

Hierarchy in green: Subordinate executives and eco-innovation dynamics

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ABSTRACT

Internal governance is the process through which subordinate executives, driven by their longer decision horizons and focus on long-term value, counteract the CEO's short-term self-interests to influence corporate decisions. We examine whether and how internal governance affects eco-innovation, which delivers long-term value at the expense of initial investment outlays. We find that more effective internal governance motivates eco-innovation and that this effect operates through two channels. First, subordinate executives' bottom-up influence on the CEO prompts them to increase their long-term awareness to exercise this influence and motivate eco-innovation. Second, more effective internal governance enhances the top management team's ecological awareness to motivate eco-innovation. We further reveal that subordinate-driven internal governance plays a more significant role when CEOs are more opportunistic. Last, we find that more effective internal governance improves eco-innovation quality, highlighting that subordinates play an important role in both the quantity and quality of firms' eco-innovation.

"Great things in business are never done by one person. They are done by a team of people."

Steve Jobs (The co-founder of Apple Inc.)

1. Introduction

The increasing importance of addressing environmental challenges has prompted a demand for eco-innovation (Marquis et al., 2015). Eco-innovation promotes the creation of a product, service, or process that is novel and that delivers value while decreasing environmental impact (Fliaster and Kolloch, 2017; Favot et al., 2023). Eco-innovation incurs significant initial investment costs (Dangelico and Pujari, 2010) and takes an extended period to reap financial returns (Zhang et al., 2019). Zaman et al. (2021) find that eco-innovative firms exhibit lower long-run stock price crash risk. As stakeholders shape favourable perceptions around corporate environmental accountability, environmental benefits accompanying eco-innovation subsequently improve financial outcomes (Choi and Luo, 2021; Gull et al., 2023).

Manso (2011) suggests that firms need to provide tolerance for short-term and reward long-term success to motivate eco-innovation. Considering managerial horizons is vital for environmental

accountability (Haque, 2017; Bui et al., 2020). Over the last two decades, there has been a notable decline in the tolerance of CEOs for short-term failures, accompanied by an increase in CEO myopia and opportunism (Breton-Miller and Miller, 2006). Specifically, CEOs may be discouraged from eco-innovation investments because of their adverse effects on short-term performance-based compensation (Barker and Mueller, 2002). Further, as CEOs are typically seen as the ultimate decision-makers and leaders of the firm, they are often held more accountable for short-term failure (Kraines, 2011).

It is thus imperative to explore mechanisms that address CEO opportunism. Prior studies document various firm-level mechanisms such as board monitoring (Balsmeier et al., 2017), incentive schemes (Manso, 2011), and institutional ownership (Aghion et al., 2013). However, subordinate executives may also influence the CEO to protect long-term firm value. This is because they may receive greater rewards from long-term firm value increases than CEOs and are subject to greater losses if a firm underperforms in the long term. Specifically, subordinate executives are subject to internal promotions and candidates for future CEO positions (Acharya et al., 2011). With more remaining years in their career, they are subject to a greater risk of future financial loss than CEOs (Cheng et al., 2016). Consequently, subordinate executives possess longer decision-making horizons, which incentivizes them to influence

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the CEO (Fama, 1980).

In addition to incentives, subordinates contribute to firm performance and thus CEO wellness, which provides them with an influential ability (Cheng et al., 2016). Under stakeholder salience theory, a higher level of contribution reflects a greater ability to influence, as it is more likely that their preferences will be responded to (Qian et al., 2023). This dependent relationship, paired with opposing decision horizons, enables power distribution and facilitates internal governance. Thus, internal governance refers to the process through which subordinate executives, driven by their longer decision horizons and focus on long-term value, counteract the CEO's short-term self-interests to influence corporate decisions (Acharya et al., 2011; Cheng et al., 2016).

From an opposing viewpoint, subordinate executives may exhibit short-term preferences comparable to those of CEOs. They may have the same short-term performance-based compensation package and neglect monitoring the CEO to avoid losing their job or compensation (Cheng et al., 2016). They may also face external competition for future CEO positions and choose to ingratiate themselves with the CEO to sway succession selection (Acharya et al., 2011). Moreover, subordinates may resist eco-innovation due to the potential jeopardy it poses to their career prospects in the event of investment failure (Holmstrom, 1999). Therefore, whether and how internal governance influences eco-innovation remains an empirical question.

Our study is related to Xie et al. (2021) and Gao et al. (2023), which focus on the impact of internal governance on innovation. Focusing on a sample of Chinese firms, Xie et al. (2021) find that internal governance motivates R&D investment but not innovation outcomes. They find that effective internal governance improves firms' response to investment opportunities, and that subordinates' innovative knowledge, rather than their incentives to monitor the CEO, enhances innovation outcomes. Gao et al. (2023) use a sample of US-listed firms and focus on subordinates' monitoring incentives based on their longer horizons. They find that subordinates' monitoring incentives spur innovation and enhance its scientific and economic value.

Xie et al. (2021) and Gao et al. (2023) report differing results, likely due to their focus on distinct institutional settings.¹ Xie et al. (2021) suggest that while CEOs may not feel compelled by subordinates' monitoring, they rely on subordinates' domain knowledge to navigate technological and market environments. They imply that a high power distance in China (Hofstede, 2001) leads to subordinates' limited influence on the CEO. In contrast, Gao et al. (2023)'s findings suggest that subordinates possess a cultural license to effectively pressure and monitor the CEO in the US due to its low power distance institutional nature.

Motivated by the differential findings, we utilize a sample of Chinese-listed firms to examine the impact of internal governance on eco-innovation. We uncover whether and how subordinate-driven internal governance affects long-term investment and risk-taking in a high power distance environment, thus differing from Gao et al. (2023). We

¹ Since Xie et al. (2021) use a sample of Chinese firms listed on the Small-and-Medium-Sized Enterprise (SME) and Growth Enterprise Market (GEM) boards, and Gao et al. (2023) use a sample of sizable S&P1500 US-listed firms, one reason for their differential findings is their focus on distinct sizes of firms. Younger subordinates' knowledge and resources, rather than their influence over the CEO, play a greater role in smaller firms' innovation decisions (Xie et al., 2021). This is because smaller firms lack the slack resources (e.g., social networks and tacit knowledge) of sizable firms and thus rely more heavily on technical expertise. In more resourceful, larger firms, on the other hand, subordinates require influence to overcome bureaucracy and sway the CEO regarding innovation decisions. In such cases, their incentives and ability to influence (i.e., internal governance), in addition to their knowledge, become crucial for innovation. This notion is supported by Gao et al. (2023)'s finding that internal governance spurs innovation only in larger firms and Xie et al. (2021)'s finding that internal governance motivates R&D investment more for complex firms.

extend both studies by uncovering the channels through which subordinates' influence takes place – namely, through improvements in their long-term awareness and the management's overall ecological awareness.² Importantly, our study differs from both Xie et al. (2021) and Gao et al. (2023) by focusing on eco-innovation rather than innovation.

Eco-innovation is distinct from traditional innovation in two important ways. First, the knowledge recombination process associated with eco-innovation exhibits greater complexity and novelty than non-eco counterparts. Eco-innovation development entails integrating a higher number of technological components and requires a unique combination of knowledge bases due to its environmental focus (Barbieri et al., 2020). As such, eco-innovation necessitates the external sourcing of information (Ghisetti et al., 2015), as the associated complexity tends to surpass a firm's existing knowledge bases (Walley and Whitehead, 1994). In contrast, traditional innovation responsibilities generally lie in the internal R&D departments. Subordinates' innovation knowledge, rather than their influence over the CEO, is more crucial for innovation than for eco-innovation (Xie et al., 2021). Building on this, we conjecture that subordinates' influence is more prominent for eco-innovation because its complexity demands external knowledge and competencies (Barbieri et al., 2020). That is, subordinates play an important role in supporting management's decisions on the sourcing of eco-innovation knowledge, and their role in providing such knowledge themselves attenuates.

Second, the added complexity of eco-innovation makes it costlier. It is also subject to a higher level of uncertainty and risk, as the associated returns are often not immediate, are intangible, and are linked to long-term objectives (Balachandra and Brockhoff, 1995). Traditional innovation is comparatively more direct, profitable, and specific (Ketata et al., 2015). Accordingly, we conjecture that subordinates' bottom-up influence, driven by their longer horizons, plays a greater role for eco-innovation than for innovation. This is because the focus of eco-innovation on long-term value over short-term performance is more salient than that of traditional innovation.

China's regulatory advances in addressing environmental pollution (Cheng et al., 2020), coupled with its unique high power distance institutional culture, makes it an important empirical setting.³ Using a sample of all Chinese listed firms from 2010 to 2020, we find that internal governance motivates eco-innovation. This emphasizes that subordinate executives' bottom-up influence on the CEO critically influences long-term firm value in China. We conduct a suite of endogeneity checks, including the use of an alternative and lagged measure of internal governance, alternative measures of eco-innovation, a two-stage least squares (2SLS) approach, and the omitted variable tests of Oster (2019), propensity score matching, alternative model specifications, and the elimination of an interference factor. Across these tests, our results remain consistent.

In channel analysis, we first find that subordinates' greater incentives and ability to influence the CEO lead to an improvement in their long-term awareness to exercise this influence and motivate eco-innovation. Second, subordinates' bottom-up influence enhances the top management team's ecological awareness to motivate eco-innovation. We also reveal that internal governance motivates eco-innovation to a greater extent when a CEO is more opportunistic, suggesting that subordinates play a greater role in long-term firm value

² Xie et al. (2021) find that more effective internal governance improves firms' response to investment opportunities to increase R&D investment. Gao et al. (2023)'s additional tests suggest that more effective internal governance supplements weaker external governance (i.e., improves overall governance) to motivate innovation.

³ For example, *Made in China 2025* issued by the State Council in 2015 is a strategic policy that sets forth distinct requirements for eco-innovation in areas including energy use, production processes, and product life-cycle (Xu, 2022).

when CEO short-termism is heightened.

Additionally, internal governance motivates eco-innovation to a greater extent when firms face a higher level of Confucianism, indicating that bottom-up governance by subordinates is affected by local cultural factors within China. Internal governance also motivates eco-innovation to a greater extent when a firm receives greater external analyst attention. Analysts share vital information about eco-innovation projects and support the pricing of their values within capital markets, thereby strengthening subordinates' influence on the CEO towards eco-innovation. Consistent with the notion that subordinate executives support long-term value, we find that more effective internal governance enhances eco-innovation quality in addition to quantity.

We contribute to the literature in two ways. First, recently, researchers have examined eco-innovation drivers, given their pivotal role in sustainable economic development (Xie et al., 2015; Huang and Li, 2017). Previous studies examine top-down and external corporate governance influence on eco-innovation (Amore and Bennesen, 2016; Asni and Agustia, 2022), and several studies document the impact of CEO attributes (Arena et al., 2018; Chen et al., 2021; Zhou et al., 2021). However, subordinate executives' bottom-up influence forms an important internal governance mechanism that supports long-term firm value. Wang et al. (2022b) and Liu (2022) shed light on how the top management team attributes affect eco-innovation. Yet, dynamic power structures within top management teams have been overlooked. Therefore, we provide a clearer picture of subordinates' incentives to exert influence on the CEO and motivate firms' eco-innovation.

Second, the studies examining subordinates' influence on the CEO focus on financial outcomes, including real earnings management (Cheng et al., 2016), financial policies (Mekhaimer et al., 2022; Brick et al., 2024), financial performance (Landier et al., 2013; Jain et al., 2016), future firm value (Li, 2014), traditional innovation (Xie et al., 2021; Gao et al., 2023), and corporate fraud (Choi et al., 2021). Chen et al. (2024b) use a sample of US firms to show that more effective internal governance leads to better CSR performance. Although CSR involves balancing present and future firm value, eco-innovation fundamentally drives long-run systemic change and requires even more substantial upfront investment outlays. Our findings are crucial, as eco-innovation facilitates the diffusion of environmental technologies across industries and generates positive spillover effects. Importantly, the focus on eco-innovation extends the prior focus on calculable financial gains. We highlight the important role of subordinate-driven governance to safeguard the development of corporate environmental initiatives. This extends prior internal governance studies' focus on anti-takeover provisions and board characteristics (e.g., Becker-Blease, 2011; Driver and Guedes, 2012; Sapra et al., 2014; Lu and Wang, 2018). We also supplement the managerial myopia literature (He and Tian, 2013; Brochet et al., 2015; Liu and Zhang, 2023) by highlighting that subordinates' bottom-up monitoring addresses managerial myopia to support environmental outcomes.

2. Theoretical grounding and hypotheses development

2.1. Main hypothesis

Previous studies document that eco-innovation contributes to long-term financial growth, albeit at the expense of short-term investment costs (Dangelico and Pujari, 2010; Rezende et al., 2019; Zhang et al., 2019). Notably, significant barriers to eco-innovation include costly research and development expenses (Rubashkina et al., 2015) and the lack of risk-taking among top management teams (Aguilera-Caracuel and Ortiz-De-Mandojana, 2013). The literature documents the role of top-down and external corporate governance in motivating eco-innovation (Amore and Bennesen, 2016; Asni and Agustia, 2022), and another strand of literature focuses on the influence of CEO characteristics (Arena et al., 2018; Ren et al., 2021; Zhou et al., 2021). Further, prior internal governance studies on long-term investments

focus on anti-takeover provisions and board characteristics (Driver and Guedes, 2012; Lu and Wang, 2018). The effect of team power distribution and subordinate executives' influence on long-term value-driven investments remains unexplored. The upper echelons theory asserts that it is important to consider subordinate executives because all executives influence corporate decisions as a team (Hambrick and Mason, 1984), and subordinates and CEOs influence each other (Fama, 1980).⁴ We build on the managerial horizon literature and the internal governance literature to understand the effect of subordinate-driven internal governance on eco-innovation.

According to the managerial myopia theory rooted in the upper echelons, managers with short horizons prioritize short-term gains at the expense of long-term value (Stein, 1989). CEOs typically have fewer years left with their current firm and in their careers (Cheng et al., 2016) and thus have shorter decision horizons. They may consider a shorter time frame of potential returns when evaluating investment choices (Mekhaimer et al., 2022), thus preferring investment alternatives with more structured and faster returns over eco-innovation. Due to their short-term focus, CEOs may also be less inclined to invest in eco-innovation due to its adverse impacts on short-term compensation and performance assessments (Antia et al., 2010). Consistent with CEOs possessing a short-term focus, prior studies observe that CEOs tend to be older than subordinate executives (Cheng et al., 2016; Mekhaimer et al., 2022; Gao et al., 2023). Hambrick and Mason (1984) highlights that older managers invest more conservatively as they value financial and career security to a greater extent. Older managers may have more difficulty adapting to new ideas and may possess lower physical and mental stamina (Hambrick and Mason, 1984). Further, as CEOs have established expectations of retirement income, they lack incentives to take additional risks to invest in eco-innovation (Child, 1974; Taylor, 1975). In support of these arguments, Khan et al. (2020) provide evidence that established CEOs focus less on corporate environmental performance. Taken together, CEOs typically exhibit shorter horizons, possess a tendency towards risk aversion, and are thus unmotivated to drive eco-innovation in firms.

Subordinate executives have both the incentive and capability to challenge the CEO's viewpoint and drive eco-innovation. Subordinates tend to focus on long-term firm value because they are potential successors for the future CEO role. Most CEOs are sourced from internal promotion (Cremers and Grinstein, 2014). Failing to engage in eco-innovation may lead to an inability to meet rising stakeholder expectations about environmental sustainability and result in significant future underperformance. In this case, subordinates are exposed to a greater risk of future financial loss than CEOs (Cheng et al., 2016). Prendergast and Stole (1996)'s managerial signalling model predicts that subordinate executives lean towards bold investments and thus counter the CEO's risk aversion due to their desire to signal superior capabilities and enhance career prospects. Given that subordinates are typically younger (Mekhaimer et al., 2022; Gao et al., 2023) and have more remaining years in their career (Cheng et al., 2016), the potential loss of income associated with their incumbent role and future career pathways is more reliant on future firm performance. As such, they are more long-term oriented and thus possess a higher-risk, higher-reward investment stance. This reliance on future firm performance motivates subordinates to monitor the CEO's investment decisions, which ultimately influence subordinates' prospective compensation (Acharya et al., 2011). Taken together, subordinates possess longer horizons than CEOs, tend to prioritize long-term firm value, and thus possess incentives to motivate eco-innovation.

Subordinates also possess an influential ability to reflect their longer horizons in a firm's investment decisions. This is because a CEO is driven

⁴ According to Graham et al. (2015), a mere 15% of surveyed CEOs and CFOs reported that the CEO alone is responsible for making capital allocation and investment decisions in their firms.

to consider subordinates' long-term preferences due to their contributions to firm performance, which also affects CEO welfare and personal benefits in the short-term (Acharya et al., 2011). This reliance on subordinates' contribution, paired with opposing horizons, distributes decision-making authority and comprises internal governance (Cheng et al., 2016).

Our discussion implies that the subordinates of a CEO drive long-term value creation. Based on this notion, past studies observe the importance of subordinates' influence on accounting outcomes (Cheng et al., 2016), future firm value (Li, 2014), financial policies and performance (Landier et al., 2013; Jain et al., 2016; Mekhaimeer et al., 2022; Brick et al., 2024), traditional innovation (Xie et al., 2021; Gao et al., 2023), and corporate fraud reduction (Choi et al., 2021). Apart from financial perspectives, subordinates also influence the CSR of firms, which entails a trade-off between short-term and longer-term value (Chen et al., 2024b). Eco-innovation differs from innovation due to its greater reliance on external knowledge and its more pronounced trade-off between initial outlays and long-term value (Ketata et al., 2015; Barbieri et al., 2020). This trade-off is also more significant than that of general CSR strategies and investments. Therefore, we posit that subordinate-driven internal governance is crucial for firms' eco-innovation. Our first hypothesis follows:

Hypothesis 1. *The effectiveness of internal governance is positively associated with a firm's eco-innovation level.*

2.2. Additional hypotheses

2.2.1. Subordinate executives' long-term awareness: A channel

The organizational ambidexterity framework (O'Reilly and Tushman, 2011) asserts that firms must simultaneously manage exploratory and exploitative activities to survive in the long term. Exploration involves experimenting with new ideas, while exploitation involves improving productivity and efficiency (Turner et al., 2013). The balancing of exploration and exploitation is referred to as ambidexterity (Birkinshaw and Gibson, 2004). Subordinates with stronger incentives to influence and a greater influential ability will strive to increase their long-term awareness to enhance ambidexterity and transform their long-term preferences into reality. Long-term awareness is the capacity to anticipate, understand, and respond strategically to future changes affecting the firm or its environment (Slawinski and Bansal, 2015). It involves the ability to balance short-term gains with long-term consequences (Hahn et al., 2015), and consider how today's decisions shape future firm outcomes under shifting stakeholder expectations (Rohrbeck and Kum, 2018).

Subordinates' cognition and foresight form a dynamic capability that guides resource allocation towards ambidexterity (Augier and Teece, 2009). Under the social-cognitive theory, executives' beliefs in their influential ability affect their efficacy (Knight et al., 2001). A greater influential ability increases subordinates' desire for long-term awareness to implement their long-term oriented decisions. Meanwhile, a greater incentive to influence the CEO motivates subordinates' learning and use of capabilities to influence firm performance (Locke and Latham, 1990).

Further, subordinates' incentives to influence are driven by career advancement prospects (Acharya et al., 2011), which are affected by their capabilities. The challenges associated with long-term value creation expose the deficiencies in their current capabilities (Bagdadli and Gianecchini, 2019). These executives, who desire to protect long-term value and advance their careers, thus seek to improve their long-term awareness (Claussen et al., 2014; Datta and Iskandar-Datta, 2014).

Long-term awareness plays a pivotal role in eco-technologies (Orsatti et al., 2020). By cultivating stronger long-term awareness, subordinates are better able to identify eco-innovation opportunities and enable firms to respond more effectively to dynamic environments (Wally and Baum, 1994; Nadkarni and Chen, 2014). Subordinates with heightened long-term awareness can also more efficiently coordinate internal and

external resources to improve ambidexterity and support eco-innovation (Zhao et al., 2022). This includes retaining talented employees to stimulate eco-innovation vitality and building the knowledge bases of eco-technologies (Berson et al., 2008; Kaplan and Tripsas, 2008). Therefore, our second hypothesis is:

Hypothesis 2. *The effectiveness of internal governance is positively associated with eco-innovation through enhanced subordinates' long-term awareness.*

2.2.2. Top management team's ecological awareness: A channel

Subordinates' longer horizons and bottom-up influence can affect the collective cognition of the top management team to influence eco-innovation decisions. Under the upper echelons theory, top management team members' values, cognition, and perceptions influence a firm's investment strategies and outcomes (Hambrick and Mason, 1984). Framing theory (Goffman, 1974) also suggests that managers' cognitive framing of environmental issues decides whether eco-innovation is seen as a cost, compliance burden, or a strategic opportunity. Ecological awareness refers to the extent to which managers recognize, interpret, and prioritize environmental issues in decision-making (Gadenne et al., 2009). The top management team's ecological awareness acts as a cognitive filter, shaping investment decisions relating to eco-innovation. Subordinate executives with longer horizons can broaden the team's ecological awareness and reframe eco-innovation as a strategic investment rather than a cost.

By enhancing the ecological awareness of top management teams, subordinates counter CEO myopia (i.e., shorter horizons) to drive eco-innovation outcomes. Liu and Zhang (2023) find that more myopic managers reduce firms' ESG disclosures due to their long-term focus on value creation, and prior research observes that less myopic managers are inclined towards environmental policies (Glossner, 2019; Krueger et al., 2020). This implies that subordinates' longer horizons foster ecological awareness for environmental outcomes. Apart from reframing eco-innovation, ecological awareness forms a dynamic capability that supports the sensing and seizing of eco-innovation risks and opportunities under the dynamic capabilities theory (Teece et al., 1997). In support of this discussion, prior studies highlight top management support and commitment as drivers of eco-innovation (Liu et al., 2012; Zhang et al., 2015). Importantly, ecological awareness interprets emerging regulations and identifies opportunities to eco-innovate and achieve long-term value (Wang et al., 2022a). Our third hypothesis is:

Hypothesis 3. *The effectiveness of internal governance is positively associated with eco-innovation through enhanced ecological awareness among the top management team.*

2.2.3. CEO opportunism

We hypothesize that when a CEO places a greater emphasis on short-term performance, subordinate executives' bottom-up monitoring plays a greater role in motivating green innovation. CEO incentive compensation can reflect managerial power and rent-seeking behaviours rather than serve as efficient incentives to address the principal-agent conflict (Almadi and Lazic, 2016). Cheng and Warfield (2005) find that the sensitivity of executive incentives to stock price fluctuations drives earnings management, implying that CEO opportunism is closely linked to stock price (Anderson and Bizjak, 2003; Bergstresser and Philippon, 2006). Since investments in eco-innovation may negatively impact the firm's share price in the short term, higher CEO shareholdings can amplify the CEO's tendency towards opportunistic behaviours, which focus on short-term self-serving interests.

Further, CEOs with large share ownership typically have less diversified investment portfolios than retail and institutional investors (Chung et al., 2002), thus making them less tolerant of risks associated with green innovation. Dominant shareholding CEOs exposed to a significant level of cash flow rights (i.e., private benefits) may also lead to their conservative corporate investment behavior, to the extent of

passing up value-enhancing risky green innovation projects (John et al., 2008). With the recent reduction in CEO tenure (Breton-Miller and Miller, 2006), CEOs with large shareholdings may choose to forego eco-innovation to preserve job security (Fudenberg and Tirole, 1995). As such, a higher level of CEO shareholding reflects greater CEO opportunism, whereby the role of subordinates' monitoring in motivating green innovation may become more pronounced.

Hypothesis 4. *The positive influence of internal governance on eco-innovation is enhanced when CEO shareholdings are higher.*

3. Research design

3.1. Sample

We include all Chinese listed firms from 2010 to 2020, as 2010 is the year the International Patent Classification (IPC) Green Inventory was launched. The IPC Green Inventory provides information on patents relating to Environmentally Sound Technologies (ESTs). We use data from the CSMAR for firm-level, executive-level, and CEO-level variables. In ensuring the internal governance measure captures decision-making influence, we only include observations where the CEO and subordinate executives remained in their positions for at least six months of a given year. Innovation data is from the Chinese National Intellectual Property Administration (CNIPA). Following prior literature (e.g., Wang et al., 2021; Cao et al., 2025), we exclude financial enterprises, ST, ST* and PT firms, and firms with missing values for key variables. We winsorize all continuous variables at the 1st and 99th percentiles. Our final sample consists of 10,545 firm-year observations.

3.2. Measure of internal governance

Following Cheng et al. (2016), we measure internal governance by assessing the incentives and ability of key subordinate executives to influence the CEO. Key subordinate executives are defined as the top five highest-paid subordinate executives who are most likely to possess influential incentives and abilities. Most subordinates hold CFO, COO, vice CEO, and board secretary positions.⁵ We proxy the decision-making horizons of subordinates using the number of years until the assumed retirement age of 60, which serves as the foundation of their incentives to influence the CEO (Antia et al., 2010). Our measure is detailed as follows:

$$Exec_Horizon = 60 - \text{the average age of top five subordinate executives} \quad (1)$$

Under competitive labour market conditions, the compensation of an executive reflects his or her contribution to and thus the influence on the firm's decision-making (Finkelstein, 1992). We measure subordinates' influential ability using the ratio of the top five subordinates' average annual compensation to the CEO's annual compensation (Cheng et al., 2016).

$$Exec_PayRatio = \frac{\text{Average annual compensation of top five subordinates}}{\text{CEO annual compensation}} \quad (2)$$

The final measure of internal governance (*Int_Gov*) is an aggregate of the standardised values of *Exec_Horizon* and *Exec_PayRatio*. As robustness checks, we use the differential horizons between the CEO and his or her subordinates (*Diff_Horizon*) and a one-year lagged measure of *Int_Gov* in Section 5.1.

⁵ Lu et al. (2023) highlight that, in practice, board secretaries are accountable for investment and financing decisions in Chinese firms.

3.3. Measure of eco-innovation

We measure eco-innovation using two approaches (Huang et al., 2021; Quan et al., 2021). First, we use the number of green patent applications that are eventually granted in the future. A patent is classified as green if (1) its patent code aligns with one of the IPC Green Inventory codes or (2) its title includes at least one of the 25 keywords listed in Appendix B.⁶ Second, we use the number of green invention patent applications that are eventually granted in the future. The CNIPA categorizes each patent as an "Invention Patent", "Utility Model", or "Appearance Design". We focus on the number of green "Invention Patents" as their development typically involves additional complexities.

The use of the number of green patents as a proxy for eco-innovation provides several advantages. First, they are an established measure of output of the inventive process in the literature, as economically significant inventions are patented in most cases (Fabrizi et al., 2018; Chatti et al., 2024). Green innovation and eco-innovation share the intent to reduce environmental harm and involve the development or application of new technologies, processes, or products with environmental benefits (Ratten, 2022). Second, green patents are available for panel analysis at the firm level and are subject to fewer sample selection concerns (Favot et al., 2023). Therefore, it is intuitive to use green patents to reflect firm-level eco-innovation.

Nonetheless, there remain concerns surrounding the misclassification and undermeasurement of eco-innovation using green patents. Eco-innovations may involve behavioural shifts that don't result in patentable inventions (Popp, 2006). Some green patents also address end-of-pipe solutions, which emphasize reactive rather than preventive or systemic changes underpinning eco-innovation (Durán-Romero and Urraca-Ruiz, 2015). To address these concerns, we utilize alternative measures of eco-innovation based on two indexes of eco-development efficiency and an indicator of whether the firm obtains environmental management certification in Section 5.2.

3.4. Empirical model

Our empirical model is as follows:

$$EcoInnovation_{it} = \beta_0 + \beta_1 Int_Gov_{it} + \beta_2 FirmLevelControls_{it} + \beta_3 CEOLevelControls_{it} + \varepsilon_{it} \quad (3)$$

EcoInnovation is the natural-log-transformed number of green patents (*Green_Patent*) or green invention patents (*Green_InvPatent*). *Int_Gov* is internal governance as measured by the aggregate of the standardised values of *Exec_Horizon* and *Exec_PayRatio*. We predict that internal governance can increase corporate eco-innovation. Thus, we expect β_1 to be positive and significant. We present the conceptual framework of our hypotheses in Fig. D.1 (Appendix D).

3.4.1. Control variables, fixed effects, and robust statistics

Following prior studies (Hirshleifer et al., 2012; Hsu et al., 2014; Linnenluecke et al., 2017; Xie et al., 2021), we incorporate firm-level control variables. We control for firm age (*Firm_Age*), firm size (*Firm_Size*), annual firm growth (*Firm_Growth*), return-on-assets (ROA), leverage (*Leverage*), and staff intensity (*Staff_Intensity*). Further, we control other corporate governance mechanisms, including board size (*B_Size*), board independence (*B_Ind*), and the percentage of institutional shareholding (*Inst_Own*). Large shareholders may influence the monitoring of firms in China (Jiang and Kim, 2015), and powerful

⁶ We find that some green patents do not have the IPC numbers on the IPC Green Inventory List. Therefore, we follow Quan et al. (2021) and use textual analysis to further identify green patents. Our results remain consistent if we only utilize the IPC Green Inventory list as a screening criterion.

shareholders may drive executives' attitudes towards eco-innovation. Thus, we control shareholding by the largest shareholder (*Largest_SH*).

As CEO characteristics affect corporate governance and environmental performance, we control for the CEO's gender (*CEO_Gender*) (Glass et al., 2016), education level (*CEO_Edu*) (Rivera and Leon, 2005; Zhou et al., 2021), and foreign work or study experience (*CEO_ForeignExp*) (Shahab et al., 2020). CEO's decision horizons may affect eco-innovation, thus we control CEO incentives using the age of the CEO (*CEO_Age*). A CEO nearing retirement is likely to be more incentivised to focus on short-term performance (Jain et al., 2016). Detailed variable definitions are presented in Appendix A.

We include year and industry-fixed effects to control for year-specific influences and time-invariant characteristics at the industry level. Industry fixed effects allow us to control for industry-level traits while exploiting cross-sectional variation across firms. As changes in internal governance may be sticky within some firms, using firm-fixed effects may absorb firm-level heterogeneity and weaken the explanatory power of our key variables. We calculate Huber–White robust standard errors to address potential heteroscedasticity and autocorrelation.

3.5. Descriptive statistics

CEOs have an average age of 49.78, which is 3.1 years above the mean of the average key subordinate executives' age of 46.68. This supports the argument that key subordinates operate with longer decision-making horizons compared to the CEO. Table D.1 reports the descriptive statistics. The average absolute (the natural log) number of green patent applications is 2.16 (0.77), and that of green invention patent applications is 1.74 (0.55). The mean (median) key subordinates' decision-making horizon (*Exec_Horizon*) is 13.32 (13.20). The mean (median) annual compensation of the key subordinates relative to the CEO's (*Exec_PayRatio*) is -0.05 (-0.17). By construction, *Int_Gov* has a near-zero mean. Our sample firms have an absolute (logged) age (*Firm_Age*) of 16.68 (2.81) years. The mean (median) annual compensation of the firm size (*Firm_Size*) is 21.89 (21.72). On average, 37% of board members are independent (*B_Ind*). 93% of CEOs in our sample are males (*CEO_Gender*). CEOs, on average, have undergraduate degrees, while the median education level of CEOs is at the master's level (*CEO_Edu*). 8% of CEOs obtained both foreign education and work experience (*CEO_ForeignExp*), and 92% of CEOs have yet to work or study overseas.

4. Results

4.1. Baseline analysis – Tests of Hypothesis 1

Hypothesis 1 predicts that more effective internal governance motivates eco-innovation. Table D.2 presents the baseline findings. As expected, we find that effective internal governance positively affects both measures of eco-innovation (Panel 1, t -statistic = 5.79, $p < 0.01$; Panel 2, t -statistic = 6.94, $p < 0.01$).⁷ These effects are economically significant, with a one standard deviation increase in *Int_Gov* associated with an average increase of 6.11% in eco-innovation (6.16% using *Green_Patent* and 6.05% using *Green_InvPatent*).⁸

4.2. Subordinate executives' long-term awareness – Test of Hypothesis 2

Hypothesis 2 predicts that more effective internal governance enhances subordinate executives' long-term awareness to boost eco-innovation. Education reflects competencies in simultaneously

managing exploratory and exploitative activities (Wally and Baum, 1994; Jiang and Murphy, 2007; He et al., 2021). We use the level of educational qualifications to proxy for subordinates' long-term awareness (*LTA*) based on the proportion of key subordinate executives with either a Master's or a PhD degree. To examine the mechanism effect, we consider the change in subordinates' long-term awareness from period t to $t + 1$ and the eco-innovation's one-year lead value ($t + 1$). We segregate our sample based on the industry-year median of the change in long-term awareness. Table D.3 presents the results. Consistent with **Hypothesis 2**, internal governance positively affects eco-innovation through enhanced subordinate executives' long-term awareness (Panel 1, t -statistic = 3.78, $p < 0.01$; Panel 3, t -statistic = 5.23, $p < 0.01$). Subordinate executives enhance their long-term awareness to implement their longer decision-making horizons and boost eco-innovation.

4.3. Top management team's ecological awareness – Test of Hypothesis 3

Hypothesis 3 predicts that more effective internal governance enhances ecological awareness among the top management team, thereby motivating eco-innovation. Under the linguistic relativity hypothesis, individuals' language and use of words reflect their inner thoughts (Whorf, 2012). In measuring ecological awareness (*Eco_Aware*), we conduct textual analysis to obtain the frequency of keywords associated with environmental protection in corporate social responsibility reports. The list of keywords is presented in Appendix C. To examine the mechanism effect, we use the change in *Eco_Aware* from period t to $t + 1$ and the one-year lead value ($t + 1$) of eco-innovation. We partition our sample based on the industry-year median value of the top management team's ecological awareness change. Table D.4 presents the results. Consistent with **Hypothesis 3**, we find that enhanced ecological awareness among top management teams facilitates the positive effect of internal governance on eco-innovation (Panel 1, t -statistic = 3.94, $p < 0.01$; Panel 3, t -statistic = 5.64, $p < 0.01$). Internal governance in the form of subordinate executives' bottom-up monitoring enhances the ecological awareness of the top management team and motivates eco-innovation developments.

4.4. The conditioning effect of CEO opportunism – Test of Hypothesis 4

Hypothesis 4 predicts that internal governance motivates eco-innovation to a greater extent when CEOs are more opportunistic. Regarding shareholding, we run subsample analyses based on the industry-year median of each CEO's shareholding. Table D.5 presents the results. Subordinate executives' monitoring influence is greater when the CEO is a female (Panel A, t -statistic = 3.55, $p < 0.01$; t -statistic = 4.12, $p < 0.01$), and when CEO shareholding is greater (Panel B, t -statistic = 7.98, $p < 0.01$; t -statistic = 7.82, $p < 0.01$), with all p -values being statistically significant. Consistent with **Hypothesis 4**, subordinates' protection of long-term firm value is greater when CEOs are opportunistic.

4.5. Additional analyses

4.5.1. The conditioning effect of Confucianism

Previous studies document that Confucianism motivates R&D (Yan et al., 2021) and environmental investment (Xu et al., 2019). Confucianism aligns with the values of corporate environmental responsibility because it emphasizes the need to bring mutual growth to organisations and communities (Low and Ang, 2012). Jin et al. (2022) highlight that a strong Confucian influence attenuates self-serving values and interests within business environments, whereby team contribution rather than those of the CEO alone is valued. Confucianism advocates the integration of humanity and nature (Xu et al., 2019). This value is consistent with investment in eco-innovation, which aims to promote organizational and economic development while conserving the environment. Thus, we expect internal governance to motivate eco-innovation to a

⁷ Due to readability, we do not report results related to our control variables in the main Appendix D. However, these results are provided in another document attached to this submission.

⁸ For economic significance, we multiply the coefficient of *Int_Gov* in Table 2 (0.057 and 0.056) by the standard deviation of *Int_Gov* (1.08).

greater extent in Confucianism-influenced firms. We measure Confucianism based on the natural-log-transformed number of Confucian temples within a radius of twenty kilometres from a firm's registered office. We run subsample analyses based on the industry-year median of Confucianism (*Confucianism*). Table D.6 presents the regression results and reports the *p*-value of the subsample difference in the coefficient of interest of *Int_Gov*. Consistent with our expectations, internal governance motivates eco-innovation to a greater extent for high-Confucianism firms. This suggests that the effectiveness of subordinates' bottom-up influence conditions on local cultural factors within China.

4.5.2. The conditioning effect of external attention

The survey by Graham et al. (2005) uncovers that external analysts play an important role in setting a firm's position in the capital market. One strand of literature (e.g., Zhang and Gimeno, 2016; Qian et al., 2019; Chen et al., 2024a) views analysts' attention as a source of pressure on firms to focus on short-term performance and limit investment in environmentally responsible activities. A contrasting strand of literature (e.g., Jensen and Meckling, 1976; Healy and Palepu, 2001; Dyck et al., 2010) suggests that external analysts' attention to a firm reduces information asymmetry, alleviates the principal-agent problem, and reduces the possibility of management focusing on short-term value at the expense of long-term growth. Yu (2008) finds that higher analyst attention reduces earnings management, thus suggesting that analysts facilitate the production and distribution of information regarding firms.

We expect the role of internal governance in motivating green innovation to be more pronounced when analyst attention is higher due to the role of analysts in distributing information. Analysts explore and distribute information related to green innovation projects, which otherwise remain highly confidential and opaque due to their high risk and cost (Wang and Cao, 2024). They assist in uncovering the value and significance of a firm's eco-innovation undertakings, which helps investors to make more accurate valuation judgments (Kimbrough, 2007). Analyst attention also increases the visibility of firm actions, which makes firms face stronger reputational and market discipline in a landscape where stakeholder environmental demand is increasing (Han et al., 2024).

Using the natural log-transformed number of securities analysts following (*External_Atten*), we run a subsample analysis of the effect of internal governance on eco-innovation based on the industry-year median of *External_Atten*. We report the results in Table D.7, which includes the *p*-value of the subsample difference in the coefficient of interest of *Int_Gov*. Consistent with expectations, internal governance has a more pronounced positive effect on eco-innovation for firms with higher analyst attention. This suggests that analysts play an important role in disseminating private information regarding eco-innovation projects and aid the market's valuation of firms' eco-innovation. Moreover, it aligns with Acharya et al. (2011)'s view that internal governance complements other governance mechanisms in alleviating CEO opportunism.

5. Endogeneity concerns and robustness tests

5.1. Alternative and lagged measures of internal governance

Our baseline analysis utilizes Cheng et al. (2016)'s measure of internal governance comprising subordinate executives' horizons and influential ability. This is because of potential confounding factors associated with using the relative decision-making horizons, as mentioned in Jain et al. (2016). While we control CEO age to account for the CEOs' horizons, our primary measure is not a relative measure that simultaneously considers both the CEO's and subordinates' incentives to innovate. Therefore, for robustness, we use the mean age variance between the CEO and key subordinates (*Diff_Horizon*) to reflect differential horizons. In the subordinates' view, an older CEO may be closer to

retirement and thus become more opportunistic as they age. As a result, their monitoring incentives increase, including incentives arising from internal promotion. Therefore, higher values of *Diff_Horizon* indicate greater subordinates' bottom-up governance. Table D.8 (Columns 1 and 2) reports the results, which remain consistent.

To alleviate causality concerns, we also use the one-year lagged internal governance measure (*Lagged_Int_Gov*) to re-estimate our model. Table D.8 (Columns 3 and 4) reports the results, which remain consistent.

5.2. Alternative measures of eco-innovation

In our baseline analysis, we use green patents to measure eco-innovation. While they are important components of eco-innovation, they possess differences in terms of focus and scope. Green patents may more closely be associated with green innovation, which refers to technologies focusing on environmental protection (Ratten, 2022). Eco-innovation has a wider scope and embeds systemic transformation towards sustainable development (Orlando et al., 2022), focusing on innovation ecosystems and broader society implications for production, consumption, and governance (Favot et al., 2023). Green innovation emphasizes incremental improvements in products or processes to reduce environmental harm, whilst eco-innovation draws from systems theory and sustainability transitions to reconfigure systems to enable changes in business models, consumer behavior, and governance structures (Rennings, 2000). Therefore, green patents may not comprehensively capture the firm's eco-innovation. To address this concern, we utilize two indexes of eco-development efficiency and an indicator of environmental management certification as alternative measures of eco-innovation.

First, in the spirit of regional green development efficiency (e.g., Zhu et al., 2020; Zhang et al., 2021) and firm-level green innovation efficiency (Ren et al., 2024; Wang et al., 2024; He and Qiu, 2025), we calculate a measure of firm-level eco-development efficiency using the DEA-SBM model. This model constructs an input-output-based measure of eco-innovation, which offers a more nuanced view of eco-innovation performance by reflecting actual sustainability impact rather than inventive intent. As the eco-innovation literature emphasizes preventative and systemic environmental protection, the consideration of inputs in addition to outputs of eco-innovation is appropriate (Durán-Romero and Urraca-Ruiz, 2015). The focus on efficiency and economic productivity also aligns with that of eco-innovation (Horbach et al., 2012).

The DEA-SBM model involves plugging in input, intermediate output, and final output indicators to calculate an efficiency measure (Ren et al., 2024). We operationalize capital input using R&D expenditure and labor input using the full-time equivalent of R&D personnel (Wang et al., 2024). Then, we operationalize intermediate outputs as the number of eco-innovation patent applications, and final outputs as new product sales revenue and the environmental composite index (Ren et al., 2024). Considering the wider scope of eco-innovation, we follow Favot et al. (2023)'s expanded IPC green code classification to identify eco-innovation patents, which considers low-carbon, sustainable, and climate change mitigation technologies. This expansion considers the Y02 code series from the Cooperative Patent Classification (CPC) [European Patent Office (EPO, 2021)], which helps align IPC-based patent data with eco-innovation themes, including climate mitigation, circularity, and systemic sustainability (Ratten, 2022). The intermediate output of eco-innovation patent applications is identified based on this expanded classification. Then, using the DEA-SBM model, we calculate *Eco_Dev1*, which is the eco-development efficiency measure based on the intermediate output of eco-innovation patent applications. Similarly, we construct *Eco_Dev2*, which uses the intermediate output of eco-innovation invention patent applications. Taken together, *Eco_Dev1* and *Eco_Dev2* serve as measures of firm-level eco-development efficiency. We rerun our baseline analysis by replacing the dependent variables and report the results on Panel A of Table D.9. The findings indicate that our

inferences remain unchanged.

Eco-innovation is the production, assimilation, or exploitation of a product, production process, service, or management or business method that is novel and that provides customers and business value while decreasing environmental impact (Favot et al., 2023). It encompasses three elements: (1) environmental policy and regulation as the driver (Rennings, 2000), (2) the utilization of environmental management systems (Wagner, 2008), and (3) the delivery of customer benefits (Kammerer, 2009). Accordingly, we further investigate whether the firm obtains ISO 14001 environmental management certification (ISO 14001) as an alternative proxy for eco-innovation. This certification is a strategic enabler of systemic, performance-oriented eco-innovation as it operationalizes the embedment of environmental objectives into organizational processes (Wagner, 2008). Panel B of Table D.9 reports the results that support our baseline findings.

5.3. 2SLS approach

To rule out the explanation that subordinates with longer horizons may self-select into innovation-driven firms with less opportunistic CEOs to protect their career, we use a 2SLS approach. We follow the spirit of Mekhaimer et al. (2022) to use the Consumer Price Index (CPI) of the CEO's registered city as the instrumental variable. Regional attributes are plausibly exogenous, as they are beyond the control of individual firms. We report the results in Table D.10. A higher CPI value of the CEO's city is positively related to the CEO's age due to the construction of the CPI index. In the subordinates' view, an older CEO may be closer to retirement and become more opportunistic as they age (Jain et al., 2016). Therefore, subordinates may exert greater bottom-up influence over the CEO as their incentives to do so increase. Consistent with this view, the CEO's city-level CPI is positively associated with the effectiveness of internal governance in the first-stage regression, thus meeting the relevance criteria. The weak identification test suggests that CPI is a relevant and powerful instrument: the F-statistic is significant at 11.65. For the exclusion criteria, it is unlikely that the CEO's city-level CPI directly affects eco-innovation except through the channel of internal governance driven by differential horizons between the CEO and subordinates. Using this as an instrument for a 2SLS approach, we observe two-stage results that support our baseline finding.

5.4. Omitted variable concern

Omitted variables may confound our results. We adopt Oster (2019)'s tests of omitted variables to mitigate this concern. Oster (2019)'s analysis draws on the fact that the bias caused by observed factors informs, to a certain extent, the bias of unobserved factors by assuming proportionality between the two biases. The results are in Table D.11. We conduct two tests. First, δ equals -1 , and R_{max} equals 1.3 times the R-squared of our baseline results. Using these values allows us to obtain the bias-adjusted treatment effect β^* , reported in Row (1) of Panels A and B. If β^* is within the 95% confidence interval of our baseline results, then our findings are robust. Second, β^* equals 0, and R_{max} remains the same. We obtain the value of δ , which is reported in Row (2) of Panels A and B. If δ is above 1, i.e., $\delta > 1$, omitted variables are unlikely to bias our baseline results. Overall, the test results indicate that potential unobservables are unlikely to confound our baseline findings.

5.5. Propensity score matching

To mitigate the possibility that internal governance and eco-innovation are jointly determined by observable firm characteristics, we employ propensity score matching (PSM) in which we assign one if a firm's internal governance is above the sample median and zero otherwise. We adopt a strict one-to-one nearest-neighbor matching approach with replacement, using control variables, including *Firm_Age*, *Firm_Size*,

Firm_Growth, *Leverage*, *Staff_Intensity*, *B_Size*, *Largest_SH*, and *Inst_Own* as matching covariates, and calculate the propensity scores accordingly. Table D.12 reports the details of the matching procedures, and Table D.13 reports the results of the matched samples. Findings remain consistent.

5.6. Alternative model specifications

In the baseline analyses, we take the natural log transformation of *Green_Patent* and *Green_InvPatent* to address truncation concerns. In this section, we first rerun our analysis using the Tobit model to account for censoring and improve the efficiency of the results. Second, log-transforming the dependent variable introduces issues associated with unit sensitivity and opaque interpretations (Chen and Roth, 2024), particularly since the values of *Green_Patent* and *Green_InvPatent* include zeroes. To address these issues, we follow Cohn et al. (2022) to rerun our analysis using the Poisson model. Tables D.14 and D.15 report the findings, which remain consistent with our empirical results.

5.7. Elimination of interference factor

Before 2017, the State Intellectual Property Office included all patent applications received regardless of payment or non-payment of associated application fees. Since 2017, only patent applications with fully paid application fees are included. Therefore, we perform a supplementary analysis after removing samples from 2017 and beyond to ensure our results are robust. Table D.16 reports the findings, which remain consistent.

6. Extended analyses

6.1. Internal governance and eco-innovation quality

Our study thus far provides empirical evidence that subordinates' monitoring of the CEO in the form of internal governance, as driven by their longer decision horizons, motivates eco-innovation of firms. We extend from the quantity of innovation to examine whether internal governance affects the quality of firms' eco-innovation. Following prior literature (e.g., Trajtenberg, 1990; Harhoff et al., 1999; Balsmeier et al., 2017) documenting the reflection of a patent's economic value on its citations, we measure eco-innovation quality using the number of green patents' citations (*Green_Patent_Cites*) and green invention patents' citations (*Green_InvPatent_Cites*). We use the one-year lead number of citations due to the delayed adoption and diffusion of environmentally focused technologies shaped by technological complexity, regulatory pacing, and market readiness (Cheng et al., 2025). The results are reported in Table D.17, which shows that more effective internal governance leads to higher eco-innovation quality. Therefore, subordinates' monitoring plays an important role in both the quantity and quality of firms' eco-innovation.

7. Conclusion and implications

We find that more effective internal governance motivates eco-innovation. Subordinate executives' decision-making influence is thus a key determinant of firms' long-run performance and risk-taking. Internal governance boosts eco-innovation by enhancing subordinate executives' long-term awareness and the top management team's ecological awareness. The influence of internal governance is more significant when CEOs possess a lower tolerance for short-term losses, when firms are influenced by a higher level of Confucianism, and subject to more external attention. Finally, more effective internal governance improves eco-innovation quality in addition to eco-innovation quantity, highlighting that subordinates' bottom-up influence is vital for firms' eco-innovation performance.

Our findings have important practical implications. First, our results

have important implications for investors by highlighting that it is essential to consider top management team dynamics in firms' decisions regarding long-term environmental investment outcomes such as eco-innovation. Second, China has indicated support for a series of incentives to encourage ecological investment and financing. This includes refinancing projects, green credit support, and interest discount guarantees. Our results are essential to the providers of green finance, as subordinate executives can assist with the legitimacy of firms' environmental investment strategies. In return, subordinate executives' influence and decision horizons may also affect the green financiers' funding decisions.

Third, shareholders and the board of directors need to appoint subordinate executives with long decision-making horizons to meet environmental objectives, especially when regulatory and market pressures on corporate environmental sustainability evolve. We support firms striving for environmental legitimacy, especially those operating in weak institutional environments in developing and transitional economies, such as China. Fourth, our study is of importance to regulators and policymakers seeking to implement environmental policies. We highlight that it is crucial to consider internal team power distribution influences and to motivate subordinate executives to embed long-term environmental strategies in firms. Our findings also offer valuable

insights for other nations and institutions aiming to improve environmental sustainability.

CRediT authorship contribution statement

Millie Liew: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Investigation, Conceptualization. **Zhuo Li:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **June Cao:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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Appendix A. Appendix A: Definition of variables.

<i>Green_Patent</i>	The natural logarithm of one plus the number of patents that are classified as green, as detailed in Appendix B.
<i>Green_InvPatent</i>	The natural logarithm of one plus the number of green invention patents.
<i>Exec_Horizon</i>	Subordinate executives' decision horizon is defined as the retirement age of 60 minus the average age of key subordinate executives.
<i>Exec_PayRatio</i>	Subordinate executives' pay ratio, calculated as the average compensation of subordinate executives, scaled by the CEO's total compensation.
<i>Int_Gov</i>	The firm's overall internal governance is measured as the sum of the standardised values of <i>Exec_Horizon</i> and <i>Exec_PayRatio</i> .
<i>B_Size</i>	The natural logarithm of one plus the number of directors on the board.
<i>B_Ind</i>	The proportion of independent directors on the board.
<i>Firm_Size</i>	Firm size is defined as the natural logarithm of total assets.
<i>Firm_Age</i>	The natural logarithm of one plus the firm's age (in years).
<i>Firm_Growth</i>	The percentage change in sales from the previous year.
<i>Leverage</i>	Financial leverage is the book value of total debts divided by the book value of total assets.
<i>ROA</i>	Return on assets, defined as net income divided by total assets.
<i>CEO_Age</i>	The natural logarithm of CEO age (in years).
<i>Inst_Own</i>	The percentage of ownership held by institutional investors.
<i>Staff_Intensity</i>	The total number of employees divided by total sales (in millions).
<i>Largest_SH</i>	The percentage of shares owned by the largest shareholder.
<i>CEO_Edu</i>	A seven-point scale reflecting the highest level of education attained by the CEO.
<i>CEO_Gender</i>	An indicator variable that equals one if a firm's CEO is male, and zero otherwise.
<i>CEO_ForeignExp</i>	An indicator variable that equals one if a firm's CEO has work experience or study experience in one or more foreign countries, and zero otherwise.
<i>CEO_Shareholding</i>	The CEO's shareholding in the firm.
<i>LTA_{it}</i>	Long-term awareness, measured as the proportion of key subordinate executives with either a Master's or PhD degree.
<i>Eco_Aware</i>	Ecological awareness among the top management team, measured based on the natural logarithm of the frequency of keywords associated with environmental protection in the corporate social responsibility report.
<i>Fin_Constraints</i>	The natural logarithm of the absolute value of the KZ index. A higher value suggests that the firm is more financially constrained.
<i>Confucianism</i>	The natural logarithm of the number of Confucian temples within a radius of twenty kilometres from the firm's registered office plus one.
<i>External_Atten</i>	The natural logarithm of the number of securities analysts following the same listed company plus one.
<i>Lagged_Int_Gov</i>	The one-year lagged value of <i>Int_Gov_{it}</i>
<i>Diff_Horizon</i>	The alternative internal governance measure is defined as <i>CEO_Age_{it}</i> -the average age of subordinate executives.
<i>Eco_Dev1</i>	Eco-development efficiency index based on eco-innovation patent applications as the intermediate output.
<i>Eco_Dev2</i>	Eco-development efficiency index based on eco-innovation invention patent applications as the intermediate output.
<i>ISO 14001</i>	Whether a firm obtains ISO 14001 environmental management system certification.
<i>CPI</i>	The Consumer Price Index of the CEO's city for the year.
<i>Green_Patent_Cites</i>	The number of citations of the firm's green patent.
<i>Green_InvPatent_Cites</i>	The number of citations of the firm's green invention patents.

Appendix B. The classification of green patents in measuring eco-innovation

We follow prior studies and use two criteria for the classification of green patents (Li et al., 2018; Rezende et al., 2019; Quan et al., 2021). A patent is classified as ‘green’ if it meets one or both of the following criteria.

- (1) If the title of the patent contains one or more of the twenty-five keywords listed, the patent is classified as a green patent. The keywords include “desulfurization, dust, dust emission, dust removal, emission reduction, energy conservation, environmental protection, flue gas, garbage, green, new energy, odour, particles, pollution, recovery, recycling, sewage, smoke, solid waste, sulphur dioxide, three wastes, waste, waste gas, waste liquid, wastewater”.
- (2) We use the IPC Green Inventory list to identify green patents according to the IPC classification number. The IPC Green Inventory provides patent information on Environmentally Sound Technologies (ESTs). As shown in Table B below, if the patent’s IPC classification number is C10L3/00, F02C3/28, H01M4/86, H01M8/00, H01M12/00, F03D, F24J1/00, F24J3/00, F24J3/06, B61, H02J, E04B1/62, E04B1/74, E04B1/88, E04B1/90, or F03G7/08, we classify it as a green patent.

Table B.1: The IPC green inventory list following Quan et al. (2021).

Topic	IPC classification number
Biofuels	C10L3/00, F02C3/28
Fuel cells	H01M 4/86-4/98, 8/00-8/24, 12/00-12/08
Wind energy	F03D
Other production of use heat not derived from combustion	F24J 1/00, F24J 3/00, F24J3/06
Rail vehicles	B61
Power supply circuitry	H02J
General thermal building insulation	E04B1/62, E04B1/74-1/80, E04B 1/88, E04B 1/90
Recovering mechanical energy	F03G7/08

Appendix C. A text-based measure of ecological awareness

We conduct textual analysis to measure ecological awareness among the top management teams of firms. Specifically, we calculate the frequency of the following terms in the corporate social responsibility report of a firm to calculate its top executives' awareness towards energy conservation and environmental protection.

Keywords	
Energy conservation and emission reduction	Environmental governance
Environmental protection department	Environmental protection training
Environmental protection strategy	Environmental technology development
Environmental protection inspection	Environmental facilities
Environmental protection concept	Environmental audit
Low-carbon environmental protection	Environmental laws and regulations
Environmental management organization	Environmental pollution control
Environmental protection effort	Environmental policies
Environmental education	

Appendix D

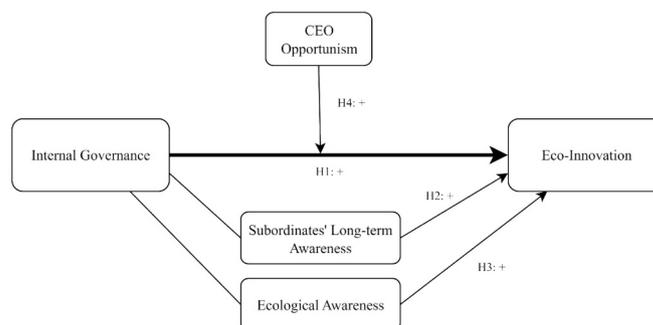


Fig. D.1. Conceptual Framework.

Table D.1: Descriptive statistics.

Variable	N	Mean	Median	SD	Min	Q1	Q3	Max
<i>Green_Patent</i>	10,545	0.77	0.00	1.16	0.00	0.00	1.39	4.48
<i>Green_InvPatent</i>	10,545	0.55	0.00	0.92	0.00	0.00	0.69	3.99
<i>Exec_Horizon</i>	10,545	13.32	13.20	4.33	-2.00	10.20	16.20	29.80
<i>Exec_PayRatio</i>	10,545	-0.05	-0.17	0.57	-0.06	-0.33	0.00	3.45
<i>Int_Gov</i>	10,545	-0.01	0.00	1.08	-2.36	-0.71	0.55	3.77
<i>Firm_Age</i>	10,545	2.81	2.83	0.37	1.61	2.64	3.09	3.50
<i>Firm_Size</i>	10,545	21.89	21.72	1.14	19.97	21.04	22.55	25.53
<i>Firm_Growth</i>	10,545	0.16	0.12	0.31	-0.48	-0.01	0.27	1.59
ROA	10,545	0.05	0.05	0.06	-0.17	0.02	0.08	0.23
<i>Leverage</i>	10,545	0.37	0.35	0.20	0.01	0.21	0.52	0.99
<i>Staff_Intensity</i>	10,545	1.46	1.24	1.04	0.10	0.71	1.92	5.47
<i>B_Size</i>	10,545	2.12	2.20	0.19	1.61	1.95	2.20	2.64
<i>B_Ind</i>	10,545	0.37	0.33	0.05	0.33	0.33	0.43	0.57
<i>Largest_SH</i>	10,545	0.34	0.33	0.14	0.09	0.23	0.43	0.73
<i>Inst_Own</i>	10,545	0.34	0.32	0.24	0.00	0.11	0.53	0.86
<i>CEO_Gender</i>	10,545	0.93	1.00	0.25	0.00	1.00	1.00	1.00
<i>CEO_Edu</i>	10,545	3.62	4.00	1.32	1.00	3.00	4.00	7.00
<i>CEO_ForeignExp</i>	10,545	0.08	0.00	0.27	0.00	0.00	0.00	1.00
<i>CEO_Age</i>	10,545	3.92	3.93	0.13	3.53	3.85	4.01	4.20
<i>CEO_Shareholding</i>	10,359	0.19	0.08	0.22	0.00	0.00	0.38	0.71
LTA	10,540	0.36	0.40	0.28	0.00	0.20	0.60	1.00
<i>Eco_Aware</i>	10,133	0.90	0.69	0.87	0.00	0.00	1.61	3.09
<i>Fin_Constraints</i>	10,280	0.62	0.93	2.41	-8.71	-0.64	2.25	7.17
<i>Confucianism</i>	10,545	0.43	0.00	0.48	0.00	0.00	0.69	1.61
<i>External_Atten</i>	10,545	1.50	1.61	1.16	0.00	0.00	2.48	3.91
<i>Diff_Horizon</i>	10,545	3.11	3.20	6.77	-14.8	-1.00	7.20	20.60
<i>Eco_Dev1</i>	10,545	0.22	0.00	0.36	0.00	0.00	0.43	4.32
<i>Eco_Dev2</i>	10,545	0.16	0.00	0.28	0.00	0.00	0.28	4.32
ISO 14001	10,545	0.08	0.00	0.27	0.00	0.00	0.00	1.00
CPI	9868	4.63	4.63	0.01	4.60	4.62	4.63	4.66
<i>Green_Patent_Cites</i>	10,545	0.51	0.00	0.93	0.00	0.00	0.69	3.93
<i>Green_InvPatent_Cites</i>	10,545	0.23	0.00	0.56	0.00	0.00	0.00	2.83

Notes: This table presents the descriptive statistics of variables, including the number of observations (N), mean, median, minimum, maximum, quartiles (25% and 75%), and standard deviation (SD). Details on variable definitions are in Appendix A.

Table D.2: Internal governance and eco-innovation.

	(1)	(2)
	<i>Green_Patent</i>	<i>Green_InvPatent</i>
<i>Int_Gov</i>	0.057*** (5.79)	0.056*** (6.94)
<i>Firm_Age</i>	-0.131*** (-4.09)	-0.071*** (-2.64)
<i>Firm_Size</i>	0.406*** (30.29)	0.327*** (28.66)
<i>Firm_Growth</i>	0.090** (2.56)	0.063** (2.19)
ROA	0.280 (1.45)	0.282* (1.81)
<i>Leverage</i>	0.136** (2.03)	0.023 (0.43)
<i>Staff_Intensity</i>	-0.010 (-1.12)	-0.013* (-1.72)
<i>B_Size</i>	0.047 (0.69)	0.023 (0.41)
<i>B_Ind</i>	-0.256 (-1.09)	-0.055 (-0.29)
<i>Largest_SH</i>	-0.240*** (-3.25)	-0.281*** (-4.61)
<i>Inst_Own</i>	0.053 (1.15)	0.075** (2.01)
<i>CEO_Gender</i>	0.007 (0.20)	0.019 (0.64)
<i>CEO_Edu</i>	0.044*** (6.21)	0.035*** (6.20)
<i>CEO_ForeignExp</i>	0.015 (0.39)	0.040 (1.27)
<i>CEO_Age</i>	-0.104 (1.40)	-0.163*** (2.74)
Year FE	Yes	Yes
Ind FE	Yes	Yes
Constant	-8.539*** (-19.43)	-7.274*** (-19.73)

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	(1)	(2)
	<i>Green_Patent</i>	<i>Green_InvPatent</i>
N	10,545	10,545
Adjusted R ²	0.267	0.237

Notes: This table presents results on the effect of internal governance on eco-innovation. Eco-innovation is measured by the log-transformed number of green patent applications (*Green_Patent*) and the log-transformed number of green invention patent applications (*Green_InvPatent*). *Int_Gov* is the internal governance measure based on subordinate executives' decision horizons and compensation relative to the CEO. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.3: The mechanism test of subordinate long-term awareness.

	(1)	(2)	(3)	(4)
	<i>Green_Patent</i> _{t+1}		<i>Green_InvPatent</i> _{t+1}	
	Δ_{t+1} Long-term Awareness	Δ_{t+1} Long-term Awareness	Δ_{t+1} Long-term Awareness	Δ_{t+1} Long-term Awareness
	High	Low	High	Low
<i>Int_Gov</i>	0.062*** (3.78)	0.066 (1.63)	0.071*** (5.23)	0.068** (2.00)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Constant	-7.769*** (-10.70)	-10.025*** (-6.01)	-6.812*** (-11.33)	-9.771*** (-6.97)
N	4032	858	4032	858
Adjusted R ²	0.264	0.267	0.230	0.238

Notes: To test the mechanism of subordinate executives' long-term awareness, we regress the one-year lead value of the eco-innovation measures on internal governance, and we run a subsample analysis based on the industry-year median of the change in subordinates' long-term awareness (*LTA*) from period *t* to *t + 1*. We measure subordinate executives' long-term awareness using the proportion of key subordinate executives with either a Master's or a PhD degree. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.4: The mechanism test of top management team's ecological awareness.

	(1)	(2)	(3)	(4)
	<i>Green_Patent</i> _{t+1}		<i>Green_InvPatent</i> _{t+1}	
	Δ_{t+1} Ecological Awareness	Δ_{t+1} Ecological Awareness	Δ_{t+1} Ecological Awareness	Δ_{t+1} Ecological Awareness
	High	Low	High	Low
<i>Int_Gov</i>	0.069*** (3.94)	0.060* (1.91)	0.083*** (5.64)	0.050* (1.93)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Constant	-6.980*** (-9.08)	-9.756*** (-6.59)	-6.479*** (-10.05)	-8.473*** (-6.99)
N	3545	1172	3545	1172
Adjusted R ²	0.260	0.274	0.223	0.233

Notes: To test the mechanism of the top management team's ecological awareness, we regress the one-year lead value of the eco-innovation measures on internal governance, and we run a subsample analysis based on the industry-year median value of the change in ecological awareness (*Eco_Aware*) from period *t* to *t + 1*. We measure the top management team's ecological awareness based on the frequency of keywords associated with environmental protection in firms' corporate social responsibility reports. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.5: The conditioning effect of CEO opportunism.

	(1)	(2)	(3)	(4)
	<i>Green_Patent</i>		<i>Green_InvPatent</i>	
	CEO Shareholding		CEO Shareholding	
	High	Low	High	Low
Int_Gov	0.117*** (7.98)	0.019 (1.40)	0.094*** (7.82)	0.032*** (2.97)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Constant	-7.629*** (-10.63)	-8.491*** (-14.65)	-6.133*** (-10.21)	-7.429*** (-15.41)
N	4299	6246	4299	6246
Adjusted R ²	0.228	0.292	0.197	0.262
P-value	0.000		0.000	

Notes: This table presents the effect of internal governance and eco-innovation conditioning on CEO opportunism. We run subsample analyses based on the industry-year median value of *CEO_Shareholding*. The p-value for the difference in the subsample coefficients on *Int_Gov* is reported. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.6: The conditioning effect of Confucianism.

	(1)	(2)	(3)	(4)
	<i>Green_Patent</i>		<i>Green_InvPatent</i>	
	Confucianism		Confucianism	
	High	Low	High	Low
Int_Gov	0.066*** (6.18)	0.003 (0.10)	0.062*** (7.09)	0.019 (0.89)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Constant	-8.878*** (-18.89)	-4.989*** (-4.05)	-7.518*** (-18.97)	-4.284*** (-4.32)
N	9299	1246	9299	1246
Adjusted R ²	0.272	0.233	0.243	0.208
P-value	0.017		0.078	

Notes: This table presents the influence of Confucianism on the relationship between internal governance and eco-innovation. We measure the extent of Confucianism influence based on the number of Confucian temples within a radius of twenty kilometres from the firm's registered office (*Confucianism*). We run subsample analyses based on the industry-year median value of *Confucianism*. The p-value for the difference in the subsample coefficients on *Int_Gov* is reported. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.7: The conditioning effect of external attention.

	(1)	(2)	(3)	(4)
	<i>Green_Patent</i>		<i>Green_InvPatent</i>	
	External Attention		External Attention	
	High	Low	High	Low
Int_Gov	0.061*** (4.45)	0.033** (2.35)	0.052*** (4.54)	0.046*** (4.24)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Constant	-9.557*** (-16.27)	-4.830*** (-8.10)	-8.344*** (-15.92)	-3.647*** (-7.86)
N	5862	4683	5862	4683
Adjusted R ²	0.308	0.154	0.275	0.119
P-Value	0.080		0.003	

Notes: This table presents the influence of external attention on the relationship between internal governance and eco-innovation. We measure external attention by taking the natural logarithm of the number of securities analysts following the same listed company plus 1 (*External_Atten*). We run a subsample analysis based on the industry-year median value of *External_Atten*. The p-value for the difference in the subsample coefficients on *Int_Gov* is reported. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.8: Alternative and lagged measures of internal governance.

	Alternative Measure		Lagged Internal Governance	
	(1)	(2)	(3)	(4)
	<i>Green_Patent</i>	<i>Green_InvPatent</i>	<i>Green_Patent</i>	<i>Green_InvPatent</i>
Diff_Horizon	0.010*** (4.03)	0.011*** (5.50)		
Lagged_Int_Gov			0.061*** (4.08)	0.071*** (5.72)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Constant	-6.648*** (-11.90)	-5.216*** (-11.14)	-8.588*** (-12.93)	-7.589*** (-13.75)
N	10,545	10,545	4890	4890
Adjusted R ²	0.265	0.235	0.277	0.241

Notes: This table presents results using an alternative measure and the one-year lagged value of internal governance. Following Jain et al. (2016), we use the average age difference between the CEO and key subordinate executives (*Diff_Horizon*) to alternatively proxy for the level of internal governance. The greater the age difference, the more effective internal governance is due to increased subordinate executives' incentives to influence the CEO. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.9: Alternative measures of eco-innovation.

Panel A: Eco-Development Efficiency		
	(1)	(2)
	Eco-Development Efficiency	
	<i>(Eco_Dev1)</i>	<i>(Eco_Dev2)</i>
Int_Gov	0.017*** (4.79)	0.017*** (5.64)
Controls	Yes	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Constant	-1.546*** (-11.45)	-1.389*** (-12.40)
N	10,545	10,545
Adjusted R ²	0.155	0.138
Panel B: Eco-Management Certification		
	(1) ISO Environmental Management System Certification <i>(ISO_14,001)</i>	
Int_Gov	0.004* (1.73)	
Controls	Yes	
Year FE	Yes	
Ind FE	Yes	
Constant	-1.669*** (-14.19)	
N	10,545	
Adjusted R ²	0.092	

Notes: This table presents results using alternative measures of eco-innovation. In Panel A, we employ two measures of eco-development efficiency based on the DEA-SBM model (*Eco_Dev1* and *Eco_Dev2*). In Panel B, we use whether a firm obtains ISO 14001 environmental management system certification (*ISO 14001*) as an alternative proxy for eco-innovation. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.10: Internal governance and eco-innovation-instrumental variables (2SLS) approach.

	(1)	(2)
	First Stage	Second Stage
	<i>Int_Gov</i>	<i>Green_Patent</i> <i>Green_InvPatent</i>
Int_Gov		0.679** (2.33) 0.434* (1.86)
CPI	5.311*** (3.41)	

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	(1)	(2)	
	First Stage	Second Stage	
	<i>Int_Gov</i>	<i>Green_Patent</i>	<i>Green_InvPatent</i>
Controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Constant	-15.576*** (-2.16)	-14.446*** (-5.41)	-11.015*** (-5.13)
<i>N</i>	9868	9868	9868
Adjusted R ²	0.124	0.270	0.240

Notes: This table presents the results of the 2SLS approach. Column (1) presents the first-stage results. Column (2) presents the second-stage results. Following Mekhaïmer et al. (2022), we construct the instrumental variables using the same approach, with the instrumental variable defined as the Consumer Price Index (*CPI*) of the CEO's city. A higher *CPI* value indicates more effective internal governance. The weak identification test suggests that *CPI* is a relevant and powerful instrument: the F-statistic is significant at 11.65. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.11: Unobservable selection and coefficient stability test.

Panel A (Dependent Variable: <i>Green_Patent</i>)			
Testing Method	Judgement Criteria	Actual Result	Test Satisfied
(1)	$\beta^*(R_{max}, \delta) \in [-0.397, -0.132]$	$\beta^*(R_{max}, \delta) = -0.264$	Yes
(2)	$\delta > 1$	$\delta = 1.105$	Yes
Panel B (Dependent Variable: <i>Green_InvPatent</i>)			
Testing Method	Judgement Criteria	Actual Result	Test Satisfied
(1)	$\beta^*(R_{max}, \delta) \in [-0.439, -0.177]$	$\beta^*(R_{max}, \delta) = -0.308$	Yes
(2)	$\delta > 1$	$\delta = 1.0672$	Yes

Notes: This table reports results for tests of unobservable selection and coefficient stability following Oster (2019). We use the model $\beta^*(R_{max}, \delta)$ to obtain consistent estimates of true coefficients. δ is the proportionality of selection, and R_{max} is the maximum goodness of fit for the baseline regression. First, δ takes the value of -1 , and R_{max} takes the value of 1.3 times the adjusted R² of the baseline results, and we obtain the value of β^* , which is reported in Row (1) of Panels A and B. Second, β^* takes the value of 0, and R_{max} remains the same as in the first test, and we obtain the value of δ , which is reported in Row (2) of Panels A and B. If β^* is in the 95% confidence interval in the first test, and $\delta > 1$, the baseline results are robust and are unlikely to contain an omitted variable bias.

Table D.12: Balance test of PSM samples.

Panel A: Matching Variable Balance Test					
Variable	Sample	Mean (Treated)	Mean (Control)	% Bias	t-Test
Firm_Age	Unmatched	2.765	2.861	-26.1	-13.37
	Matched	2.765	2.767	-0.5	-0.24
Firm_Size	Unmatched	21.808	21.975	-14.6	-7.52
	Matched	21.808	21.821	-1.1	-0.61
Firm_Growth	Unmatched	0.180	0.136	14.7	7.52
	Matched	0.180	0.186	-1.7	-0.83
Leverage	Unmatched	0.366	0.379	-7.0	-3.57
	Matched	0.365	0.366	-0.4	-0.24
Staff_Intensity	Unmatched	1.471	1.444	3.6	1.35
	Matched	1.471	1.476	-0.4	-0.24
B_Size	Unmatched	2.101	2.136	-18.0	-9.21
	Matched	2.102	2.100	0.7	0.36
Largest_SH	Unmatched	0.341	0.345	-3.3	-1.70
	Matched	0.341	0.339	1.3	0.69
Inst_Own	Unmatched	0.318	0.360	-17.6	-9.01
	Matched	0.318	0.322	-1.8	-0.94
Panel B: Sample Population Mean Deviation Test					
	Sample	LR chi ²	Mean Bias		P > chi ²
	Unmatched	336.42	13.0		0.000
	Matched	3.33	1.0		0.912

Notes: This table details the propensity-score-matching procedures. Panel A provides the matching variable balance tests, and Panel B provides the sample population mean deviation test. Matching variables include the natural log of firm age (*Firm_Age*), the natural log of total assets (*Firm_Size*), the percentage change of sales from the previous year (*Firm_Growth*), financial leverage (*Leverage*), the total number of employees divided by total sales in millions (*Staff_Intensity*), the natural log number of directors on the board (*B_Size*), the percentage of shareholding by the largest shareholder (*Largest_SH*) and the percentage of institutional shareholding (*Inst_Own*).

Table D.13: Propensity score matching (PSM).

	(1)	(2)
	<i>Green_Patent</i>	<i>Green_InvPatent</i>
Int_Gov	0.050*** (4.43)	0.048*** (5.23)
Controls	Yes	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Constant	-8.451*** (-17.19)	-7.121*** (-17.30)
N	8285	8285
Adjusted R ²	0.262	0.233

Notes: This table presents the baseline results based on matched samples using PSM. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.14: Alternative model specification – The tobit approach.

	(1)	(2)
	<i>Green_Patent</i>	<i>Green_InvPatent</i>
Int_Gov	0.113*** (4.89)	0.141*** (6.82)
Controls	Yes	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Constant	-19.160*** (-18.51)	-18.176*** (-19.34)
N	10,545	10,545
Adjusted R ²	0.116	0.118

Notes: This table presents Tobit regression results about the impact of internal governance on eco-innovation. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.15: Alternative model specification – the Poisson approach.

	(1)	(2)
	<i>Green_Patent</i>	<i>Green_InvPatent</i>
Int_Gov	0.062*** (5.29)	0.082*** (6.51)
Controls	Yes	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Constant	-9.670*** (-18.81)	-11.582*** (-20.19)
N	10,545	10,545
Adjusted R ²	0.174	0.168

Notes: This table presents Poisson regression results about the impact of internal governance on eco-innovation. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.16: Elimination of interference factor.

	(1)	(2)
	<i>Green_Patent</i>	<i>Green_InvPatent</i>
Int_Gov	0.062*** (4.47)	0.058*** (5.13)
Controls	Yes	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Constant	-7.627*** (-13.15)	-6.272*** (-12.70)
N	5107	5107
Adjusted R ²	0.236	0.193

Notes: This table presents the results after removing samples from 2017 onwards. Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Table D.17: Extended analysis – eco-innovation quality.

	(1)	(2)
	<i>Green_Patent_Cites_{t+1}</i>	<i>Green_InvPatent_Cites_{t+1}</i>
Int_Gov	0.038*** (2.95)	0.032*** (3.74)
Controls	Yes	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Constant	-6.323*** (-11.29)	-4.218*** (-10.98)
N	4890	4890
Adjusted R ²	0.239	0.153

Notes: This table examines the influence of internal governance on the quality of eco-innovation. We measure eco-innovation quality as the number of citations of a firm's green patents in the following year (*Green_Patent_Cites_{t+1}*) and the number of citations of a firm's green invention patents in the following year (*Green_InvPatent_Cites_{t+1}*). Details on variable definitions are in Appendix A. All specifications include year and industry-fixed effects. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust t-statistics are reported in parentheses.

Appendix E. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.eneco.2026.109146>.

Data availability

Data used in this study are available from the sources identified in the text.

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