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Chapter: Strategic Digital Transformation: Enhancing Business through Innovation

IS GREEN TECHNOLOGICAL INNOVATION PROMOTED? POLICY EFFECT OF GREEN FINANCE REFORM INNOVATION PILOT ZONES

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Annotation. The implementation effect of green financial policies has always been widely concerned by scholars, and abundant research results have been achieved. However, systematic research is lacking on whether green financial policies can promote green technological innovation of enterprises and what mechanism exists at the micro level. To clarify the relationship between green financial policies and enterprises' green technological innovation, the Green Finance Reform Innovation Pilot Zones (GFRIZs) in China were utilized as a quasi-natural experiment. Drawing on the innovation-driven theory, resource-based theory, and environmental regulation theory, the influencing effect and mechanisms of GFRIZs on enterprises' green technological innovation were systematically investigated using the annual data from Chinese A-share listed companies from 2012 to 2023, and a multiperiod difference-in-differences method. Results show that GFRIZs can significantly promote enterprises' green technological innovation, which is mainly achieved by relaxing financing constraints and strengthening environmental regulations. However, this effect is heterogeneous due to the differences in property rights, industry types, and pollution levels of enterprises. The conclusion provides theoretical support and empirical evidence for the government to scientifically evaluate the policy effect of GFRIZs. It also helps the government improve enterprises' green technological innovation ability by enhancing the green financial policy system, reducing the financing constraints on enterprises, and giving full play to environmental regulations.

Keywords: green finance, green technological innovation, policy effect, difference-in-differences method.

JEL classification: G38, M38, O32.

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Introduction

Climate change and ecological imbalance have been widely concerned by the international community, and governments worldwide are formulating and implementing "green recovery plans" (Barbier, 2010; Yan *et al.*, 2022), emphasizing the importance of green transformation to economic development (Chen *et al.*, 2020). Green finance has multiple functions, such as investment orientation, resource integration, information transmission, and environmental regulations, aiming at the environment, and it is an important means of achieving green and sustainable economic development (Ibrahim *et al.*, 2022). Green finance primarily aims to influence enterprise behavior by efficiently allocating financial resources to limit polluting investments and promote resource conservation and efficient use (Udeagha, Ngepah, 2023; Agrawal *et al.*, 2024). Recently, scholars have increasingly focused on the impact of green financial policies on both macro and micro-economies. At the macro level, green financial policies enhance the development of financial institutions (Chami *et al.*, 2002; Scholtens and Dam, 2007), boost industrial total factor productivity (Tong *et al.*, 2022; Jiaku *et al.*, 2023; Lin, Zhong, 2024; Liu *et al.*, 2024), facilitate export trade (Caggese, Cuñat, 2013; Jin *et al.*, 2022), advance high-quality regional economic development (Wen *et al.*, 2021; Razzaq *et al.*, 2023; Lin, Xiao, 2023; Nie *et al.*, 2024), and enhance environmental performance (Song *et al.*, 2019; Umar, Safi, 2023). At the micro level, these policies provide external oversight, curbing corporate environmental violations (Hasan, Du, 2023; Du *et al.*, 2024), increasing investment in environmental protection (Madaleno *et al.*, 2022; Cheng, Zhu, 2024), promoting energy conservation and emission reduction (Li *et al.*, 2024; Ma *et al.*, 2024; Zhang *et al.*, 2024; Lv *et al.*, 2025), and emphasizing ESG performance (Hu *et al.*, 2024), thereby compelling enterprises to undergo green transformation (Wang *et al.*, 2024; Hao *et al.*, 2024; Xiang *et al.*, 2024). Although scholars have made great achievements in the research on green finance, systematic research on the effect on enterprises' technological innovation at the micro level remains lacking. Green technological innovation, integrating environmental protection with technological advancement, is crucial for achieving a green, low-carbon transition and addressing environmental challenges like global climate change and ecological imbalance (Liu, Wang, 2023; Irfan *et al.*, 2022; Agrawal *et al.*, 2024). Examining the connection between green financial policies and green technological innovation, as well as their transmission mechanisms, hold significant theoretical and practical importance. This study can help explore potential solutions to global environmental issues.

This study examines the relationship between green financial policies and enterprises' green technological innovation by integrating the Green Finance Reform Innovation Pilot Zone (GFRIZ) policy, introduced by the Chinese government, with the innovation-driven theory, resource-based theory, and environmental regulation theory. The creation of GFRIZs combines diverse green financial tools (Yan *et al.*, 2022), market incentives, and governmental oversight (Liu, Wang, 2023), facilitating a thorough assessment of green financial policy impacts (Shi *et al.*, 2022). The policy introduces reform measures for green technological innovation across government, financial institutions, and enterprises. However, green technological innovation has dual externalities, and enterprises lack endogenous incentives to actively invest in green technological innovation (Xie, 2021). Consequently, further investigation is needed to determine if GFRIZs can enhance high-quality green technological innovation in enterprises. This raises the question: Does the creation of GFRIZs enhance green technological innovation in enterprises? What is the action mechanism? Does the action process exhibit varying effects? This study employed the establishment of GFRIZs approved by China as a quasi-natural experiment, analyzed samples of listed Chinese companies from 2012 to 2023, and developed a multiperiod difference-in-

differences (DID) model to address these questions. The study examined how the development and execution of pilot policies affect enterprises' green technological innovation activities.

This study potentially contributes by enhancing the understanding of how green financial policies impact green technological innovation. (1) This study uniquely examines the relationship between green financial policies and enterprises' green technological innovation, emphasizing the core objectives of these policies, unlike existing research that focuses on internal factor endowment and resource structure. The study emphasized that GFRIZs facilitate enterprises' green technological advancements by alleviating financial constraints and enhancing environmental regulations, thus deepening the comprehension of green financial policies' impact on green technological innovation. (2) The effects of green financial policies are more accurately identified. In prior research, the treatment group has been identified mainly from the provincial or urban level. In this study, the treatment group was determined at the enterprise level using GFRIZs as a quasi-natural experiment. (3) The identification of causal relationships is disturbed less. In this study, the exogenous policy -GFRIZs – was regarded as a green financial policy. This approach minimizes the measurement error generated by quantitative indicators, avoids possible reverse causality problems, and mitigates the possible endogeneity problem in the empirical analysis as much as possible.

The remainder of this study is organized as follows. In Section 1, the theoretical analysis and hypothesis development were presented, and the research hypotheses were proposed by consolidating relevant literature. In Section 2, the research design was described, mainly including variable setting, modeling, and data selection, based on which the descriptive statistical analysis of data was performed. In Section 3, results were analyzed, which was the emphasis of this research. In addition, the policy effect of GFRIZs on enterprises' technological innovation was empirically tested, and a robustness test was implemented. The study analyzed the impact of financing constraints and environmental regulations, conducted subsample tests based on property rights, industry type, and pollution level, and revealed the policy's heterogeneous effects. Section 4 presents the findings and analyzes the underlying causes of the empirical results. Section 5 presents the conclusions, managerial implications, and expectations of future research.

1. Theoretical Analysis and Hypothesis Development

1.1 Effect of Green Technological Innovation

Sustainable development and innovation-driven theories emphasize that green technological innovation is crucial for achieving resource conservation and sustainable development by minimizing environmental impact through advancements in green production technologies and models (Dat, Hung, 2023; Streimikiene, 2024). Green technological innovation exhibits microl-evel enterprise incentive effect and macro-level environmental governance effect. At the microenterprise level, companies aim to comply with environmental standards and enhance their social image by innovating green technologies that minimize or eliminate hazardous substances (Berrone *et al.*, 2013), thus avoiding penalties for regulatory non-compliance. As green technological innovation proceeds, enterprises' resource utilization efficiency has been improved, and they will not only obtain the excess unexpected income but also win the competitive advantage (Ghisetti, Rennings, 2014).Relevant research has shown that green technological innovation can significantly improve business performance (Zhang *et al.*, 2019), green dynamic capability, and competitive advantage (Qiu *et al.*, 2020).Green technological innovation is crucial for achieving "carbon neutrality" and "peak carbon dioxide emissions" (Yu *et al.*, 2021) and is essential for fostering

high-quality economic development. Research indicates that green technological innovation significantly enhances both energy efficiency (Sun *et al.*, 2019) and environmental performance (Song *et al.*, 2019).

1.2 Effect Evaluation of Green Financial Policies

According to the innovation-driven theory, green financial policies change the cost–benefit structure of enterprises' innovation decision by guiding funds to low-carbon fields. Such policies also promote enterprises to shift resources from traditional technology to green technology research and development (R&D). The current green financial policies mainly include green credits, green bonds, carbon emission trading pilot, and GFRIZs. Green credits (Fan *et al.*, 2021; Wang, Wang, 2021), green bonds (Liu *et al.*, 2019; Lu *et al.*, 2022), and carbon emission trading pilots (Chen *et al.*, 2021) influence enterprise investment behaviors and penalize the financing activities of polluting firms (Su, Lian, 2018; Hu *et al.*, 2020). Conversely, these mechanisms enhance the risk-taking capacity of green enterprises (Li *et al.*, 2023), facilitate their green and low-carbon transformation (Dong, Tao, 2022; Chen, Zhang, 2023), boost green innovation activities (Ding *et al.*, 2022), promote social and environmental responsibility (Wu *et al.*, 2022; Si, Cao, 2022), and improve environmental information disclosure (Liu *et al.*, 2022). Existing green financial policies are widely regarded by scholars as catalysts for advancing green financial system innovation (Lee, Lee, 2022) and enhancing environmental quality (Niu *et al.*, 2020; Li *et al.*, 2022). Despite being individual green financial policies, green credit, green bonds, and carbon emission trading pilots do not achieve the "Porter effect" (Chen *et al.*, 2021; Lu *et al.*).2021), and the implementation effect of China's green financial policies cannot be comprehensively measured.

To address these shortcomings and advance green finance, China has established GFRIZs that incorporate diverse green financial instruments from a strategic level. These zones serve as an ideal quasi-natural experiment for assessing the impact of green financial policies. Literature review indicates that GFRIZs influence regional green innovation (Irfan *et al.*, 2022), ESG performance (Hu *et al.*, 2024), investment efficiency (Yan *et al.*, 2022), debt financing costs (Shi *et al.*, 2022), total factor productivity (Wang *et al.*, 2021; Liu *et al.*, 2022), energy conservation and emission reduction (Li *et al.*, 2024; Ma *et al.*, 2024; Zhang *et al.*, 2024; Lv *et al.*, 2025), environmental governance, and high-quality economic development (Lin, Xiao, 2023).

1.3 GFRIZs and Green Technological Innovation

In recent years, the influence of GFRIZs on enterprises' green technological innovation has attracted extensive attention from scholars. The environmental regulation theory emphasizes the influence of the institutional environment for policy implementation on enterprise behavior. The GFRIZ policy aligns with regional economic development and resource endowments, directing green financial resources through innovative tools, models, and policies to enhance enterprise green technological innovation (Liu, Wang, 2023). GFRIZs have transcended traditional financial policy limitations, actively enhancing the variety of green financial instruments (Huang *et al.*, 2022), thereby supporting enterprises in advancing green technologies. Green credits and green bonds encourage financial institutions to increase loan support for green environmental protection projects (Irfan *et al.*, 2022). In addition, green funds and green insurance stimulate green innovation by guiding private capital into cleaner production sectors (Gilbert, Zhou, 2017). Secondly, GFRIZs have innovated their operational mechanisms by creating a dedicated green financial service platform to facilitate direct market-enterprise interactions in green investment and financing. They have also set up green franchise organizations to manage these transactions, aiding in the strategic allocation of credit resources across various regions, industries, and enterprises (Liu, Wang, 2023). In addition, GFRIZs have the property of environmental supervision (Liu, Wang, 2023). By

developing a trading market for environmental rights and interests and promoting their use in mortgage and pledge financing, businesses are incentivized to meet environmental protection and governance criteria for loan approval (Liu *et al.*, 2024).This method enhances production efficiency (Rubashkina *et al.*, 2015) and boosts environmental performance (Song *et al.*).The initial research hypothesis was formulated following the preceding analysis.

Hypothesis 1: The GFRIZ policy implementation enhances enterprise green technological innovation.

From the internal resources and capabilities of enterprises, the resource-based theory explains how policies can improve the technological innovation capabilities of enterprises by optimizing resource allocation. Green technological innovation demands substantial early-stage investment due to its high cost, risk, and extended development period (Yu *et al.*, 2021). Green financial policies can mitigate financing constraints by fostering a resource-efficient green financial market, creating diverse green financial instruments, and enhancing capital allocation and risk-sharing functions (Yu *et al.*, 2021; Huang *et al.*, 2022). This strategy effectively boosts external capital supply to satisfy the significant capital requirements of green innovation (Irfan *et al.*, 2022). GFRIZs enhance local government backing for green initiatives by bolstering fiscal, taxation, land, and talent policies; stimulate financial institutions to engage in green finance; and attract domestic and foreign investments through financial risk prevention, green insurance, and bonds, thereby fostering regional green financial industry concentration and resource flow (Liu, Wang, 2023). Following the preceding analysis, the second research hypothesis was formulated.

Hypothesis 2: GFRIZs enhance enterprise green technological innovation by alleviating financing constraints.

According to externality theory, green technological innovation generates positive externalities, which hinder the market mechanism's ability to adequately compensate enterprises for their input costs. As highlighted by the environmental regulation theory, the government can impose environmental constraints on enterprises through policy tools and drive enterprises to obtain compensation through technological innovation and correct market failures. Enterprises often lack internal motivation for green technological innovation due to its external nature; however, effective environmental regulations significantly encourage such innovation (Porter, Linde, 1995; Liu, Xiao, 2022). Green technological innovation mitigates environmental pollution and the adverse impacts of production and consumption (Song *et al.*, 2019). GFRIZs can create a trading market for environmental rights, including carbon emissions, discharge, and energy use, by facilitating mortgage and pledge financing for these rights, such as franchise and project income rights. Additionally, these zones can develop information-sharing platforms to enhance governmental oversight and management of environmental issues, incorporating data on corporate pollution emissions and environmental violations. The government will strengthen environmental supervision and impose stricter environmental constraints on enterprises (Yang *et al.*, 2021), which will inhibit the development of enterprises failing to take environmental protection actions. Enhancing environmental oversight can foster green technological innovation in enterprises. Enterprises often lack internal motivation for green technological innovation due to its externality. However, the Porter hypothesis suggests that well-crafted environmental regulations significantly encourage technological innovation (Porter, Linde, 1995). Therefore, the strengthening of environmental supervision implies that the government imposes stricter environmental constraints on enterprises (Yang *et al.*, 2021). Enterprises that neglect environmental protection during production face developmental constraints, while green technological innovation mitigates pollution and minimizes environmental impact from

production and consumption (Song *et al.*, 2019). The establishment of GFRIZ enhances both formal and informal environmental regulations (Liu *et al.*, 2023), while increased environmental supervision fosters green technological innovation. Based on the preceding analysis, the third research hypothesis was proposed.

Hypothesis 3 posits that GFRIZs enhance corporate green technological innovation through the reinforcement of environmental regulations.

2. Methodology

2.1 Sample and Data

This study examines the impact of GFRIZ policies on corporate green technological innovation by analyzing listed companies on the Shanghai and Shenzhen Stock Exchanges in China from 2012 to 2023.The research data mainly included the green patent application data of listed companies and enterprise characteristic data. The data on green patents of listed companies were derived from the China Research Data Services Platform. This platform categorizes green patents based on World Intellectual Property Organization standards, compiling data from the China National Intellectual Property Administration and Google Patent. Data on enterprise characteristics were sourced from the China Stock Market Accounting Research (CSMAR) database. The data processing involved several steps: (1) Exclusion of ST and *ST enterprises; (2) Removal of financial enterprises, as green innovation primarily pertains to nonfinancial sectors; (3) Exclusion of companies listed post-2012 to maintain sample balance; (4) Deletion of listed companies with significant data gaps; and (5) Application of 1% winsorization on financial data to mitigate the impact of extreme values on parameter estimation. Afterward, a total of 26,318 observational samples of 2,270 listed companies in 31 provinces of China were obtained.

2.2 Variable Definition

2.2.1 Dependent Variable

In this study, the dependent variable was green technological innovation (*Innovation*). Patent applications more accurately represent current innovation capabilities and are less influenced by external factors than granted patents (Yang *et al.*, 2021). The level of green technological innovation in enterprises was assessed by counting the number of green patent applications. The authorization and approval of enterprise patents take a long period, the business performance of enterprises may be influenced for a long term during the application and execution of achievements of some patented technologies, and enterprises may not submit the green patent application in some years. Following the methodology of Wang X and Wang Y (2021), the number of green patent applications was incremented by 1 before applying a natural logarithm transformation. This approach mitigates the right-skewness in patent application distributions and preserves observed values.

2.2.2 Independent Variable

The core independent variable of this study was the pilot policy of green finance reform innovation, which is expressed by the cross-product term $Treat_{it} \times Time_t$. $Treat_{it}$ is a binary variable representing the experimental group membership, assigned a value of 1 if enterprise i is situated in a GFRIZ city, and 0 otherwise. $Time_t$ is a binary variable indicating the implementation of the GFRIZ policy, assigned a value of 1 from the year the policy is introduced onward, and 0 for prior years. This study employs a multiperiod DID model to evaluate the impact of the green finance reform innovation pilot policy.

2.2.3 Mediator Variables

Mediator variables included financing constraint (*FC*) and environmental regulation (*ER*). The SA index was utilized to assess the level of financing constraint. A higher index value indicates a lower degree of financing constraint. Environmental regulation was assessed using the entropy weight method, incorporating data on industrial wastewater discharge, sulfur dioxide emissions, and soot emissions across regions. A higher index indicates greater pollutant discharge and weaker environmental regulations.

2.2.4 Control Variables

Acknowledging that various enterprise-level factors influence green technological innovation, and following Shi, Zhang (2024), the study selected key control variables (*Control*): enterprise scale (*Scale*), defined as the natural logarithm of the firm's total closing assets; debt-to-asset ratio (*DAR*), which is the ratio of the total year-end debt scale to the total asset scale of the enterprise and reflects the debt level of the enterprise; number of listed years (*Age*), which is the time span since the enterprise is listed; enterprise growth opportunity (*TobinQ*), defined as the ratio of a company's market value to the cost of repurchasing its total assets; return on total assets (*ROA*), which reflects the earning power and profitability of the enterprise and can also be utilized to judge the stability and sustainability of enterprise profitability; ownership concentration (*Big*), which is measured using the share ratio of the largest shareholder; and cash flow level (*Cf*), which is measured through the ratio of the net amount of cash flow in operating activities to the total assets.

Table 1 provides the definitions and explanations of the variables.

Table 1. Definition and Description of Variables

Type	Variable	Definitions and Descriptions
Explained variable	*Innovation*	*Innovation* represents Green technological innovation and was measured by selecting the number of green patent applications. When calculating, the number of green patent applications was added with 1 and then subject to natural logarithm processing.
Explanatory variable	*Treat*Time*	*Treat*Time* represents the implementation of the pilot policy for green finance innovation reform.
Mediator variables	*FC*	*FC* represents financing constraint and was measured by the SA index.
	ER	*ER* represents environmental regulation and was calculated through the entropy weight method.
Control variables	*Scale*	*Scale* represents enterprise scale and is measured using natural logarithm of the closing total assets of the enterprise.
	DAR	*DAR* represents debt-to-asset ratio and is the ratio of the total year-end debt scale to the total asset scale of the enterprise.
	Age	*Age* is the time span since the enterprise is listed.
	TobinQ	*TobinQ* represents enterprise growth opportunity, and is measured the ratio of the market value of the listed company to the cost needed to repurchase its total assets.
	ROA	*ROA* represents return on total assets, and stands for the ratio of net profit to average total assets.
	Big	*Big* represents ownership concentration, and is measured using the share ratio of the largest shareholder.
	Cf	*Cf* represents cash flow level, and is measured through the ratio of the net amount of cash flow in operating activities to the total assets.

Source: own calculations.

2.3 Modeling

To test Hypothesis 1 and assess the impact of GFRIZs on enterprise green technological innovation, a multiperiod DID model was employed.

$$Innovation_{it} = \beta_0 + \beta_1 Treat_{it} \times Time_t + \beta_2 Control_{it} + \delta_p + \gamma_t + \varepsilon_{it} \quad (1)$$

Let I represent the enterprise and t the year. $Inovation_{it}$ indicates the enterprise's green technological innovation capability, while Treat and Time are dummy variables for the province and the policy implementation year, respectively. The interaction term coefficient *β1*, $Treat_{it} \times Time_t$, is the primary estimation parameter, indicating the net impact of the green finance reform innovation policy. A significantly positive β1 indicates that the established GFRIZs enhance the enterprise's green technological innovation. $Control_{it}$ represents a series of control variables, including *DAR*, *Age*, *TobinQ*, *ROA*, *Big*, and *Cf*. δ_p and γ_t represent the individual fixed effect and the time fixed effect, respectively. ε_{it} stands for the random error term.

To test Hypotheses 2 and 3, Models 2 and 3 were built by reference to the practice of Xu *et al.* (2023).

$$Innovation_{it} = \beta_0 + \beta_1 Treat_{it} \times Time_t \times FC_{it} + FC_{it} + \beta_2 Control_{it} + \delta_p + \gamma_i + \varepsilon_{it} \quad (2)$$

$$Innovation_{it} = \beta_0 + \beta_1 Treat_{it} \times Time_t \times ER_{it} + ER_{it} + \beta_2 Control_{it} + \delta_p + \gamma_i + \varepsilon_{it} \quad (3)$$

In Models 2 and 3, FC_{it} denotes the financing constraint level of enterprise *i* in year *t*. A significantly positive coefficient *β1* for the interaction term $Treat_{it} \times Time_t \times FC_{it}$ indicates that alleviating financing constraints in GFRIZs enhances the enterprise's green technological innovation. ER_{it} denotes the environmental regulation intensity for city *i* in year *t*. A significantly positive coefficient β1 for the interaction term $Treat_{it} \times Time_t \times ER_{it}$ indicates that enhanced environmental regulations in GFRIZs foster green technological innovation within enterprises. The other variables were the same as those in Model 1.

2.4 Descriptive Statistics

Table 2 statistical analysis of 26,318 observations reveals a standard deviation of 0.943 for the natural logarithm of green patents, with a maximum of 7.342, a minimum of 0, and a mean of 0.476. This suggests significant variability in green technological innovation capabilities among listed companies. From the statistical results of the control variables, great differences were observed between the characteristic variables of listed companies, also manifesting the diversity of sample selection, thereby ensuring the reliability and credibility of the empirical results.

Table 2. Descriptive Statistics

Varlables	N	Mean	S.d.	Min	Max
Innovation	26318	0.476	0.943	0	7.342
Size	26318	22.587	1.418	14.942	28.697
DAR	26318	0.475	1.166	-0.195	178.346
Age	26318	14.502	7.102	1	33
TobinQ	26318	2.129	7.160	0.611	729.629
ROA	26318	0.022	0.776	-30.688	108.366
Big	26318	33.237	14.959	0.290	89.990
Cf	26318	0.054	0.112	-10.216	2.222

Source: own calculations.

3. Results Analysis

3.1 Baseline Regression Analysis

The benchmark model prioritized the establishment of GFRIZs and their impact on enterprises' green technological innovation. *Table 3* regression analysis indicated that the coefficient for the interaction term *Treat×Time* was consistently positive and significant at the 5% level. After accounting for individual and time fixed effects, the interaction term *Treat×Time* had a coefficient of 0.063, suggesting that the establishment of GFRIZs led to an average 6.3% increase in enterprises' green technological innovation levels. Consequently, the GFRIZ policy significantly enhances enterprises' green technological innovation. Additionally, the control variables *Scale*, *Age*, and *TobinQ* contribute to enhancing enterprises' green technological innovation. The scale of an enterprise, its number of years listed, and its growth opportunities positively influence its green technological innovation. The influence coefficients of *DAR*, *ROA*, *Big*, and *Cf* were found to be insignificant, suggesting they are not central factors in affecting enterprises' green technological innovation.

Table 3. The influence of green finance policies on corporate innovation in green technology

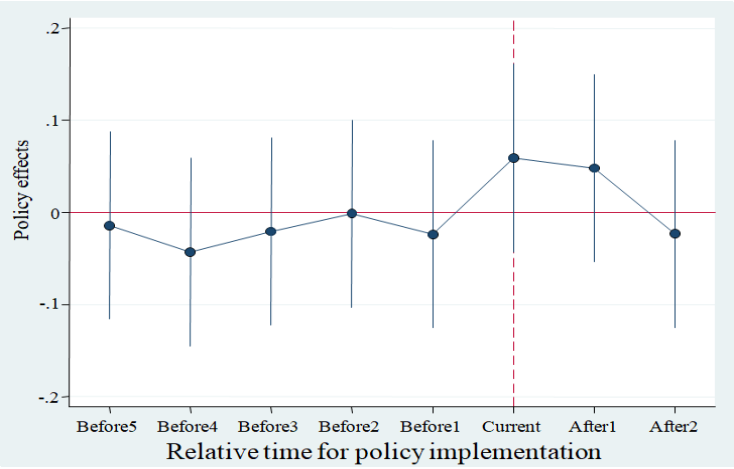
Variables	*Innovation*	*Innovation*	*Innovation*
Treat×Time	0.115*** (4.84)	0.050** (1.99)	0.063*** (2.59)
Size		0.049*** (4.00)	0.089*** (8.02)
DAR		-0.002 (-1.62)	-0.001 (-0.63)
Age		0.006*** (2.71)	0.001 (-0.37)
TobinQ		0.001*** (2.61)	0.001*** (3.08)
ROA		-0.012*** (-3.41)	-0.010*** (-3.48)
Big		-0.001 (-0.61)	-0.001 (-1.12)
Cf		-0.061** (-1.81)	-0.049 (-1.48)
Constant	0.455** (27.03)	-0.705*** (-2.67)	-1.495*** (-6.40)
Time fixed effects	Yes	No	Yes
Individual fixed effects	Yes	Yes	Yes
N	26318	26318	26318
R-squared	0.482	0.467	0.493

Note: Significance levels are denoted by *, **, and *** for 10%, 5%, and 1%, respectively. The model incorporates individual and time fixed effects, employs cluster robust standard errors, and presents t-values in parentheses.

Source: own calculations.

3.2 Parallel Trend Test

The parallel trend assumption is essential for employing DID, requiring that the outcome variables of both experimental and control groups exhibit parallel trends prior to the policy implementation. Here, parallel trend test was performed through the regression model-based test method.



Source: own calculations.

Figure 1. **Parallel Trend Test**

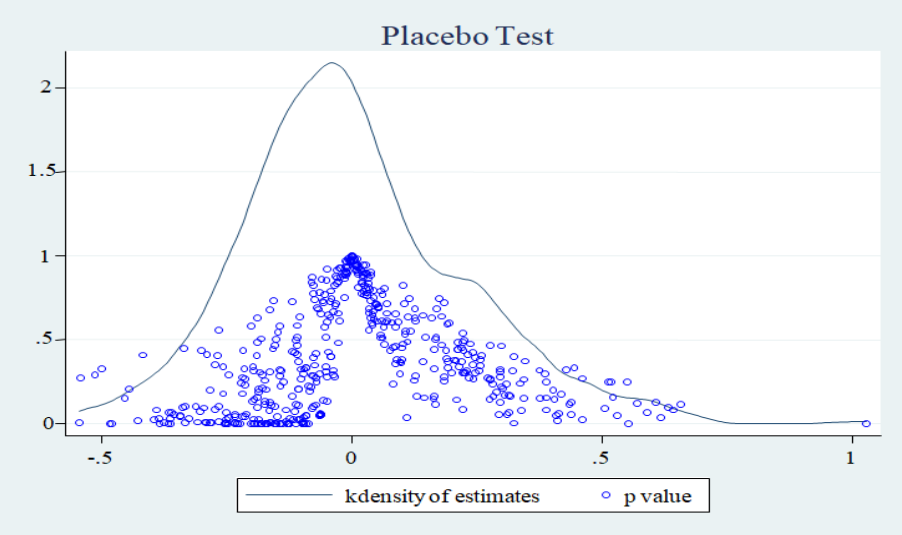
Figure 1 presents the regression results, with the x-axis indicating the year and a dotted vertical line marking the policy's inception year. The y-axis shows the policy's influence coefficient, represented by points that indicate specific coefficient values. Each point is accompanied by a vertical line representing the 95% confidence interval. The inclusion of 0 in the confidence interval of the coefficients prior to the policy implementation indicates that each interaction term's coefficient is insignificant, confirming the parallel trend test was passed. The findings indicate that the interaction term's coefficient was both insignificant and small prior to the policy implementation. Prior to the policy implementation, both the experimental and control groups exhibited no significant differences in green innovation, thus meeting the parallel trend assumption. After the policy was implemented, the influence coefficient of the pilot policy was positive, manifesting that the pilot policy can promote green innovation.

3.3 Robustness Test

3.3.1 Control Test

To ensure the study's results solely reflect the successful implementation of the green finance reform pilot project, and to mitigate the impact of significant unknown variables, the method's accuracy and efficacy were validated through 500 random tests. *Figure 2* illustrates the distribution of estimation coefficients for pseudo-policy dummy variables over 500 iterations, along with their corresponding p-values. The horizontal axis depicts the estimation coefficients, while the vertical axis shows the p-values. The curve represents the density distribution of these coefficients, and the blue dots indicate their respective p-values. The figure demonstrates that the placebo test samples' estimation coefficients cluster around 0, significantly deviating from the true coefficient of 0.060 identified in this study. Furthermore, the majority of these estimates have p-values exceeding 0.1, suggesting they are not statistically significant at the 10% level. This implies that the results are not coincidental and are unlikely influenced by random factors. Therefore, the test results passed the placebo test, and the successful establishment of GFRIZs plays a positive role in the healthy development and innovation of enterprises in a GFRIZ.

To further analyze, the establishment time of GFRIZs was advanced by two to three years for retesting, with regression results presented in Columns (1) and (2) of *Table 4*. The insignificance of the *Treat×Time* coefficient indicates that the enhancement in green technological innovation is attributed to the establishment of GFRIZs, reinforcing the robustness of the research conclusion.



Source: own calculations.

Figure 2. **Placebo Test**

3.3.2 Propensity Score Matching (PSM)–Difference-in-Differences (DID)

To reduce the bias caused by sample selection to DID estimation, the two groups of samples were screened using the PSM method, followed by DID estimation on this basis. To be specific, the two types of enterprise were matched through the Logitech model and 1:1 neighborhood matching with *DAR*, *ROA*, *Size*, and *TobinQ* as covariables. Column (3) of *Table 4* presents the regression results post-PSM processing, aligning with the baseline findings and confirming the robustness of the study's conclusions.

Table 4. The robustness test of GFRIZs on enterprise green technology innovation

Variables	(1) Two years in advance	(2) Three years in advance	(3) PSM-DID	(4) Replacement of explained variable
	Innovation	***Innovation***	***Innovation***	***Innovation***
Treat×Time	0.072 (0.75)	0.111 (0.97)	0.190*** (2.56)	0.289*** (3.63)
Constant	-10.222*** (-2.62)	-10.098** (-2.44)	-8.681** (2.32)	-8.271** (-2.27)
Control variables	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes
N	26318	26318	26318	26318
R-squared	0.466	0.466	0.469	0.364

Note: Significance levels are denoted by *, **, and *** for 10%, 5%, and 1%, respectively. The model incorporates individual and time-fixed effects, employs cluster robust standard errors, and presents t-values in parentheses.

Source: own calculations.

3.3.3 Replacement of Explained Variable

Enterprise green patents encompass both invention and non-invention types, with the former typically exhibiting greater innovation. In the robustness test, green technological innovations were quantified by counting green non-invention patent applications. In addition, given the self-quotation phenomenon of patents, the green technological innovation quality of enterprises was measured by eliminating the number of self-quoted green patents. Column (4) of *Table 4* presents regression results that align with the baseline findings, confirming their robustness.

3.4 Mechanism Analysis

3.4.1 Financing Constraint Mechanism

Hypothesis 2 was tested by incorporating financing constraints into the model, with the regression outcomes presented in Column (1) of *Table 5*. The positive coefficient of the double interaction term *Treat×Time* and the significant 0.170 coefficient of the triple interaction term *Treat×Time×FC* at the 1% level suggest that GFRIZs have facilitated an increase in green technological innovations among enterprises by easing financing constraints. GFRIZs positively influence enterprise green technological innovation by easing financing constraints, confirming Hypothesis 2.

Table 5. Mechanism Analysis of GFRIZs' Impact on Enterprise Technological Innovation

Variables	(1) Financing constraints	(2) Environmental regulation
	Innovation	***Innovation***
Treat×Time×FC	0.170*** (3.21)	
Treat×Time×ER		0.060*** (2.62)
Treat×Time	0.635** (2.38)	0.297* (1.79)
FC	1.111*** (4.20)	
ER		-0.003 (-0.29)
Constant	-0.41** (0.17)	
Control variables	Yes	Yes
Time fixed effects	Yes	Yes
Individual fixed effects	Yes	Yes
N	26318	26318
R-squared	0.472	0.469

Note: Significance levels are denoted by *, **, and *** for 10%, 5%, and 1%, respectively. The model incorporates individual and time fixed effects, employs cluster robust standard errors, and presents t-values in parentheses.

Source: own calculations.

3.4.2 Environmental Regulation Mechanism

Hypothesis 3 was tested by incorporating environmental regulation into the model, with the regression outcomes presented in Column (2) of *Table 5*. The positive coefficient of the *Treat×Time* interaction term and the significant 0.160 coefficient of the *Treat×Time×ER* triple interaction term at the 1% level suggest that the establishment of GFRIZs has enhanced green technological innovation in enterprises through

reinforced environmental regulations. Thus, GFRIZs enhance enterprise green technological innovation through reinforced environmental regulations, confirming Hypothesis 3.

3.5 Heterogeneity Analysis

3.5.1 Property Right Heterogeneity Analysis

The study investigates the varying impacts of green financial policy on green technological innovation by categorizing samples into state-owned and non-state-owned enterprises based on the nature of their ultimate controller. *Table 6* indicates that the regression coefficient for the interaction term *Treat×Time* on the variable Innovation is 0.634 and statistically significant at the 1% level for state-owned enterprises, whereas it is not significant for non-state-owned enterprises. This reveals that compared with non-state-owned enterprises, the green technological innovation level of state-owned enterprises can be significantly elevated by establishing GFRIZs.

Table 6. The differentiation effects based on property right heterogeneity

Variables	(1) state-owned enterprises	(2) non-state-owned enterprises
	Innovation	***Innovation***
Treat×Time	0.634*** (5.77)	0.077 (0.71)
Constant	-7.610* (-1.75)	-17.985*** (-3.40)
Control variables	Yes	Yes
Time fixed effects	Yes	Yes
Individual fixed effects	Yes	Yes
N	26318	26318
R-squared	0.568	0.472

Note: Significance levels are denoted by *, **, and *** for 10%, 5%, and 1%, respectively. The model incorporates individual and time fixed effects, employs cluster robust standard errors, and presents t-values in parentheses.

Source: own calculations.

3.5.2 Industry Heterogeneity

To investigate the varying impacts of green financial policy on green technological innovation across industries, the samples were categorized into manufacturing and non-manufacturing enterprises based on industry classification standards.

Table 7. The differentiation effects based on industry heterogeneity

Variables	(1) Manufacturing enterprises	(2) Non-manufacturing enterprises
	Innovation	***Innovation***
Treat×Time	0.201** (1.85)	0.423** (1.69)
Constant	-8.601** (-2.01)	-4.260 (-0.39)
Control variables	Yes	Yes
Time fixed effects	Yes	Yes
Individual fixed effects	Yes	Yes
N	26318	26318
R-squared	0.460	0.586

Note: Significance levels are denoted by *, **, and *** for 10%, 5%, and 1%, respectively. The model incorporates individual and time fixed effects, employs cluster robust standard errors, and presents t-values in parentheses.

Source: own calculations.

Table 7 indicates that the regression coefficient for the interaction term *Treat×Time* on the explained variable Innovation was 0.201 for manufacturing enterprises and 0.423 for non-manufacturing enterprises, both significant at the 5% level. The establishment of GFRIZs more significantly enhances green technological innovation in non-manufacturing enterprises compared to manufacturing enterprises.

3.5.3 Heterogeneity of Pollution Level

To investigate the varying impacts of green financial policy on green technological innovation across enterprises with differing pollution levels, the samples were categorized into heavy- and low-polluting industry groups based on their respective pollution levels. *Table 8* shows that the regression coefficient for the interaction term *Treat×Time* on the variable Innovation is 0.610 and significant at the 1% level in the heavy-polluting industry group, while it is not significant in the low-polluting industry group. The establishment of GFRIZs significantly enhances the green technological innovation level in heavy-polluting industries compared to low-polluting industries.

Table 8. The differentiation effects based on heterogeneity of pollution level

Variables	(1) Heavy-polluting industry	(2) Low-polluting industry
	Innovation	***Innovation***
Treat×Time	0.610*** (2.64)	0.116 (0.96)
Constant	-2.848 (-0.42)	-16.210*** (-3.22)
Control variables	Yes	Yes
Time fixed effects	Yes	Yes
Individual fixed effects	Yes	Yes
N	26318	26318
R-squared	0.561	0.503

Notes: Significance levels are denoted by *, **, and *** for 10%, 5%, and 1%, respectively. The model incorporates individual and time fixed effects, employs cluster robust standard errors, and presents t-values in parentheses.

Source: own calculations.

4. Discussion

Utilizing green patent data from A-share listed companies in China between 2012 and 2023, a quasi-natural experiment was conducted, taking into account the establishment of GFRIZs in China. The impact of GFRIZs on corporate green technological innovation was empirically analyzed using a multiperiod DID approach.

The creation of GFRIZs notably enhances the green technological innovation capabilities of enterprises, aligning with findings by Gilbert and Zhou (2017) and Irfan *et al.* (2022). According to the environmental regulation theory, the implementation of government environmental policies affects enterprise behaviors. The potential reasons for GFRIZs enhancing corporate green technological innovation are outlined below. The government has implemented various policies to advance green finance by supporting GFRIZs (Irfan *et al.*, 2022). This has surpassed the limitations of conventional financial policies by motivating financial institutions to support green environmental projects and encouraging enterprises in GFRIZs to pursue green technological innovations (Gilbert, Zhou, 2017). More benefits can be brought to enterprises because of numerous preferential policies. Second, GFRIZs have explored various green financial instruments, including green credits, bonds, insurance, and funds (Huang *et al.*, 2022). They have

promoted cleaner production and environmental governance among enterprises, offering ample financial support for the development of green technologies. Third, GFRIZs have actively improved and perfected the operation mechanism and established a direct connection between the market and enterprises through a green financial service platform, which contributes to the more convenient green investment and financing business and promotes the rational flow and distribution of technological innovation capital (Liu, Wang, 2023). Finally, the environmental supervision function of GFRIZs can provide external incentives for enterprises (Liu, Wang, 2023), promote enterprises to optimize production processes and improve environmental performance, and force enterprises to participate in environmental governance activities (Liu *et al.*, 2024), thereby improving the utilization efficiency of green technological innovation capital.

Second, GFRIZs can enhance enterprises' green technological innovation by easing financing constraints, aligning with Yu *et al.*'s (2021) findings. Huang *et al.* (2022) and Irfan *et al.*(2022). According to resource-based theory, optimal allocation of internal and external resources alleviates enterprise financing constraints, overcoming research investment capital bottlenecks and fostering a competitive advantage in technology accumulation. The establishment of GFRIZs provides support policies for enterprises in GFRIZs in terms of finance, taxation, land, and talent and increases support for green projects (Liu, Wang, 2023). Moreover, by implementing and perfecting many green financial policies, GFRIZs have actively cultivated a green financial market with efficient circulation of resources (Irfan *et al.*, 2022). The combined factors have enhanced external capital for green technology R&D in the zones, triggering the Porter effect, facilitating the concentration of green financial industries, and promoting the movement of green financial resources (Yu *et al.*, 2021). This has alleviated financing constraints through effective capital allocation and risk diversification (Huang *et al.*, 2022), leading enterprises to engage in high-quality green technological innovation spontaneously.

Third, GFRIZs improve the green technological innovation level of enterprises by strengthening environmental regulations, which is a discovery of this study. Based on externality and environmental regulation theories, green technological innovation exhibits positive externalities. However, if market mechanisms fail to adequately compensate enterprises for their R&D investments, it can dampen their motivation for technological innovation. In this case, the government will correct market failure by formulating and implementing environmental regulation policies to impose constraints on enterprises. GFRIZs enhance environmental oversight and governance by facilitating mortgage and pledge financing systems for environmental rights, establishing trading markets for these rights, and creating platforms for sharing corporate pollution and violation data, thereby elevating environmental regulatory standards (Porter, Linde, 1995; Shi, Zhang, 2024). With the improvement of environmental regulations, enterprises will be subject to stricter environmental constraints, and those performing well in environmental governance will be stimulated (Yang *et al.*, 2021).To mitigate costs associated with pollution discharge due to environmental regulations, enterprises engage in green technological innovation, optimize production processes, enhance green productivity, and decrease pollutant emissions. The external nature of technological innovation often results in a lack of internal motivation for enterprises to pursue green technological advancements. However, GFRIZs can potentially enhance technological innovation through the strategic design of environmental regulations.

Fourth, this study newly finds that the impact of GFRIZs on technological innovation in enterprises differs based on property rights, industry types, and pollution levels. (1) The primary goal of non-state-owned enterprises is to maximize profits, whereas state-owned enterprises bear more social responsibilities. While environmental regulations apply to all businesses, state-owned enterprises often receive

preferential treatment and protection from the government (Zhang *et al.*, 2019; Han *et al.*, 2021). State-owned enterprises, due to their greater social responsibilities and less stringent environmental regulations, are more likely to engage in technological innovation activities. (2) Compared with the non-manufacturing industry, the manufacturing industry features a focus on assets and strong organizational inertia, making it less likely to proactively pursue green transformation (Xie, Han, 2022). The significant investments made in earlier stages create a reliance on existing products and technologies, which diminishes the motivation for green innovation (Wan *et al.*, 2022). Moreover, the willingness to conduct green technological innovation is weakened by government environmental regulations (Lu *et al.*, 2025). Consequently, the establishment of GFRIZs encourages the manufacturing industry to pursue green technological innovation more effectively than the non-manufacturing sector. (3) Compared with low-polluting industries, heavy-polluting industries face greater public pressure and environmental litigation risks (Qi *et al.*, 2018). They also bear higher environmental supervision costs, and environmental regulations put forward stricter credit requirements and stronger environmental pressure on them (Liu *et al.*, 2019). Therefore, to protect the source of external credit funds and maintain the reputation of enterprises, when implementing the green financial policy, heavy-polluting industries are more willing to carry out the green transformation, improve the level of green technology, and fully enjoy the policy dividend brought by the establishment of GFRIZs.

Conclusions and Implications

Conclusions

Utilizing green patent data from A-share listed companies in China between 2012 and 2023, a quasi-natural experiment was designed using the establishment of GFRIZs as the policy variable. A multiperiod DID method was used to empirically test the impact of GFRIZs on enterprises' green technological innovation. The study concludes that GFRIZs significantly enhance green technological innovation by alleviating financing constraints and reinforcing environmental regulations.

Managerial Implications

The conclusions are crucial for accurately understanding the impact of GFRIZs on enhancing enterprises' green technological innovation. Additionally, the mechanism analysis offers managerial insights for the government to elevate green technological innovation through relevant policy implementation.

(1) Continuously promote and perfect the policy system construction of GFRIZs: The government should formulate detailed and operable green financial standards, actively cultivate professional financial intermediaries and green financial talents, and attach greater importance to the innovation of green financial tools. Moreover, it should continuously perfect the guarantee mechanism for green finance, guide and promote financial institutions to enhance the support for green technological innovation, and strengthen green financial supervision and impose strict punishments on environmental violations.

Investigate replicable and scalable experiences to facilitate the growth of GFRIZs. During the implementation of green financial policies, it is crucial to summarize existing experiences in GFRIZ development to effectively utilize these policies and progressively expand them nationwide based on specific circumstances. In addition, the experience in GFRIZ construction should be the focus, further enhancing the transformation effect of innovation results in GFRIZs.

(3) Fully release the optimization effect of green financial resources brought by the construction of GFRIZs and establish a long-acting mechanism to support the innovation and development of green

technology: The government should build a multilevel green financing model, risk prevention mechanism, and green project investment risk compensation mechanism. A sustainable mechanism should be established to support green technological innovation, lower financing costs for green projects, and foster a market for mortgage and pledge financing of environmental rights. The government should implement mechanisms for tracking capital investments and sharing enterprise environmental information to enhance the effectiveness of environmental regulations. This will encourage enterprises to proactively adjust their investment strategies and increase funding for green technology research and development.

(4) Fully consider the heterogeneous characteristics of enterprises and accurately implement green financial policies: In the process of promoting the effect of GFRIZs, the government should fully consider enterprise differences in nature, industry types, and pollution levels. Then, they should formulate targeted measures to implement green financial policies to better stimulate the willingness of enterprises to conduct green technological innovation. The GFRIZs management should leverage the resource strengths of state-owned enterprises and the innovation capabilities of manufacturing firms, aligning with the specific circumstances of zone enterprises, to promote high-quality green technological innovation. The government should focus on enforcing environmental regulations and enhancing supervision effectiveness, establish an investment and financing mechanism for heavily polluting industries, and compel these industries to pursue green technological innovation and transformation.

Limitations and Future Direction

This research is not without limitations. Initially, the research used data from publicly traded companies in China, where GFRIZs are still in the experimental phase. Therefore, the impact of the green financial policy remains unclear. Second, given the profitability of data, only relevant data from listed companies were utilized, failing to acquire data from non-listed companies. Thus, the sample size of the experimental and control groups was relatively small. Influenced by the above factors, biases may exist in the estimation results. However, as time progresses and GFRIZs are more comprehensively implemented, the policy effect of green finance will further emerge, making it possible to acquire more sample data. Future research will enhance sample data collection to better demonstrate and assess the impact of green financial policy using more empirical evidence.

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AR SKATINAMOS EKOLOGIŠKOS TECHNOLOGINĖS INOVACIJOS? ŽALIOJO FINANSAVIMO REFORMOS: POLITINIS INOVACIJŲ BANDOMŲJŲ ZONŲ POVEIKIS

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Santrauka. Žaliosios finansų politikos įgyvendinimo poveikis visada buvo glaudžiai susijęs su mokslininkais ir moksliniais tyrimais. Tačiau trūksta sisteminių tyrimų apie tai, ar žalioji finansų politika gali skatinti žaliąsias technologines įmonių inovacijas ir koks mechanizmas egzistuoja mikrolygmeniu. Siekiant išsiaiškinti ryšį tarp žaliosios finansų politikos ir įmonių žaliųjų technologinių inovacijų, Žaliųjų finansų reformos inovacijų bandomosios zonos (GFRIZ) Kinijoje, buvo pasitelktas beveik natūralus eksperimentas. Remiantis inovacijomis pagrįsta teorija, ištekliais pagrįsta teorija ir aplinkos reguliavimo teorija, buvo sistemingai tiriama GFRIZ įtaka ir mechanizmai įmonių žaliosioms technologinėms inovacijoms. Naudoti metiniai Kinijos A akcijų biržoje kotiruojamų bendrovių 2012–2023 m. duomenys ir daugiaperiodis skirtumų skirtumo metodas. Rezultatai atskleidė, kad GFRIZ gali reikšmingai skatinti įmonių žaliųjų technologijų inovacijas, o tai daugiausia pasiekiama sušvelninant finansavimo apribojimus ir stiprinant aplinkosaugos taisykles. Tačiau šis poveikis yra nevienalytis dėl įmonių nuosavybės teisių, pramonės tipų ir taršos lygių skirtumų. Išvadoje pateikiama teorinė parama ir empiriniai įrodymai, kad vyriausybė galėtų moksliškai įvertinti GFRIZ politinį poveikį. Ji taip pat padeda vyriausybei gerinti įmonių gebėjimą diegti žaliąsias technologines inovacijas stiprindama žaliosios finansų politikos sistemą, mažindama įmonių finansavimo suvaržymus ir visapusiškai atsižvelgdama į aplinkosaugos taisykles.

Reikšminiai žodžiai: žaliasis finansavimas; žaliosios technologinės inovacijos; politikos poveikis; skirtumų skirtumo metodas.