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Information acquisition or just going through the motions? Institutional investors' site visits and green innovation

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Abstract

The importance of green innovation in global sustainable development is increasingly recognized. Literature has documented that enhancing external oversight can improve green innovation performance. However, few studies systematically investigate the relationship between external supervisory behavior and green innovation. This study employs a game-theoretic model to examine the relationship between institutional investors' site visits (SVs) and green innovation. Using a unique dataset covering SVs from 2012 to 2021, empirical findings reveal that institutional investors' SVs are dramatically favorable to green innovation performance, particularly among stress-resistant institutional investors. More broadly, SVs by institutional investors with higher shareholdings and stronger reputations exhibit a substantial response to green innovation. Similarly, institutional investors' SVs significantly boost the green innovation of firms with inadequate environmental disclosure. Additional analysis documents that the quality improvement of green innovation significantly increases after institutional investors conduct more than three SVs in a calendar year. This study proposes that policymakers should improve the institutional environment for site visits, and enterprises can strategically involve institutional investors to enhance external monitoring mechanisms. The theoretical and practical implications of this contribute to boosting green innovation capabilities.

KEYWORDS

game theory, green innovation, institutional investors' site visits, threshold regression

1 | INTRODUCTION

While governments globally align on the role of green innovation in the enhancement of resource efficiency and the reduction of energy consumption (Huang & Yang, 2021; Yu et al., 2023), mitigating externalities linked to green innovation is imperative for environmental governance (Rahman et al., 2022; Shah et al., 2022; Shi et al., 2023). Amplifying external governance emerges as a pivotal approach to addressing these concerns (Cao et al., 2022; Chen et al., 2021; Wei et al., 2023). Institutional investors, renowned for their size and expertise, stand as potent external governance mechanisms (Miller et al., 2022; Xu et al., 2023), with their site visits (SVs) revealing valuable environmental insights and reinforcing ecological regulations. From a theoretical standpoint, institutional investors' SVs grant direct access to R&D facilities and deepen comprehension of green innovation through interactions with corporate management and staff (Cao et al., 2022; Jiang & Yuan, 2018; Su et al., 2021). Simultaneously, information unearthed from SVs reduces information asymmetry, disseminating insights on green innovation to stakeholders keen on corporate environmental performance (Cui et al., 2023; Qi et al., 2021; Qi et al., 2022).

Existing literature primarily examines the economic implications of institutional investors' SVs, including financial performance, corporate investment, and environmental management. Gao et al. (2017) revealed a positive correlation between the frequency of institutional investors' SVs and the risk of stock price crashes, linked to information transmission and supervision effects. Additionally, Saci and Jasimuddin (2021) highlighted how institutional investors' SVs decrease the cost of equity capital. Guo et al. (2023) found that corporate SVs bring about a reduction in tax avoidance for highly tax-avoidant plants while promoting tax avoidance among those with lower levels. Concerning firm investments, Wang et al. (2022) discovered substantial increases in cash holdings due to institutional investors' SVs. Furthermore, other literature documents that institutional investors' SVs alleviate underinvestment concerns, enhance investment efficiency, and do not hinder overinvestment (Zhao et al., 2023). In a similar fashion, Liu and Hou (2023) observed that institutional investors' SVs significantly contribute to improving corporate social responsibility (CSR) performance, mainly through their supervisory impact. By and large, the current literature predominantly centers on the financial domain, with limited exploration of the link between institutional investors' SVs and corporate green innovation.

In response to the research gaps, this paper aims to investigate the impact of institutional investors' SVs on corporate green innovation. Overall, this study primarily addresses three key questions: Q1. Whether and how institutional investors' SVs influence corporate green innovation, and to what extent? Q2. Does the relationship between institutional investors' SVs and corporate green innovation vary across institutional investor and corporate characteristics? Q3. Does the frequency of institutional investors' SVs exhibit a threshold effect on corporate green innovation?

To address these inquiries, this paper utilizes game theory models and numerical simulation methods to examine the mechanisms of institutional investors' SVs in corporate green innovation. Building on this foundation, this paper empirically evaluates the impact of institutional investors' SVs on corporate green innovation using data from publicly traded Chinese companies spanning 2012–2021. Additionally, this study analyzes additional factors influencing the relationship, including institutional shareholders' ownership proportion, the reputation of investigative institutions, and the disclosure status of corporate information environments. Lastly, this paper quantifies the minimum number of SVs that have a meaningful impact on corporate green innovation using a threshold strategy.

This paper contributes to two strands of the literature. First, it integrates institutional investors' SVs and corporate green innovation into an analytical framework, enhancing the research on the economic consequences of SVs. Existing literature related to institutional investors' SVs largely focuses on the impact on compliance management (Guo et al., 2023; Su et al., 2021), investment efficiency (Qi et al., 2021; Zhao et al., 2023), and corporate social responsibility (Liu & Hou, 2023). However, literature on the implications of institutional investors' SVs on corporate green innovation is scarce. Moreover, prior studies primarily concentrated on assessing the effects related to the reduction of agency conflicts and the mitigation of information asymmetry, but they lacked empirical evidence from mathematical modeling. (Anderson et al., 2007; Broadstock & Chen, 2021; Cai et al., 2023; Cao et al., 2023; Wang & Wang, 2023). In this article, we employ a game model to rigorously investigate the nexus between institutional investors' SVs and corporate green innovation. Subsequently, empirical analyses are undertaken to evaluate its marginal effects. This study contributes to the academic discourse by broadening the understanding of institutional investors' SVs and enriching the examination of institutional investor behavior in corporate governance.

Second, the assessment of institutional investors' SVs in promoting corporate green innovation holds significant practical implications for advancing sustainability agendas. This study confirms a positive association between institutional investors' SVs and green innovation. This interplay is particularly pronounced when institutional investors have higher ownership stakes, enjoy favorable reputations, and operate in contexts with limited information disclosure. The findings offer practical recommendations for policymakers, institutional investors, and corporations. In practice, policymakers should strengthen institutional frameworks supporting SVs to enhance regulatory oversight. Institutional investors ought to increase engagement with SVs to drive green innovation and secure long-term investment returns. Corporations should strategically introduce institutional investors to maximize the benefits of SVs and improve green innovation.

The subsequent sections of the paper proceed as follows: Section 2 develops a game model to examine the influence of institutional investors' SVs on green innovation. Section 3 is the research design, including a discussion of data sources and methodology, alongside the descriptive statistics of variables. Section 4 presents the empirical results. Section 5 provides the conclusion and insights of the entire paper.

2 | THEORETICAL ANALYSIS

Institutional investors' SVs, serving as a manifestation of external governance, are designed to exert influence on green innovation decisions via supervisory and pressure effects. However, the attendant risks and costs may dissuade businesses from undertaking green innovation initiatives, with the decision contingent upon the extent of constraints imposed by institutional investors. The interplay between institutional investors and corporate green innovation can be conceptualized as a strategic game. Leveraging this conceptual framework, we construct a game model to formulate the reaction function based on economic returns, thereby scrutinizing the static impact of institutional investors' SVs on corporate green innovation. We set numerical parameters for this function and employ numerical simulation techniques to analyze dynamic trends. Ultimately, synthesizing the results, this paper derives general conclusions regarding the influence of institutional investors' SVs on corporate green innovation. The game model is structured as follows:

This study treats institutional investors and plants as participants in a strategic game, considering them as finite rational individuals capable of learning and making behavioral choices. Institutional investors are denoted as G, and plants are represented as E. The strategy choices available to institutional investors are either conducting a site visit or not conducting one, indicated by {*Conducting a site visit*, *Do not conducting a site visit*}, while plants have the choice to engage in or abstain from green innovation, denoted as {*Conducting green innovation*, *Do not conducting green innovation*}. The proportion of institutional investors conducting site visits is $y(t)$, and the proportion of plants participating in green innovation is $x(t)$, both within the ranges of $0 \le x \le 1$ and $0 \le y \le 1$.

The cost of corporate green innovation is C_1, and green innovation activities are capable of upgrading environmental quality, represented by the net benefit Δ. Plants engaged in green innovation also generate added operating profit R. However, a spillover effect from green innovation decreases operating profit by a rate of α. Factoring in technology spillover, the plant's operating profit is $(1-\alpha)R$. Corporate income tax at a rate of t is collected by government authorities, resulting in a payable income tax of $(1-t)(1-\alpha)R$.

By conducting SVs, institutional investors access confidential corporate information, including environmental facilities and R&D investments. This access boosts violation detection odds, motivating plants to prioritize green innovation. For plants in green innovation, they receive government incentive funds J, and face a lower environmental tax F_1. Conversely, non-participating plants lose subsidies and face a higher environmental tax F_2.

In the absence of institutional investors' SVs, plants still pursue green innovation to protect their reputation. In this context, plants can receive government incentives J and entail an environmental tax F_1 with a probability of β. Conversely, plants not adopting green innovation might deceptively access environmental grants J with a probability of $1-\beta$, and face environmental taxes F_2 with a probability of β. Additionally, the cost of institutional investors' SVs is labeled as C_2.

Let $U_E, U_{\overline{E}}$ denote the expected utilities for the corporate strategies involving and abstaining from green innovation, respectively. $\overline{U_E}$ corresponds to the combined utility.

$$U_E = y[J+(1-t)(1-\alpha)R - C_1 - F_1] + (1-y)(1-t)(1-\alpha)R - C_1 - \beta F_1],$$

$$U_{\overline{E}} = y(-F_2) + (1-y)[(1-\beta)J - \beta F_2],$$

$$\overline{U_E} = xU_E + (1-x)U_E.$$

The replication dynamic equation for the firm's strategy choice is as follows:

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x\left(U_E - \overline{U_E}\right) = x(1-x)\left(U_E - U_{\overline{E}}\right) \\ &= x(1-x)[-C_1 + \beta(F_2 - F_1 + J) + (1-t)(1-\alpha)R + y(1-\beta)(F_2 - F_1 + J)]. \end{aligned}$$

Similarly, the replication dynamic equation for institutional investors is derived as follows.

$$\begin{aligned} F(y) = \frac{dy}{dt} &= y\left(U_G - \overline{U_G}\right) = y(1-y)\ \left(U_G - U_{\overline{G}}\right) \\ &= y(1-y)\ [(1-\beta)\ (F_2 + J - C_2) - x(1-\beta)\ (F_2 - F_1 + J)]. \end{aligned}$$

Equation (1) represents a dynamic system that includes replication dynamic equations for both plants and institutional investors.

$$\begin{cases} \dfrac{dx}{dt} = x(1-x)\Big[-C_1 + \beta(F_2 - F_1 + J) + (1-t)(1-\alpha)R \\ \qquad + y(1-\beta)(F_2 - F_1 + J)\Big] \\ \dfrac{dy}{dt} = y(1-y)[(1-\beta)(F_2 - J - C_2) - x(1-\beta)(F_2 - F_1 + J)]. \end{cases} \tag{1}$$

Equation (2) the computed Jacobi matrix, derived from Equation (1).

$$\begin{bmatrix} (1-2x)\begin{bmatrix} -C_1 + \beta(F_2 - F_1 + J) \\ +(1-t)(1-\alpha)R \\ +y(1-\beta)(F_2 - F_1 + J) \end{bmatrix} & x(1-x)(1-\beta)(F_2 - F_1 + J) \\ -y(1-y)(1-\beta)(F_2 - F_1 + J) & (1-2y)\begin{bmatrix} [(1-\beta)(F_2 + J - C_2) - x] \\ (1-\beta)(F_2 - F_1 + J) \end{bmatrix} \end{bmatrix}. \tag{2}$$

With a local stability analysis of the Jacobi matrix, this study computes the asymptotic stability for each equilibrium state across different scenarios and confirms the presence of a pure strategy evolutionary stable equilibrium (Friedman, 1991; Friedman, 1998). The results are presented in Table 1.

Table 1 displays the convergence results of the evolutionary game system towards the Evolutionarily Stable Strategy (ESS) point in six distinct scenarios. In situation 1, with $\pi_1 < 0$ and $\pi_3 < 0$, the ESS is denoted by (0, 0), indicating that plants abstain from green innovation while institutional investors abstain from SVs. In terms of pure strategy evolutionary equilibrium, (0, 1) represents the least favorable equilibrium, where plants avoid green innovation while institutional investors tend towards SVs for stricter supervision, bringing about a non-cooperative situation. In contrast, (1, 0) signifies plants selecting green innovation independently, without the need for SVs from institutional investors, serving as an optimal solution. Lastly, (1, 1) denotes a suboptimal equilibrium where both plants and institutional investors engage in green innovation and SVs, respectively. The preceding results suggest that institutional investors' SVs contribute to an evolutionary stable point (1, 1) in the game system, signaling improved corporate green innovation.

In practice, the components of the game system dynamically change, necessitating an exploration of its evolutionary stability. To do so, this study constructs a numerical simulation model in MATLAB by assigning values to the parameters to investigate the dynamic impact of institutional investors' SVs on corporate green innovation. Following previous studies (Eghbali et al., 2022; Hao et al., 2022; Jiang et al., 2022; Shi et al., 2021; Xi et al., 2022; Zhou et al., 2022), as well as real-world datasets, this paper assigns initial values to several parameters, including participant costs, green innovation profits, and green subsidies. Specifically, the values are determined as follows: $C_1 = 2$, $C_2 = 0.6$, $R = 3$, $F_1 = 3$, $F_2 = 4$, $J = 6$, $\alpha = 0.5$, $\beta = 0.5$. Furthermore, the initial point of the game is set at [0.3, 0.5].

The left panel of Figure 1 clearly shows the initial state. The ratio of plants opting for green innovation is at 1, aligned with institutional investors selecting SVs, forming a stable point at (1, 1). However, it is noteworthy to note that there is a declining number of plants

TABLE 1 Asymptotic stability of system evolutionary equilibrium points.

EP.	Situation 1			Situation 2			Situation 3			Situation 4			Situation 5			Situation 6		
	$\pi_1 < 0, \pi_3 < 0$			$\pi_1 < 0, \pi_3 > 0$, $\pi_4 < 0$			$\pi_1 > 0, \pi_2 < 0$, $\pi_3 < 0$			$\pi_2 > 0, \pi_3 < 0$			$\pi_2 > 0, \pi_3 > 0, \pi_4 < 0$			$\pi_2 > 0, \pi_4 > 0$		
(x, y)	detI	trI	Stab	detI	trI	Stab	detI	trI	Stab	detI	trI	Stab	detI	trI	Stab	detI	trI	Stab
(0, 0)	+	–	ESS	–	UC	SAP	+	–	ESS	–	UC	SAP	+	+	IST	+	+	IST
(0, 1)	–	UC	SAP	+	–	ESS	+	+	IST	+	+	IST	–	UC	SAP	–	UC	SAP
(1, 0)	–	UC	SAP	–	UC	SAP	–	UC	SAP	+	–	ESS	+	–	ESS	–	UC	SAP
(1, 1)	+	+	IST	+	+	IST	–	UC	SAP	–	UC	SAP	–	UC	SAP	+	–	ESS

Abbreviations: ESS, evolutionarily stable strategy; IST, instability; SAP, saddlepoint; UC, means uncertainty.

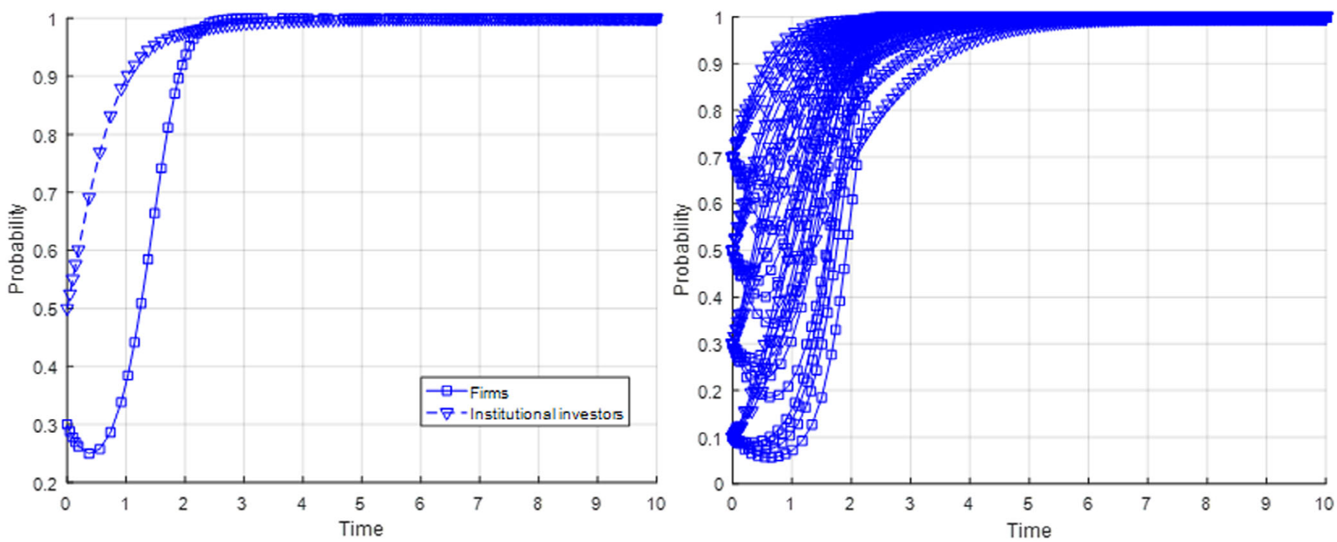

FIGURE 1 Initial convergence of participants.

choosing to participate in green innovation, even with an increased probability of institutional investors' SVs. This indicates that plants do not consistently improve their performance in green innovation. To demonstrate this scenario, simulations are conducted by randomly selecting initial values ranging from 0.1 to 0.8. The right panel of Figure 1 presents the simulation results for distinct initial values. Overall, regardless of the initial probability values, plants engage in green innovation and institutional investors perform SVs, ultimately tending towards cooperation.

The left panel of Figure 2 depicts the shift of corporate green innovation across varying site-visit probabilities. Previous research indicates that plants often pursue green innovation to secure specialized subsidies. Nevertheless, there comes a stage where plants resort to deceptive green practices, as evidenced by a declining range. The right panel of Figure 2 illustrates the progression of initial probabilities for institutional investors' SVs. Importantly, it is noticeable that these SVs have a significant impact on the performance of corporate green innovation.

Based on the preceding findings, this paper concludes that institutional investors' SVs exert a favorable impact on corporate green innovation. However, the precise marginal effects of this influence remain undisclosed. Subsequently, this study utilizes an empirical regression strategy in the ensuing sections to investigate the concrete impacts of institutional investors' SVs on corporate green innovation.

3 | RESEARCH DESIGN

3.1 | Sample and data

The principal sample for this study consists of Chinese publicly traded companies listed on both the Shenzhen Stock Exchange (SZSE) and the Shanghai Stock Exchange (SHSE), spanning the years 2012–2021. The primary data sources for the variables are as follows: Corporate green patents are retrieved from the China Research Data Service Platform (CNRDS) database, whereas datasets concerning institutional investors' SVs and control variables are acquired from the China Stock Market & Accounting Research Database (CSMAR), supplemented by the Wind database (WIND).

To ensure the reliability of our findings, this paper excludes the following samples: (i) ST and PT firm observations; (ii) samples of financial plants; (iii) samples of firms delisted due to financial misconduct; and (iv) samples containing missing values. Following this rigorous screening process, we obtained a dataset comprising 11,507

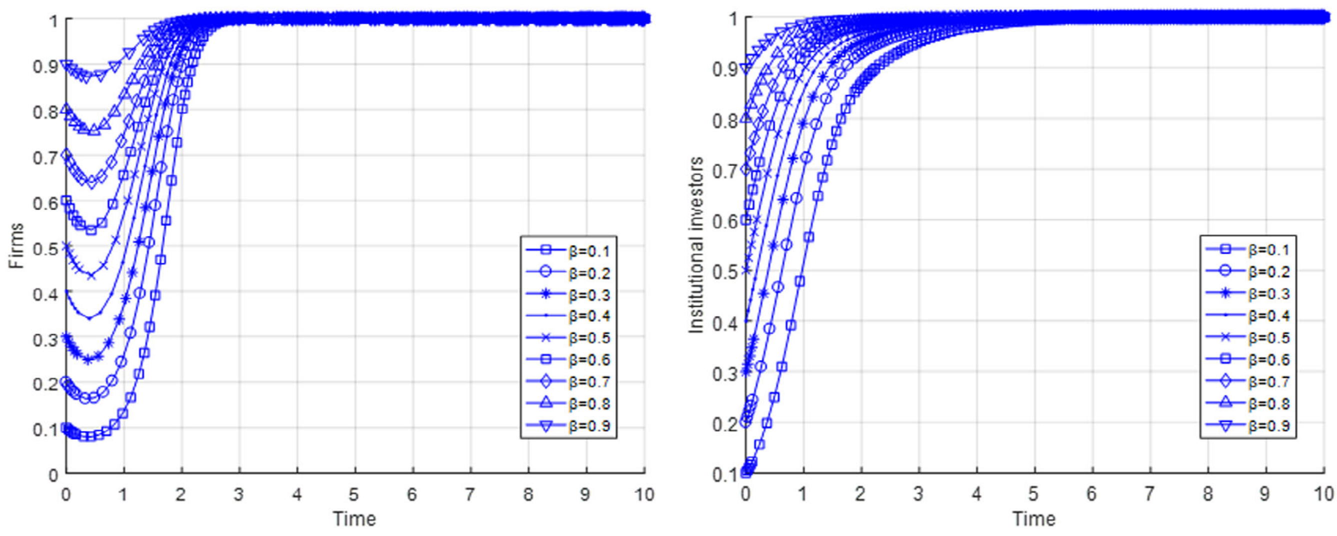

FIGURE 2 Participant evolution under varying probabilities.

firm-year observations spanning from 2012 to 2021. Additionally, all continuous variables underwent winsorization, whereby extreme values at the top and bottom 1% were adjusted to mitigate their influence.

3.2 | Empirical design

According to Cheng et al. (2016) and Zhou and Gan (2022), this paper constructs Specification (3) to examine the impact of institutional investors' SVs on green innovation.

$$GINNO_{pjit} = \alpha + \beta INSVISIT_{pjit} + \gamma X_{pjit} + \mu_i + \gamma_t + \delta_{jt} + \tau_{pt} + \varepsilon_{pjit}, \quad (3)$$

where i indexes a plant, t indexes a year, j indexes the corporate two-digit SIC code, and p indexes the province in which plant i is headquartered. α denotes the constant term. Additionally, GINNO represents green innovation, and INSVISIT, indicating institutional investors' SVs, is the variable of interest, and its net effect on green innovation is represented by β. X is a set of variables controlling for other sets of factors affecting both institutional investors and green innovation. Moreover, μ and γ are the corporate fixed effect and the year fixed effect, respectively. δ and τ are the industry-year fixed effect and the province-year fixed effect, respectively. ε is the residual. Table A1 provides specific variable definitions in model (3).

3.3 | Variables definition

3.3.1 | Corporate green innovation

Following Amore and Bennedsen (2016) and Jiang and Bai (2022), this paper adopts the count of green patent applications as a metric for assessing green innovation. Specifically, our analysis focuses on the tally of green patents, including green invention patents and green utility patents, to capture the breadth and quality of green innovation efforts. Prior scholarship commonly employs the number of green patent applications and their citations as proxies for green innovation (Aghion et al., 2013; Jiang & Bai, 2022; Wei et al., 2023). However, due to the lower citation frequency for recent patents compared to older ones, the count of green patent applications has emerged as a prevalent method for measuring green innovation (Amore & Bennedsen, 2016; Jiang & Bai, 2022; Sun et al., 2019). To mitigate the temporal disparity between green patent application and acquisition and account for the positively skewed distribution of green patent data, this study introduces a lag of one period to the green patent count. Subsequently, this study computes the logarithm of one plus the green patent count, yielding the variables GPATENT, GINVENT, and GUTILITY.

Figure 3 presents an analysis of the temporal trends and distribution patterns of green patents across the examined periods. The left panel exhibits the fluctuation in the count of green patents categorized by type for each fiscal year. Notably, corporate green patents show a remarkable surge in 2020, indicating a substantial expansion in China's capabilities in providing a technological underpinning for environmental progress. Furthermore, since 2013, the tally of green invention patents has consistently surpassed that of green utility patents, highlighting a growing emphasis on the quality aspect of green innovation within corporate initiatives. However, a significant decline in the number of green patents, particularly green utility patents, is discernible post-2000. This reduction could plausibly be attributed to disruptive events, such as black swan occurrences, exemplified by the COVID-19 outbreak, which disrupted corporate R&D processes in green innovation.

The right panel delineates the distributional characteristics of green patents across different plants. An overarching left-skewed distributional trend is discernible within the realm of green patents, where a substantial proportion of plants exhibit holdings of less than

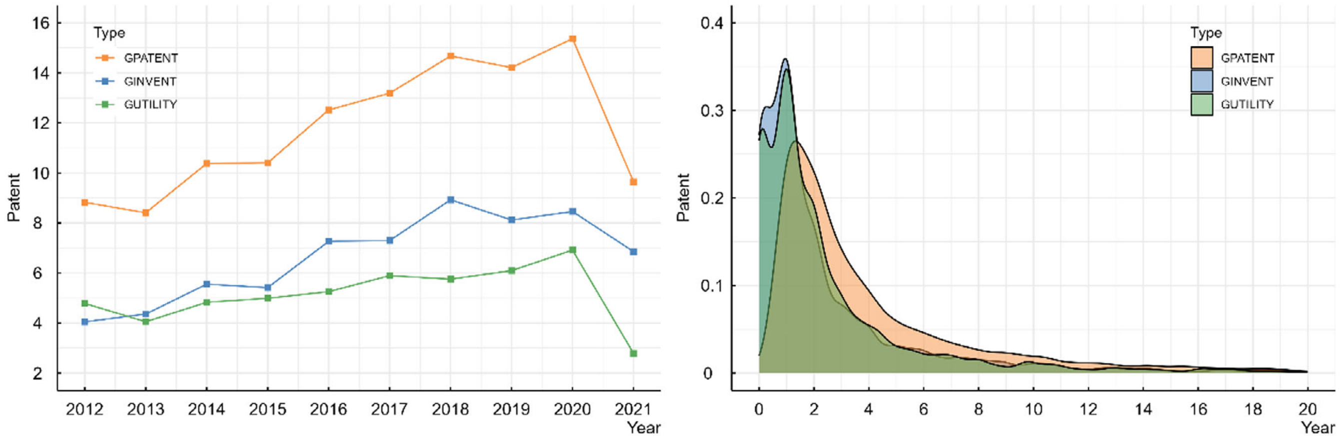

FIGURE 3 Trend and distribution of green patents. In this figure, GINVENT and GUTILITY represent the counts of green invention and utility patents, respectively. GPATENT equals the combined counts of GINVENT and GUTILITY. The left panel illustrates the yearly average of green patent counts, excluding instances with zero green patents. Similarly, for a precise representation of corporate green patent distribution, we apply right-hand truncation during the creation of the right panel.

12 patents of this nature. This implies noteworthy divergences in the patenting activities among diverse enterprises.

3.3.2 | Institutional investors' SVs

In line with Cheng et al. (2016), our method of quantifying institutional investors' SVs involves aggregating the frequency of visits to individual plants. Institutional investors constitute a diverse group of investors with significant financial commitments, including funds, QFIIs, brokerages, insurance firms, social security funds, trust companies, finance institutions, banks, and non-financial listed companies. This research operationally defines institutional investors' SVs as encompassing visits to physical facilities, corporate headquarters, and direct face-to-face engagements with management (Chen et al., 2021; Cui et al., 2023; Gao et al., 2023; Lai et al., 2022). Similarly, our study classifies institutional investors into stress-resistant and stress-sensitive categories (Jiang & Bai, 2022). Stress-resistant institutional investors include holdings by securities investment funds, QFII, and the proportion of social security fund holdings relative to outstanding shares. Conversely, stress-sensitive institutional investors comprise brokerages and their financial products, insurance firms, trust companies, finance institutions, banks, and non-financial listed companies.

Figure 4 displays the count of institutional investors' SVs categorized by type. The left panel distinctly shows the fluctuation in the count of institutional investors' SVs across fiscal years. Apart from 2019, there has been an observable upward trajectory in the number of SVs, particularly post-2019. This trend suggests an increasing emphasis by institutional investors on utilizing SVs to gather information and inform investment decisions. The right panel depicts the distribution of various institutional investors throughout the sample period. Notably, fund firms, security firms, and investment institutions exhibit a higher proportion of SVs compared to alternative institutional investor types. Due to their substantial investment commitments, fund and security firms engage in SVs to access internal information, mitigating investment risks.

3.3.3 | Control variables

Following Gao et al. (2017), Jiang and Yuan (2018), and Liu and Hou (2023), this study controls for an array of variables to fortify the empirical findings from potential confounding influences. Initially, this study introduces variables that account for firm characteristics, including firm size (ASSET), leverage (LEV), return on assets (ROA), and asset tangibility (PPE). Additionally, this study considers factors associated with the board and ownership structures, including the proportion of independent directors (INDEP), board size (LNDIR), state-owned enterprise (STATE), the percentage ownership by the largest stockholder (FIRST), the top nine shareholders (TOPNINE), and the same person as chairman and general manager (DUAL). Table A1 provides detailed definitions of the variables.

3.4 | Descriptive statistics and correlation analysis

Table 2 depicts the statistical results for the primary variables in this study. Over the period from 2012 to 2021 within our sample, the mean of GPATENT is 1.105, ranging from 0.000 to 3.466, with a standard deviation of 1.666. Specifically, the means of GINVENT and GUTILITY are 0.563 and 0.542, respectively, accompanied by standard deviations of 0.937 and 0.877, indicating considerable variations in green innovation across firms. The statistical indicators for various variables are generally in line with those reported in prior research by Gao et al. (2017) and Jiang and Bai (2022), thus corroborating the robustness of our variable selection.

Figure 5 depicts the person coefficients among the principal variables within the baseline model. Specifically, the coefficients between

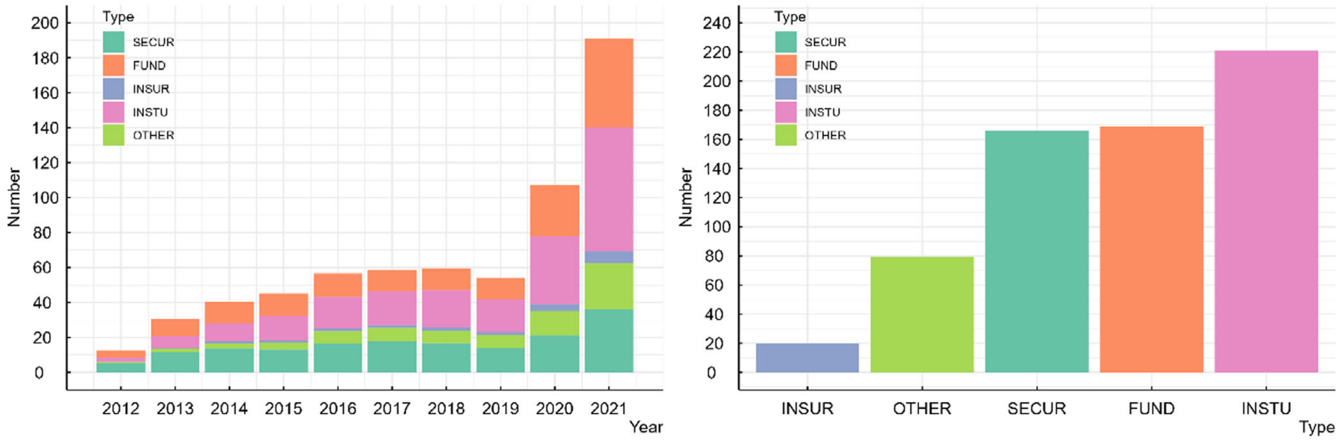

FIGURE 4 Site visits (SVs) across varying institutional investor types. Figure displays the count of SVs for securities firms (SECUR), fund firms (FUND), insurance firms (INSUR), investment firms (INSTU), and other investment firms (OTHER). Additionally, it is essential to emphasize that the numerical values are expressed in thousands.

TABLE 2 Summary statistics.

Varname	*N*	Mean	SD	P10	P90
GPATENT	11,507	1.105	1.666	0.000	3.466
GINVENT	11,507	0.563	0.937	0.000	1.946
GUTILITY	11,507	0.542	0.877	0.000	1.792
INSVISIT	11,507	12.697	15.462	1.000	29.000
ASSET	11,507	22.133	1.241	20.731	23.743
LEV	11,507	0.378	0.195	0.134	0.647
ROA	11,507	0.050	0.059	0.006	0.113
PPE	11,507	0.189	0.142	0.027	0.385
FIRST	11,507	0.326	0.143	0.156	0.527
TOPNINE	11,507	0.272	0.125	0.111	0.446
LNDIR	11,507	2.226	0.176	2.079	2.398
STATE	11,507	0.244	0.417	0.000	1.000
DUAL	11,507	0.353	0.478	0.000	1.000
INDEP	11,507	0.377	0.053	0.333	0.429

INSVISIT and green patents (GPATENT, GINVENT, and GUTILITY) are 0.13, 0.15, and 0.09, respectively. These values suggest a positive correlation between institutional investors' SVs and green innovation, aligning harmoniously with the theoretical analysis presented in Section 2. Notably, utilizing multiple regression analysis holds paramount importance in elucidating the intricate relationships among variables. Additionally, the coefficients for the majority of variables remain below the threshold of 0.5, indicating the absence of significant multicollinearity issues among these variables.

Figure 6 illustrates the univariate analysis results of institutional investors' SVs on green innovation. We analyzed the relationship between institutional investors' SVs and green innovation using the calculated average for each fiscal year. In Figure 6, the estimations of INSVISIT consistently demonstrate notably positive values. This observation provides tentative support for the validity of our theoretical framework and is consistent with the outcomes obtained from correlation analysis.

4 | EMPIRICAL RESULTS

4.1 | Baseline estimates

This study initiates its analytical inquiry by examining the impact of institutional investors' SVs on corporate green innovation. Table 3 presents the regression estimates, with GPATENT, GINVENT, and GUTILITY as dependent variables and INSVISIT as the independent variable. Correspondingly, columns (1)–(3) exclusively focus on outcomes related to the variable of interest, while columns (4)–(6) adjust for control variables influencing corporate green innovation. Across all columns, INSVISIT exhibits a statistically significant and positive impact on GPATENT, GINVENT, and GUTILITY, with a p-value of <0.01, suggesting a connection between institutional investors' SVs and an elevated level of green innovation, reinforcing the conclusions drawn in Section 2.

This finding aligns with Jiang and Bai (2022). However, Jiang and Bai (2022) focused solely on manufacturing industries, while this paper covers all industries except for the financial and insurance sectors. Additionally, this paper strengthens the robustness of empirical findings by incorporating joint fixed effects into the models. Compared to existing studies, this paper benefits from a large sample size and sophisticated empirical models, thus enhancing the scope and reliability of empirical findings.

This study then examines the influence of different types of institutional investors' SVs on green innovation. Brickley et al. (1988) and Almazan et al. (2005) documented that institutional investors with a sole investment relationship with plants are inclined to engage in managerial oversight, while those with a business-dependent relationship are predisposed to endorse corporate decisions. As a result, the response to green innovation varies across specific types of institutional investors' SVs. Similar to Brickley et al. (1988), this study categorizes securities investment funds, social security funds, and QFIIs as stress-resistant institutional investors, and insurance companies, trust companies, and other institutional investment entities as sensitive to such pressures.

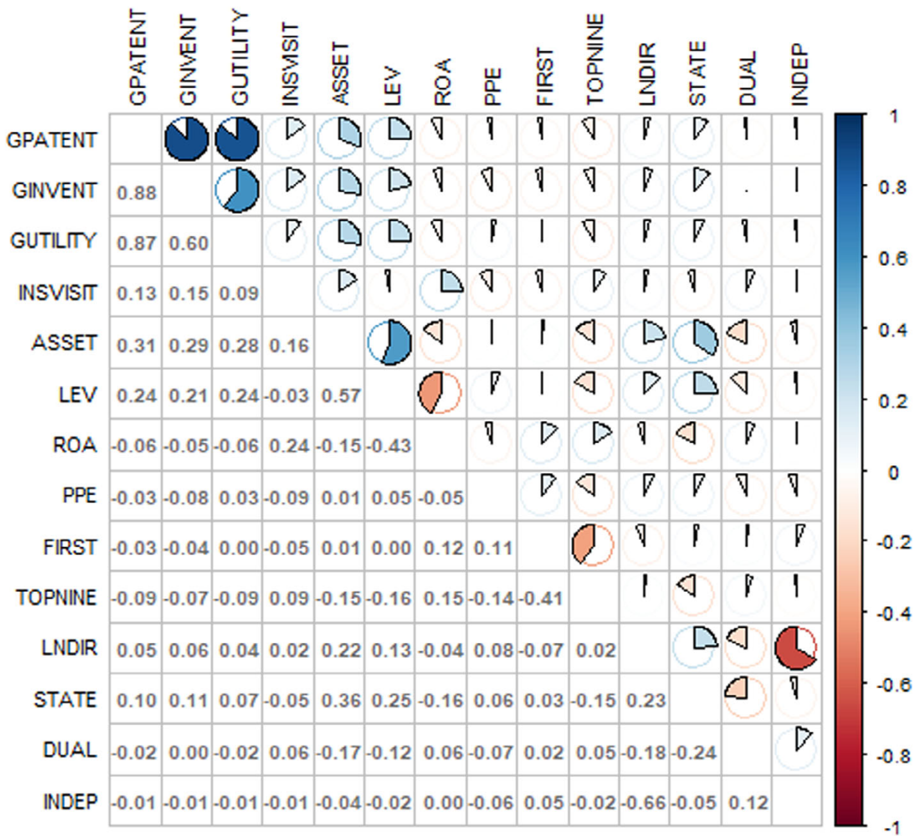

FIGURE 5 Correlation analysis.

Table 4 displays the responses of different categories of institutional investors' SVs to green innovation. RESISINS and SENSINS represent the count of SVs for stress-resilient and stress-sensitive institutional investors, respectively. In columns (1)–(3), the estimations of RESISINS exhibit significant positive values, implying that pressure-resistant institutional investors' SVs substantially contribute to corporate green innovation. Conversely, columns (4)–(6) show no significant effects between SENSINS and green innovation (GPATENT, GINVENT, GUTILITY). Altogether, this study confirms that SVs from stress-resistant institutional investors notably foster green innovation compared to their stress-sensitive counterparts.

Unlike Zhao et al. (2023), which directly scrutinized diverse institutional investors, this study takes a distinct approach by categorizing and analyzing institutional investors based on their investment objectives and attributes. Through this approach, the paper reveals the distinct impact of different institutional investor characteristics on green innovation when implementing SVs.

4.2 | Robustness checks

This section employs rigorous endogeneity treatment procedures and conducts a range of alternative robustness tests to ensure the reliability of the baseline outcomes. Specifically, we employ instrumental and Heckman regressions to tackle endogeneity concerns. Moreover, we leverage diverse estimation strategies and alternative measures to strengthen the robustness of the baseline estimates.

4.2.1 | Endogeneity tests

Endogeneity concerns may arise between institutional investors' SVs and green innovation, posing a potential threat to the integrity of benchmark estimates. Institutional investors may deliberately choose companies that demonstrate distinct profitability, stability, and notable performance in green innovation for on-site investigations, potentially confounding the findings of this study.

Instrumental variable estimation

This study employs the proportion of extreme weather occurrences (WEATHER) in each fiscal year within prefecture-level cities where firms are headquartered as an instrumental variable. First, adverse weather conditions at a corporate location are capable of impacting the feasibility of SVs, given safety concerns and other considerations. Second, the decision-making procedure regarding green innovation is a long-term strategy of corporate governance that remains unaffected by transient weather conditions. Hence, it is theoretically justified to utilize weather data from registered corporate locations as an instrumental variable based on criteria of relevance and exogeneity.

Columns (1)–(3) of Table 5 present the estimates of instrumental variable regressions. We define extreme weather (EXTRM) as a day with either a minimum temperature below -10°C, a maximum temperature above -38°C, or when rainfall exceeds 50 mm. Operationally, EXTRM takes a value of 1 on days with extreme weather and 0 otherwise. The instrumental variable WEATHER is calculated as the proportion of extreme weather events occurring in a calendar year

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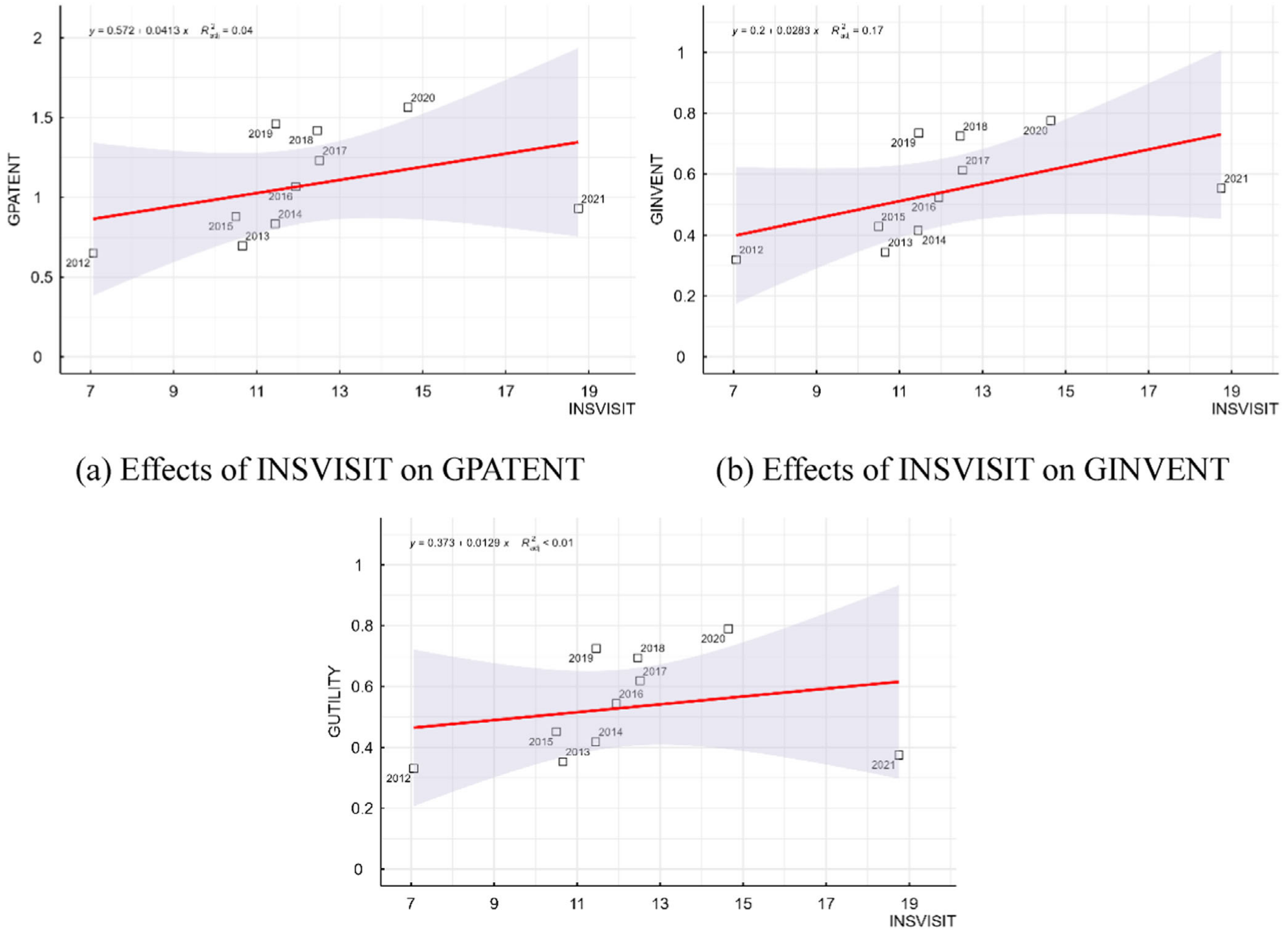

(a) Effects of INSVISIT on GPATENT

(b) Effects of INSVISIT on GINVENT

(c) Effects of INSVISIT on GUTILITY

FIGURE 6 Effects of institutional investors' Site visits (SVs) on green innovation. (a) Effects of INSVISIT on GPATENT. (b) Effects of INSVISIT on GINVENT. (c) Effects of INSVISIT on GUTILITY.

within the municipality where firms are headquartered. In columns (1)–(3), the estimated coefficients of INSVISIT are all significantly positive, indicating that institutional investors' SVs display a favorable reaction to corporate green innovation, even after considering potential endogeneity concerns.

Heckman two-stage estimation

This study generates a dummy variable by computing the mean value of RESISINS and subsequently takes advantage of the Probit strategy to estimate the first phase, with firm size, gearing, nature of ownership, profitability, and firm growth as covariates. The inverse Mills ratio (LAMBA) computed during the initial phase is integrated into equation (1) to facilitate empirical analysis.

Columns (4)–(6) of Table 5 depict the results of Heckman regression analyses. Remarkably, the coefficients of LAMBA are statistically significant and negative, indicating the existence of selection bias across samples. Concurrently, INSVISIT exerts a significant positive impact on green innovation, with a p value <0.01, reaffirming the robustness of our primary conclusion even after mitigating potential sample selection bias.

4.2.2 | Other robustness tests

Alternative model specification

The data concerning corporate green patents is non-negative, implying a constrained explanatory variable. To enhance accuracy in estimation, we exploit the Tobit strategy for analysis. Columns (1)–(3) of Table 6 present the outcomes of the Tobit analyses. The estimates of INSVISIT are notably positive and statistically significant, confirming the robustness of our findings.

Alternative proxies for green innovation

According to Alcácer et al. (2009) and Huang and Li (2019), we measure green innovation by employing the natural logarithm of one plus the count of cited green patents for each fiscal year. Furthermore, we introduce a one-period lag to mitigate potential concerns arising from asynchronous patent citations. Columns (4)–(6) of Table 6 present the results with the number of citations to green patents as the dependent variable of interest. Notably, the coefficients of INSVISIT demonstrate statistically significant positivity, reinforcing the robustness of

TABLE 3 Effects of institutional investors' site visits (SVs) on corporate green innovation.

Variables	(1) GPATENT	(2) GINVENT	(3) GUTILITY	(4) GPATENT	(5) GINVENT	(6) GUTILITY
INSVISIT	0.061***	0.034***	0.027***	0.040***	0.023***	0.018***
	(5.472)	(4.587)	(4.754)	(3.688)	(3.141)	(3.135)
ASSET				0.541***	0.289***	0.252***
				(9.598)	(8.023)	(9.156)
LEV				0.039	−0.063	0.102
				(0.260)	(−0.748)	(1.210)
ROA				−0.348	−0.218	−0.130
				(−1.414)	(−1.434)	(−0.908)
PPE				0.398*	0.260**	0.139
				(1.873)	(2.198)	(1.145)
FIRST				0.394	0.339*	0.055
				(1.339)	(1.912)	(0.334)
TOPNINE				−0.110	0.079	−0.189
				(−0.470)	(0.564)	(−1.476)
LNDIR				0.074	0.122	−0.047
				(0.433)	(1.124)	(−0.506)
STATE				0.019	0.026	−0.007
				(0.270)	(0.588)	(−0.189)
DUAL				0.014	0.032	−0.018
				(0.357)	(1.308)	(−0.792)
INDEP				0.598	0.396	0.202
				(1.298)	(1.429)	(0.793)
CONSTANT	1.046***	0.529***	0.517***	−11.477***	−6.431***	−5.046***
	(73.242)	(55.934)	(70.714)	(−8.693)	(−7.295)	(−8.051)
FIRM FE	Yes	Yes	Yes	Yes	Yes	Yes
YEAR FE	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY×YEAR	Yes	Yes	Yes	Yes	Yes	Yes
PROVINCE×YEAR	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.702	0.660	0.633	0.713	0.670	0.642
N	11,507	11,507	11,507	11,507	11,507	11,507

Note: This table displays the regression outcomes associated with the relationship between institutional investors' SVs and green innovation. Three indicators of green innovation are employed: the natural logarithm of one plus the count of green patents, the natural logarithm of one plus the count of green invention patents, and the natural logarithm of one plus the count of green utility patents. The quantification of institutional investors' SVs is based on the count of visits by investment institutions in each fiscal year. All regressions encompass individual-specific and year-specific fixed effects, along with joint fixed effects. The t-statistics enclosed in parentheses are calculated using standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1.

our conclusions even when employing an alternative measure of green innovation.

Alternative measurement of institutional investors' SVs

Following Jiang and Bai (2022), we leverage the sum of institutional investors actively engaged in SVs for each fiscal year as an explanatory variable (NUMVISIT). The estimation results are presented in Columns (7)–(9) of Table 6. The coefficients of NUMVISIT are statistically significant and positive, indicating the robustness of our empirical results.

Excluding heavily polluting industries' samples

Heavily polluting industries, as primary contributors to pollutants, often experience increasing pressure to embrace green innovation due to the widespread concerns of regulatory authorities regarding environmental degradation. As a result, we re-estimated the sample by excluding observations from heavily polluting industries. Columns (10)–(12) in Table 6 display the estimates. The coefficients of INSVISIT are uniformly and significantly positive, with a p-value <0.01, suggesting that the estimates of benchmark regression are reliable, even when accounting for specific sample characteristics.

TABLE 4 Effects of different types of institutional investors' site visits (SVs) on green innovation.

Variables	(1) GPATENT	(2) GINVENT	(3) GUTILITY	(4) GPATENT	(5) GINVENT	(6) GUTILITY
RESISINS	0.109***	0.060**	0.050**			
	(2.814)	(2.133)	(2.509)			
SENSINS				0.080	0.069	0.011
				(0.693)	(0.806)	(0.199)
CONSTANT	−11.595***	−6.504***	−5.092***	−11.477***	−6.425***	−5.052***
	(−8.804)	(−7.383)	(−8.144)	(−8.696)	(−7.287)	(−8.062)
FIRM FE	Yes	Yes	Yes	Yes	Yes	Yes
YEAR FE	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY×YEAR	Yes	Yes	Yes	Yes	Yes	Yes
PROVINCE×YEAR	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.713	0.670	0.642	0.713	0.670	0.642
N	11,507	11,507	11,507	11,507	11,507	11,507

Note: The *t* statistics in parentheses are based on standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1.

TABLE 5 Endogenous tests.

Variables	(1) GPATENT	(2) GINVENT	(3) GUTILITY	(4) GPATENT	(5) GINVENT	(6) GUTILITY
INSVISIT	0.031**	0.018**	0.013*	0.040***	0.022***	0.017***
	(2.365)	(2.123)	(1.906)	(3.649)	(3.117)	(3.085)
LAMBA				−0.061***	−0.037***	−0.024**
				(−2.952)	(−2.891)	(−2.014)
CONSTANT	–	–	–	−11.221***	−6.277***	−4.944***
	–	–	–	(−8.486)	(−7.091)	(−7.917)
FIRM FE	Yes	Yes	Yes	Yes	Yes	Yes
YEAR FE	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY×YEAR	Yes	Yes	Yes	Yes	Yes	Yes
PROVINCE×YEAR	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.00330	−0.00579	−0.0118	0.714	0.670	0.642
N	11,507	11,507	11,507	11,507	11,507	11,507

Note: The *t* statistics in parentheses are based on standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1.

4.3 | Heterogeneity analyses

4.3.1 | Shareholdings of institutional investors

A substantial body of literature identifies that institutional investors, particularly those maintaining a sizable equity interest, possess the capacity to oversee corporate executives and enhance corporate governance (Basak & Pavlova, 2013; Basse Mama & Mandaroux, 2022; Gompers & Metrick, 2001; Hartzell & Starks, 2003). This is because institutional investors directly or indirectly undertake a supervisory role in the realm of corporate management after reaching a certain threshold of ownership. Gompers and Metrick (2001), along with Krueger et al. (2020), documented that institutional investors with substantial ownership stakes play a pivotal role in improving corporate governance through increased R&D investments and adjustments in capital structure.

To examine how the effects of institutional investors' SVs vary with different levels of shareholdings, this study creates a dummy variable that equals 1 when the shareholding proportion exceeds the mean and 0 otherwise. Table 7 displays the results of the empirical estimation. In columns (1)–(3), the coefficients of SRATIO×INSVISIT are statistically significant and positive, indicating a heightened influence of institutional investors' SVs on green innovation when their shareholdings are more substantial.

TABLE 6 Other robustness tests.

	(1) Tobit strategy	(2)	(3)	(4) Alternative green innovation measurements	(5)	(6)	(7) Re-measuring institutional investors' SVs	(8)	(9)	(10) Excluding specialized industry samples	(11)	(12)
Variables	GPATENT	GINVENT	GUTILITY	GAPATENT	GAINVENT	GAUTILITY	GPATENT	GINVENT	GUTILITY	GPATENT	GINVENT	GUTILITY
INSVISIT	0.055***	0.036***	0.022***	0.030***	0.015**	0.015***				0.035***	0.020***	0.015***
	(7.088)	(7.749)	(4.816)	(2.890)	(2.424)	(2.649)				(3.314)	(2.844)	(2.805)
NUMVISIT							0.060***	0.035**	0.025***			
							(3.139)	(2.541)	(2.734)			
CONSTANT	−8.544***	−4.914***	−3.459***	−12.422***	−7.067***	−5.355***	−11.471***	−6.420***	−5.051***	−11.246***	−6.241***	−5.006***
	(−17.788)	(−17.684)	(−12.975)	(−9.839)	(−8.421)	(−8.972)	(−8.694)	(−7.281)	(−8.064)	(−8.221)	(−6.830)	(−7.733)
FIRM FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YEAR FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY×YEAR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PROVINCE×YEAR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	–	–	–	0.622	0.570	0.549	0.713	0.670	0.642	0.717	0.673	0.648
N	12,051	12,051	12,051	11,507	11,507	11,507	11,507	11,507	11,507	10,810	10,810	10,810

Note: The t statistics in parentheses are based on standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1. Heavily polluting industries are defined by 2-digit Standard Industrial Classification (SIC) codes, ranging from B06, B07, B08, B09, C17, C19, C22, C25, C26, C28, C29, C30, C31, C32 to D44.

TABLE 7 Analysis of institutional investors' shares.

Variables	(1) GPATENT	(2) GINVENT	(3) GUTILITY
INSVISIT	0.028**	0.014*	0.014**
	(2.542)	(1.948)	(2.421)
SRATIO	−0.153*	−0.123**	−0.031
	(−1.960)	(−2.475)	(−0.714)
SRATIO×INSVISIT	0.097***	0.069***	0.029**
	(4.339)	(4.952)	(2.346)
CONSTANT	−11.592***	−6.514***	−5.078***
	(−8.779)	(−7.378)	(−8.105)
FIRM FE	Yes	Yes	Yes
YEAR FE	Yes	Yes	Yes
INDUSTRY×YEAR	Yes	Yes	Yes
PROVINCE×YEAR	Yes	Yes	Yes
Adj. R^2	0.714	0.671	0.642
N	11,507	11,507	11,507

Note: The *t* statistics in parentheses are based on standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1.

TABLE 8 Analysis of institutional investors' reputation.

Variables	(1) GPATENT	(2) GINVENT	(3) GUTILITY
INSVISIT	0.005	0.007	−0.002
	(0.544)	(0.950)	(−0.646)
INSFAME	1.367***	0.313***	1.054***
	(40.145)	(13.072)	(66.572)
INSFAME×INSVISIT	0.051***	0.027**	0.024***
	(3.205)	(2.486)	(3.189)
CONSTANT	−8.461***	−5.705***	−2.757***
	(−7.515)	(−6.735)	(−6.094)
FIRM FE	YES	YES	YES
YEAR FE	YES	YES	YES
INDUSTRY×YEAR	YES	YES	YES
PROVINCE×YEAR	YES	YES	YES
Adj. R^2	0.807	0.688	0.837
N	11,507	11,507	11,507

Note: The *t* statistics in parentheses are based on standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1.

4.3.2 | Reputation of research institutions

In capital markets, reputable institutional investors attract heightened attention and possess a comprehensive understanding of corporate investment strategies (Gong & Liu, 2023; Neupane & Thapa, 2013), facilitating vigilant oversight of corporate governance (Benzion et al., 2018; Bhattacharya & Sardashti, 2022; Hu et al., 2021). Given this context, this study explores how institutional investor reputation influences the relationship between institutional investors' SVs and green innovation. Notably, funds and securities plants constitute a substantial portion of SVs participants. Considering the availability of data, this study leverages the rankings of fund companies and securities plants to assess institutional reputation (INSFAME). Operationally, INSFAME is set to 1 if any institution involved in site visits during each fiscal year ranks among the top 10 companies in funds or securities; otherwise, it is coded as 0. The ranking data for fund and securities plants is sourced from the Bank of China Securities Fund Research Center and the Securities Association of China's website.

Table 8 illustrates the role of reputation mechanisms in mediating the relationship between institutional investors' SVs and green innovation. In columns (1)–(3), the coefficients of INSFAME×INSVISIT are substantially positive, implying that institutional investors with considerable reputations in SVs contribute to corporate green innovation. From a theoretical standpoint, reputable institutional investors enhance corporate environmental disclosure and boost innovation expenditure, thereby fostering corporate green innovation.

This empirical finding resonates with several existing studies to some extent. Zhou and Gan (2022) discovered that well-regarded institutional investors' SVs offer valuable insights into corporate environmental investments and the fulfillment of environmental responsibilities. In a similar fashion, the manner and content of management's responses to inquiries demonstrate direct oversight of management's self-interested actions and the promotion of green innovation (Chemmanur et al., 2009; Zhou & Gan, 2022).

4.3.3 | Corporate information environment

Site visits are an effective form of external surveillance that accesses comprehensive corporate information and exerts external pressure to oversee governance (Cai et al., 2023; Li et al., 2022; Qi et al., 2021), particularly on firms with inadequate information disclosure (Amankwah-Amoah et al., 2023; Han & Yan, 2022; Panicker et al., 2022; Xiao et al., 2023). For this purpose, this study investigates how information disclosure impacts the relationship between institutional investors' SVs and corporate green innovation. To do so, this study assesses the corporate information environment by using the disclosure results of SZSE. In practice, this study introduces a binary variable (ENINF) and categorizes the "excellent" assessment outcome as indicative of a high-quality information environment, assigning ENINF a value of 0. Conversely, the assessment outcomes of "good," "qualified," or "unqualified" reflect lower-quality information environments, and ENINF is assigned a value of 1.

Table 9 reports the responses of the corporate information environment to the correlation between institutional investors' SVs and green innovation. In columns (1)–(3), the estimates of ENINF×INSVISIT are remarkably positive, implying that institutional

TABLE 9 Analysis of corporate information environment.

Variables	(1) GPATENT	(2) GINVENT	(3) GUTILITY
INSVISIT	0.021**	0.011	0.010*
	(2.036)	(1.637)	(1.803)
ENINF	0.093	0.110**	−0.017
	(1.135)	(2.274)	(−0.371)
ENINF×INSVISIT	0.070***	0.042**	0.028**
	(2.903)	(2.419)	(2.124)
CONSTANT	−11.220***	−6.239***	−4.981***
	(−8.626)	(−7.243)	(−7.977)
FIRM FE	Yes	Yes	Yes
YEAR FE	Yes	Yes	Yes
INDUSTRY×YEAR	Yes	Yes	Yes
PROVINCE×YEAR	Yes	Yes	Yes
Adj. R^2	0.714	0.672	0.643
N	11,507	11,507	11,507

Note: The *t* statistics in parentheses are based on standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1.

TABLE 10 Results of threshold estimation.

Variables	(1) GPATENT	(2) GINVENT	(3) GUTILITY
INSVISIT ≤3	0.084*	0.043	0.041
	(1.889)	(1.598)	(1.574)
INSVISIT >3	0.042***	0.025***	0.017***
	(5.055)	(4.973)	(3.504)
CONSTANT	−10.609***	−6.159***	−4.450***
	(−14.668)	(−14.164)	(−10.440)
FIRM FE	Yes	Yes	Yes
YEAR FE	Yes	Yes	Yes
INDUSTRY×YEAR	Yes	Yes	Yes
PROVINCE×YEAR	Yes	Yes	Yes
Adj. R^2	−0.0753	−0.127	−0.122
N	12,051	12,051	12,051

Note: The *t* statistics in parentheses are based on standard errors clustered at the firm level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Variable definitions are provided in Table A1.

investors' SVs tend to facilitate green innovation, particularly in samples with lower-quality information environments.

From the theoretical side, institutional investors' SVs serve as both external monitoring mechanisms for corporate management (Gao et al., 2023) and effective means to alleviate corporate information asymmetry (Zhao et al., 2023; Zhou & Gan, 2022). In the same vein, investors encounter obstacles in uncovering negative information due to limited corporate transparency. Nonetheless, the role of SVs in gathering information contributes to mitigating the risks associated with green innovation.

4.4 | Further analyses

Previous sections have furnished empirical evidence substantiating the favorable reaction of institutional investors' SVs to green innovation. However, uncertainties persist regarding the potential threshold effect of the number of institutional investors' SVs on green innovation. Consequently, this section endeavors to examine this conjecture within the analytical framework introduced by Hansen (1999), employing a threshold econometric model (4).

$$\begin{aligned} GINNO_{pjit} = {} & \alpha + \beta_1 INSTVISIT_{pjit} I\left(INSTVISIT_{pjit} \le \varsigma\right) \\ & + \beta_2 INSTVISIT_{pjit} I\left(INSTVISIT_{pjit} \ge \varsigma\right) + \gamma X_{pjit} + \mu_i \\ & + \gamma_t + \delta_{jt} + \tau_{pt} + \varepsilon_{pjit}. \end{aligned} \tag{4}$$

where $I(\bullet)$ denotes an indicator function and ζ represents a specified threshold value. The remaining parameters are defined in specification (1).

Table 10 indicates the estimated results of the threshold regression. In column (1), the estimates of INSVISIT pass statistical significance tests regardless of the count of SVs, aligning with the previous findings. In columns (2)–(3), the estimates of INSVISIT are significantly positive only when the count of SVs exceeds 3, with p-values <0.01, implying that increasing the count of SVs enhances the quality of green innovation. In a nutshell, institutional investors' SVs have a significant positive impact on green innovation performance, requiring a minimum of three SVs to effectively elevate its quality.

Prior literature commonly includes quadratic terms in models to investigate non-linear relationships. For instance, Zhao et al. (2023) meticulously employ coefficients for quadratic terms to capture the non-linear association between institutional investors' SVs and investment efficiency. Still, reliance on quadratic terms for assessing non-linear relationships triggers inaccuracies in identifying threshold points, thus producing less precise empirical estimates for the sample data. In contrast to preceding studies, this study employs a threshold model to accurately examine the impact of institutional investors' SVs on green innovation, offering evidence of a threshold effect for enhancing green innovation quality.

5 | CONCLUSION AND IMPLICATIONS

Green innovation is widely acknowledged as essential for bolstering core competitiveness and advancing sustainable development within businesses. Nonetheless, it is the protracted timelines, elevated risks, and substantial financial commitments associated with green innovation that frequently dissuade enterprises from active participation. Institutional investors' SVs emerge as a promising avenue to alleviate information asymmetry concerns and upgrade the requisite resources for green innovation. Despite this potential, extant literature has inadequately scrutinized the intricate dynamics between institutional investors' SVs and corporate green innovation. In response, this study employs game theory for analysis and empirically investigates the impact of institutional investors' SVs on corporate green innovation, utilizing a unique dataset documenting institutional investor visits. The findings of this investigation yield substantial theoretical insights and practical implications for stakeholders.

This study reveals that institutional investors' SVs play a crucial role in fostering corporate green innovation, especially among investors resilient to external pressures. Furthermore, greater ownership stakes and esteemed institutional reputations magnify the effects of SVs on green innovation performance. Similarly, the impact of institutional investors' SVs on green innovation performance is particularly notable for firms with inadequate information disclosure. Additional investigation uncovers a threshold effect of institutional investors' SVs on the quality of green innovation. Specifically, when the number of institutional investors' SVs surpasses three within a calendar year, a substantial improvement in the quality of corporate green innovation is observed.

5.1 | Theoretical implications

The possible theoretical contributions of this paper are as follows: First, it integrates institutional investors' SVs and corporate green innovation into an analytical framework, expanding and deepening the study of the economic consequences of institutional investors' behavior. Existing literature on institutional investors' SVs largely focuses on the impact on corporate governance, including compliance management (Guo et al., 2023; Su et al., 2021), investment efficiency (Qi et al., 2021; Zhao et al., 2023), and corporate social responsibility (Liu & Hou, 2023). However, literature on the implications of institutional investors' SVs on corporate green innovation is scarce. This paper explores the impact of institutional investors' SVs on corporate green innovation and offers a comprehensive analysis of heterogeneity from both institutional investors' and plants' perspectives, thereby addressing a gap in the existing literature.

Second, this paper employs a game-theoretic model to examine the relationship between institutional investors' SVs and corporate green innovation, expanding the theoretical literature for analyzing institutional investor behavior. Regarding how institutional investors' SVs play a role in corporate governance, prior studies primarily concentrated on assessing the effects related to the reduction of agency conflicts and the mitigation of information asymmetry, yet lacked empirical evidence through mathematical modeling (Anderson et al., 2007; Broadstock & Chen, 2021; Cai et al., 2023; Cao et al., 2023; Wang & Wang, 2023). In contrast, this paper employs a game-theoretic model to objectively investigate the impact of institutional investors' SVs on green innovation, extending the theoretical framework in the field of institutional investors' behavior.

Third, this paper utilizes a quantitative model to empirically examine the heterogeneous effects of institutional investors' SVs frequency on corporate green innovation and clarifies the threshold value of SVs required for effective supervision. Previous studies consistently explore the linear impact of institutional investors' SVs, such as on equity offering discounts (Li et al., 2022), capital structures (Wang et al., 2022), and investment efficiency (Xiao, 2023; Zhao et al., 2023). However, these studies overlook the limitations of governance. To the best of our knowledge, this study is the first to employ threshold models proposed by Hansen (1999) to pinpoint the precise threshold value for the incentivizing influence of SVs on green innovation, bearing significant implications for subsequent research in this domain.

5.2 | Practical implications

The practical implications of this study for policymakers, institutional investors, and enterprises are multifaceted. First, policymakers should consider the study's findings, which indicate that institutional investors' SVs positively impact corporate green innovation. Thus, enhancing institutional frameworks supporting investor research is recommended to ensure robust oversight mechanisms. More importantly, government authorities should encourage institutional investors to engage in SVs, thus improving green innovation performance. Furthermore, policymakers should prioritize improving information disclosure platforms to address internal and external information asymmetry within firms, ultimately facilitating the provision of essential elements for fostering green innovation.

Second, there is a recommendation for institutional investors to intensify their SVs to leverage their influence in promoting corporate green innovation for long-term investment returns. More specifically, boosting the innovative capacities of listed firms is recognized as a potent driver of market value augmentation. Leveraging their specialized expertise, institutional investors are inclined towards the pursuit of long-term value from companies. Consequently, they should enhance managerial oversight by elevating the frequency of SVs, engaging in collaborative research initiatives, and employing diverse strategies to bolster corporate green innovation.

Third, the study reveals that higher ownership stakes or esteemed institutional reputations of institutional investors enhance the impact of SVs on green innovation. Therefore, companies should strategically invite institutional investors, particularly those with strong reputations, to leverage the positive outcomes of SVs and improve corporate green innovation. Moreover, optimizing the synergistic effects of institutional investors' SVs would promote the rational allocation and effective utilization of green innovation resources, thus strengthening green innovation via robust internal governance mechanisms.

5.3 | Limitations and future research

This study presents two primary limitations. First, owing to the constraints inherent in the mathematical model employed, this paper is unable to discern potential mechanisms for analyzing the impact of institutional investors' SVs on green innovation using a game-theoretic approach. Several studies in this field have employed empirical models to validate underlying mechanisms after theoretical analysis (Jiang & Bai, 2022; Jiang & Yuan, 2018; Liu & Hou, 2023; Wang et al., 2022). Thus, a prospective avenue for future research involves examining how institutional investors effectively promote green innovation in practical contexts.

Second, on account of limitations in available data, this paper does not thoroughly scrutinize the heterogeneous impact of institutional investors' SVs on green innovation in terms of research themes and contents. However, with the advancement of web crawler technology, future research is able to develop a detailed heterogeneity, thereby offering a more profound understanding of the underlying impact mechanism via the comprehensive information gathered through crawler technology.

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APPENDIX A

TABLE A1 Variable definitions.

Variable	Definition
GPATENT	Natural logarithm of the number of green patents applied for each fiscal year plus 1.
GINVENT	Natural logarithm of the number of green invention patents applied for each fiscal year plus 1.
GUTILITY	Natural logarithm of the number of green invention patents applied for each fiscal year plus 1.
INSVISIT	Total number of institutional investors' SVs for each fiscal year.
ASSET	Natural logarithm of total assets.
LEV	Ratio of total debt to total assets.
ROA	Ratio of net profit to total assets.
PPE	Ratio of property, plant, and equipment to total assets.
FIRST	The sum of shares owned by the largest shareholder divided by the total number of shares outstanding.
TOPNINE	The sum of shares owned by the top nine shareholders divided by the total number of shares outstanding.
LNDIR	Natural logarithm of board size.
STATE	An indicator variable taking a value of 1 for state-owned enterprises, otherwise 0.
DUAL	A dummy variable equal to one when the CEO also chairs the board, and zero otherwise.
INDEP	The percentage of independent directors on the board.