm size is below the threshold of −0.3985, indicating a significant positive effect of the green technology R&D investment on firm performance. Small start-ups are more likely to try breakthrough innovations, which involve higher risks but also higher returns. Thus, when small firms invest in green technology R&D, the costs of breakthrough innovations are of the research type, and their firm performance takes a leap forward. Second, when the firm size is in the range of (−0.3985, −0.3965), the coefficient of green technology R&D investment is 0.1269, and the positive effect of green technology R&D investment on firm performance becomes weaker. This could indicate that the higher the green technology R&D investment before the firm size reaches a certain level, the weaker the effect of green technology R&D investment on firm performance.

When the firm size is in the range of (−0.3965, −0.3923), the coefficient of green technology R&D investment is −0.2147, and the effect of green technology R&D investment on firm performance changes to a significant negative effect. This is mainly due to the fact that the company's business model and management style tend to become uniform once the company reaches a certain size. Mature firms are more inclined to iterative innovation based on existing green technology R&D results. Although iterative innovation is sound, its economic performance is limited, and green technology R&D investment ties up a certain amount of the firm's resources. Therefore, the enterprise profit generated by large enterprises' green technology R&D investment cannot compensate for the loss of enterprise performance due to the depletion of other resources, resulting in a decline in enterprise performance. Finally, the effect of green technology R&D investment on firm performance is not significant when the firm size exceeds −0.3923. This suggests that the correlation between green technology R&D investment and firm performance has an inversely-U-shaped nonlinear relationship when firm size is the threshold variable.

Overall, due to the differences in the selection of breakthrough and iterative innovations by firms of different sizes, green technology R&D investments only have a positive impact on firm performance when the firm size reaches an appropriate level. Depending on firm size, green technology R&D investment shows an inversely-U-shaped nonlinear relationship with firm performance.

(2) The Threshold Effect of Capital Structure on the Relationship between green technology R&D Investment and Firm Performance

The estimation results using capital structure as a threshold variable show that the coefficient of green technology R&D investment is −0.0508 when the level of capital structure is below 0.0990, indicating a significant negative impact of green technology R&D investment on firm performance. Conversely, when the level of capital structure is above 0.0990, the coefficient of green technology R&D investment is −0.7921, indicating a significant negative impact of green technology R&D investment on firm performance that is even more pronounced than in the previous stage. The negative threshold effect of capital structure on the relationship between green technology R&D investment and firm performance can be attributed to the fact that when the value of the capital structure is too high, the total debt of the firm is larger. Since green technology R&D investment is inherently associated with the risk of failure, a further increase in green technology R&D investment in a company with high business risk may cause panic among investors and other stakeholders, affecting the normal operation and financial management of the company and reinforcing the negative correlation between green technology R&D investment and company performance. In summary, this study shows that green technology R&D investment is negatively and nonlinearly correlated with firm performance when the impact of capital structure is considered, taking into account the increased business risk associated with high leverage.

(3) The Threshold Effect of Capital Intensity on the Relationship between green technology R&D Investment and Firm Performance

The estimation results based on capital density as a threshold variable show that, first, the coefficient of green technology R&D investment is −0.2030 when capital density is less than −1.1516, and green technology R&D investment has a significant negative impact on firm performance. When the capital density is in the range of (−1.1516, −1.1446), the coefficient is −2.0919, and the negative influence is even more significant than in the previous interval. The negative correlation between green technology R&D investment and firm performance can be attributed to the fact that in this interval, liquid assets account for a larger proportion of the firm's total assets, which leads to overinvestment in low-value green technology R&D projects with lower returns, thus reducing the firm's overall performance. In the interval with the highest liquidity, the negative relationship between green technology R&D investment and firm performance weakens, possibly because firms can make breakthrough innovations and overcome major green technology R&D obstacles when they have sufficient liquidity, leading to better firm performance.

Second, when capital density is in the interval (−1.1446, −0.67), the coefficient is 0.1610, and the relationship between green technology R&D investment and firm performance becomes positive. However, when the capital density is greater than −0.67, the coefficient is −0.1661, and the relationship between green technology R&D investment and firm performance starts to turn into a significant negative effect again. The main reason for this result is that when the fixed asset density is too high, fixed assets account for a larger share of total assets while current assets are insufficient, and part of the green technology R&D investment may have to be financed by the company itself or supported by reallocating resources from other projects. This can lead to high interest rates and increased operational risks, which can negatively impact earnings and reduce company performance.

Overall, the study suggests that while sufficient liquid assets can enable firms to realise some breakthrough innovations, both too-high and too-low capital intensity can lead to inefficient allocation of funds to green technology R&D projects, which in turn affects firm performance. That is, green technology R&D investments only have a positive impact on firm performance for firms with an appropriate capital density. Under the condition of a capital density threshold, there is an inverse-N-shaped, nonlinear relationship between green technology R&D investment and firm performance.

### *4.3. Hysteresis Effect Analysis*

Energy companies typically have a long green technology R&D cycle and invest a significant amount in green technology R&D before bringing new products or technologies to market and increasing profits [78]. To account for possible lagged effects, we tested the sample with a lag of one period while we examined the relationship between green technology R&D investment in the current period and firm performance. The results from Tables 6 and 7 show that the *p*-values for the single-, double- and triple-threshold tests are smaller than 0.05 when lagged by one period, and the statistics from LR are larger and pass the test in the single-, double- and triple-threshold regressions.

Tables 7 and 8 show that the coefficient of green technology R&D investment intensity is 0.1813 when green technology R&D investment intensity is below the value of −0.479, indicating a positive relationship between green technology R&D investment and firm performance at this stage. When green technology R&D intensity is in the range of (−0.479, 1.213), the coefficient of green technology R&D investment intensity is −0.2942, indicating a negative relationship between green technology R&D investment and firm performance at this stage. When green technology R&D investment intensity is in the range of (1.213, 1.576), the coefficient of green technology R&D investment intensity is 0.0210, indicating a positive relationship between green technology R&D investment and firm performance at this stage. When the green technology R&D investment intensity is greater than 1.576, the coefficient of green technology R&D investment intensity is −0.7216, indicating a negative relationship between green technology R&D investment and firm performance in this period.

Comparing the threshold estimates of the lagged one-period model and the current total sample model, we find that the lagged effect leads to a smaller positive coefficient and a larger negative coefficient, resulting in a slower upward trend in the positive effect interval and a stronger downward trend in the negative effects. This suggests that there is a lagged effect of green technology R&D investment on firm performance and that the relationship between green technology R&D investment and firm performance is affected differently in the positive and negative intervals. Therefore, the impact of the lagged effect of Beijing-listed energy companies should be considered in the future.

**Table 7.** Estimation Results of the One-period Lag Test.

| Threshold Variables | Models | Threshold Estimates | LR Statistical Quantities | Bootstrap *p*-Value | BS Times |
|---|---|---|---|---|---|
| Lagged one-period test | Single Threshold | −0.479 | 16.7531 | 0.0000 | 300 |
| | Double Threshold | 1.213 | 11.4459 | 0.0300 | 300 |
| | Three thresholds | 1.576 | 10.4473 | 0.0360 | 300 |

**Table 8.** Estimated Results of the Overall Sample Test and Lagged One-period Test Coefficients.

| Test | *RD 1* | *RD 2* | *RD 3* | *RD 4* | *OPC* | *RQ* |
|---|---|---|---|---|---|---|
| Lagged one-period test | 0.1813 *<br>(1.8369) | −0.2942 **<br>(−1.9665) | 0.0210 **<br>(2.3822) | −0.07216 *<br>(−1.6821) | 0.0262 *<br>(1.9380) | 0.0116<br>(0.5508) |

Note: ** and * represent significance at the 5% and 10% levels respectively.

### 4.4. Endogenous Problems Discussion

In the previous section, the relationship between green technology R&D investment and a firm's ROA was discussed in detail. However, to examine the impact of green technology R&D investment on ROA, certain endogenous aspects between green technology R&D investment and ROA should be considered. First, there may be a bidirectional causal relationship between green technology R&D investment and ROA, whereby high ROA may lead to more green technology R&D investment and vice versa. Second, intrinsic factors such as company size, industry affiliation, capital structure, market share, etc. may influence a company's green technology R&D investment. If these intrinsic factors are not taken into account, this can lead to biased estimates of the relationship between green technology R&D investment and ROA. Therefore, to accurately assess the impact of green technology R&D investment on ROE, it is essential to apply appropriate control variable methods to eliminate the effects of bidirectional causal and intrinsic factors.

In this study, we use government green technology R&D subsidies as instrumental variables to mitigate the endogeneity problem described above. Government green technology R&D subsidies fulfil the three conditions for instrumental variables [80]. First, there is a correlation between government green technology R&D subsidies and a firm's green technology R&D investment, whereby the subsidies promote a firm's green technology R&D activities and thus increase its green technology R&D investment. Second, there is no direct correlation between government green technology R&D subsidies and a firm's return on equity, meaning that subsidies are not affected by the firm's return on equity. Moreover, government green technology R&D subsidies affect a firm's return by influencing its green technology R&D investment, and there are no other possible mediating variables that could affect the relationship between government green technology R&D subsidies and the firm's return. Consequently, government green technology R&D subsidies can be used as an instrumental variable to remove the estimation error due to endogeneity problems and thus more accurately assess the impact of green technology R&D investment on ROA. The regression results for the threshold effect in the hypothesis under the dynamic panel threshold model with instrumental variables are shown in Table 9 [81]. The regression of the model with instrumental variables remains largely consistent with the hypothesis when controlling for two-way fixed effects, and the regression results in the main text exhibit statistical robustness.

**Table 9.** Regression Results of Dynamic Panel Threshold Models for Instrumental Variables.

| Constraints | *RD 1* | *RD 2* | *RD 3* | *RD 4* |
|---|---|---|---|---|
| *RD* | 4.991 *<br>(1.668) | −0.638<br>(−1.042) | 0.801 ***<br>(3.053) | −0.483 ***<br>(−2.960) |
| *FS* | 1.198<br>(0.497) | 31.581 ***<br>(3.037) | −13.703 ***<br>(−2.693) | −0.483 *<br>(−1.960) |
| *LEV* | −66.877 **<br>(−2.006) | −10.014 ***<br>(−5.580) | | |
| *FAR* | −113.614 **<br>(−2.132) | −5.027 **<br>(−2.432) | 1.828 ***<br>(3.362) | −1.725 **<br>(−2.109) |

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels respectively.

### 4.5. Robustness Tests

Robustness tests are conducted by replacing the explanatory variables and shifting part of the sample. Specifically, we used ROE instead of ROA as the dependent variable and re-estimated the model [82] (Tables 10 and 11) and used Tobin-Q instead of ROA as the dependent variable and re-estimated the model [83] (Tables 12 and 13). In the regression, we also excluded companies with performance levels above the 95th percentile and below the 5th percentile and re-estimated the model to examine the stability of the results across the sample.

Using the results in the tables of the robustness tests for the full sample and the lagged period in Tables 10–13, we find that the magnitude of the coefficients for the robustness treatment and the green technology R&D investment intensity of the original sample are different, but the positive and negative relationships remain unchanged. These results suggest that the positive and negative relationships between green technology R&D investment and firm performance for the same green technology R&D investment interval remain robust to changes in the sample and model specifications. Moreover, the robustness tests show that the extreme values do not significantly affect the results of the study, as the sample is not seriously affected by their exclusion. These results confirm the appropriateness of using a threshold regression model.

**Table 10.** Robustness Estimation Results for ROE and Green Technology R&D Investment.

| Threshold Variables | Models | Threshold Estimates | LR Statistical Quantities | Bootstrap *p*-Value | BS Times |
|---|---|---|---|---|---|
| Overall sample robustness test | Single Threshold | −0.6447 | 14.4822 | 0.0030 | 300 |
| | Double Threshold | 1.2476 | 9.9879 | 0.0466 | 300 |
| | Three thresholds | 1.4375 | 12.8156 | 0.0267 | 300 |
| One period lag Robustness test | Single Threshold | 0.0056 | 10.2161 | 0.0397 | 300 |
| | Double Threshold | 0.0580 | 12.5995 | 0.0130 | 300 |
| | Three thresholds | 0.1224 | 14.7075 | 0.0033 | 300 |

**Table 11.** Robustness Test Coefficients for ROE and Green Technology R&D Investment.

| Test | *RD 1* | *RD 2* | *RD 3* | *RD 4* | *OPC* | *RQ* |
|---|---|---|---|---|---|---|
| Overall sample robustness test | 0.1226 ** (2.4096) | −0.0752 * (−1.6858) | 0.1600 *** (3.2153) | −0.0116 ** (−2.3846) | −0.0009 (−0.0851) | 0.0151 *** (2.7590) |
| One period lag Robustness test | 2.7955 *** (3.3359) | −1.7444 ** (−2.5272) | −0.9821 * (−1.6484) | −0.1621 *** (−4.453) | −0.0093 * (−1.8557) | 0.0169 *** (3.4415) |

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels respectively.

**Table 12.** Robustness Estimation Results for Tobin-Q and Green Technology R&D Investment.

| Threshold Variables | Models | Threshold Estimates | LR Statistical Quantities | Bootstrap *p*-Value | BS Times |
|---|---|---|---|---|---|
| Overall sample robustness test | Single Threshold | −0.6879 | 8.9801 | 0.0000 | 300 |
| | Double Threshold | 0.3383 | 9.0325 | 0.0000 | 300 |
| | Three thresholds | 0.3815 | 9.0415 | 0.0000 | 300 |
| One period lag Robustness test | Single Threshold | −0.3877 | 7.8134 | 0.0000 | 300 |
| | Double Threshold | 0.1539 | 7.6103 | 0.0000 | 300 |
| | Three thresholds | 0.3639 | 7.6811 | 0.0000 | 300 |

**Table 13.** Robustness Test Coefficients for Tobin-Q and Green Technology R&D Investment.

| Test | *RD 1* | *RD 2* | *RD 3* | *RD 4* | *OPC* | *RQ* |
|---|---|---|---|---|---|---|
| Overall sample robustness test | 0.3419 ** (2.2109) | −0.5200 ** (−2.1702) | 1.9525 * (1.7029) | −0.0128 * (1.7703) | −0.0451 (−0.3667) | 0.1193 (1.0800) |
| One period lag Robustness test | 0.5538 * (1.6551) | −2.6757 *** (−3.3853) | 0.7724 ** (2.0307) | −0.1112 * (−1.9460) | −0.0920 (−0.6749) | 0.3095 ** (2.3192) |

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels respectively.

## 5. Discussions

### *5.1. Main Findings*

Based on the panel data of 44 Beijing-listed energy companies for the period of 2016–2021, this study used a threshold regression model to examine the impact of green technology R&D investment on firm performance. The following findings are summarised:

(1) There is an inverse-W-shaped, nonlinear relationship between green technology R&D investment and firm performance, where the optimal green technology R&D investment intensity has a positive effect on firm performance. Extreme green technology R&D investment (which can be too low or too high) has a negative impact on firm performance. Therefore, companies should conduct adequate preliminary research before investing in green technology R&D. Appropriate green technology R&D investment can not only reduce green technology R&D costs but also maximise the benefits to the company. When green technology R&D investment increases, the company can efficiently discover, absorb and apply new knowledge and technologies, resulting in new products that improve the company's performance. However, when green technology R&D investment reaches a certain threshold, new product development bottlenecks may occur, and the impact on company performance may diminish. A further increase in green technology R&D investment could break through the bottleneck and lead to newer products and technologies, thus improving company performance. Nevertheless, when green technology R&D investment enters the high investment phase, it may consume the company's internal resources and limit investment in other areas, leading to higher opportunity costs that negatively impact the company's performance.

(2) Green technology R&D investment and firm performance exhibit an inversely-U-shaped, nonlinear relationship when firm size matters. The relationship is initially positive but slows down after the −0.3965 threshold is exceeded. Iterative innovation and breakthrough innovation were used to explain that if the firm is too small, it is difficult to take advantage of the learning effect and the scale effect, which reduces the efficiency of green technology R&D investment to increase performance. Additionally, if the company is too large, it tends to opt for iterative innovations based on the existing green technology R&D base and avoid risks. Only when the company is of moderate size is it easiest to stimulate breakthrough innovations for optimal benefit.

(3) Under the threshold condition of capital structure, green technology R&D investment has a negative and nonlinear relationship with firm performance. Excessive debt increases the liquidity risk and operational risk of the firm and increases the uncertainty of green technology R&D investment. When the capital structure exceeds the threshold, the relationship between green technology R&D investment and the firm changes from a non-significant negative correlation to a highly significant negative correlation, and the magnitude of the effect increases significantly.

(4) Under the threshold condition of capital intensity, there is an inverse-N-shaped nonlinear relationship between green technology R&D investment and firm performance. Too high a proportion of current assets tends to lead to excessive green technology R&D investment, while too low a proportion of current assets tends to limit the use of green technology R&D investment funds. Adequate capital density enables firms to better perform green technology R&D and generate profits.

(5) Given the long cycle and high cost of green technology R&D investment in energy firms, the lag effect between green technology R&D investment and firm performance has also been analysed. The lag effect influences the relationship between green technology R&D investment and firm performance. When the relationship is positive, the lag effect reduces the impact of subsequent green technology R&D investments and vice versa. Therefore, the right interval for green technology R&D investment is crucial for companies.

### *5.2. Policy and Practice Recommendations*

Based on the summarised findings, the following policy recommendations can be proposed to help companies optimise their R&D investments in green technologies and improve firm performance:

Promote breakthrough innovations: For medium-sized enterprises, promoting breakthrough innovations can bring optimal benefits. Policymakers can provide incentives for medium-sized companies to invest in R&D activities that promote breakthrough advances in green technologies. This could be achieved through tax credits, grants or targeted funding programmes aimed at encouraging breakthrough research.

Regulate capital structure: Policymakers should closely monitor and regulate the capital structure of companies, especially when it comes to R&D investments in green technology. Excessive debt can increase financial risk and uncertainty and negatively impact R&D initiatives. A balanced capital structure will improve a company's ability to invest in sustainable technologies without compromising its financial stability.

Encourage appropriate capital intensity: Policymakers can encourage companies to maintain appropriate capital intensity that enables effective R&D in green technologies. Financial incentives or support for companies to optimise their capital allocation can improve their ability to invest in sustainable R&D projects and generate profits from green innovations.

### *5.3. Limitations and Future Research*

This study encountered some limitations. First, while the energy industry served as a broad basis for our study, it is important to recognize the potential limitations of such a narrow focus. Generalising the results to other sectors should be approached with caution, as different sectors may have different structural, operational and competitive characteristics that affect the outcomes of R&D investments in green technologies. Additionally, the conclusions of this article are based on current technology and market conditions, and future technological advances and market changes may affect the validity of these findings. Therefore, investigating the impact of the different stages of green technology development on performance can help companies better identify the right time for R&D.

As more comprehensive and diverse data may yield different results, future research may focus more on the characteristics and market environment of different sectors, which may mean that the conclusions of this article are not applicable to other sectors. Furthermore, different countries or regions may have different levels of commitment to green initiatives, creating different incentives for firms to invest in sustainable R&D. Future research should therefore take a global perspective to capture the complexity of regional differences, such as how regional differences in environmental policy and regulation are taken into account, which is crucial. Moreover, understanding how different R&D stages influence outcomes can shed light on the optimal timing and sequencing of investment decisions for companies. Future research could also differentiate between R&D stages, exogenous technological impacts, and potential risk categories, considering variations in outcomes across multiple influencing factors. Additionally, to fully capitalize on the potential of green technology R&D investments, it is imperative, for the future, to take into account the profound impact of technological innovation on green finance. These innovations have the capacity to significantly contribute to achieving financial inclusion for carbon neutrality and offer crucial policy implications [84].

## 6. Conclusions

This study utilized data from 44 Beijing-listed energy companies between 2016 and 2021, using a threshold regression model to examine the impact of R&D investment in green technologies on firm performance. Key findings reveal an inverse-W-shaped relationship, indicating that optimal investment intensity has a positive impact on performance, while extreme values have negative consequences. Adequate upfront research is critical before investing, and medium-sized companies benefit most from green technology R&D. Excessive debt and capital intensity can have a negative impact on performance. Lag effects should be considered when timing R&D investments. Policymakers and businesses can use these insights to optimise green technology R&D strategies for sustainable growth.

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