

The Dark Side of Controlling Shareholders Equity Pledges for Corporate Green Innovation

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ABSTRACT

Green innovation is fundamental to sustainable development but frequently encounters financial and governance constraints in newly industrialized and export-oriented economies. Controlling shareholders' behaviors, particularly equity pledges, may erode firms' long-term innovation incentives. This study investigates how controlling shareholders' equity pledges influence corporate green innovation in Taiwan and explores the underlying mechanisms and contextual variations of this relationship. The research focuses on Taiwan Stock Exchange (TWSE) and Taipei Exchange (TPEX) listed companies over the period from 2013 to 2023, offering insights from a high-technology economy in which green transformation ambitions coexist with concentrated family ownership structures and active equity pledging practices. Using panel data regression analysis and mediation models, this study examines the direct impact of equity pledges on green innovation and further analyzes three mediating channels: Environmental, Social and Governance (ESG) performance, financing constraints, and tunneling behavior. The results show that controlling shareholders' equity pledges significantly reduce firms' green innovation efforts, primarily by lowering research and development (R&D) investment. The adverse effects operate through worsened ESG performance, tighter financing constraints, and increased tunneling activities. However, the inhibitory effect is mitigated in firms with low pledge ratios, high pollution levels, or government-linked ownership structures. Equity pledging by controlling shareholders poses a substantial threat to green innovation in most Taiwanese firms, although certain firm characteristics can buffer this effect. This article contributes to the literature by uncovering the dark side of shareholder pledging behavior in the context of environmental innovation within a high-technology export economy, highlighting the need for regulatory scrutiny and corporate governance reforms to safeguard long-term sustainable development.

Keywords: Equity Pledge, Green Innovation, ESG Performance, Financing Constraint, Tunneling.

INTRODUCTION

The exponential expansion of industrial activity over recent decades has generated unprecedented pressures on natural ecosystems. Despite remarkable gains in economic output and living standards, the by-products of production-oriented growth, namely carbon emissions, resource depletion, and ecological degradation, have precipitated increasingly severe environmental crises globally (Nawaz et al. 2021). Extreme weather events, soil deterioration, and biodiversity loss now represent tangible threats to regional economies and social welfare, rendering the reconciliation of economic ambition with environmental stewardship one of the defining policy challenges of the contemporary era (Li et al., 2024).

Conventional economic thinking, rooted in neoclassical frameworks, tends to frame environmental protection as a cost burden that reduces competitiveness and dampens growth prospects (Gustiari, 2023). This perspective, however, neglects the transformative potential of technological innovation, which can convert environmental constraints into drivers of productivity and market advantage (Illge & Schwarze, 2009) Porter's hypothesis, positing that carefully designed environmental regulations can stimulate innovation capable of more than offsetting compliance costs, has accumulated considerable empirical support over time (Porter and Van der Linde 1995). Green innovation, broadly understood as the application of novel technological or non-technological methods to reduce environmental impacts during production while simultaneously improving resource utilization efficiency, emerges as a critical mechanism linking environmental responsibility with sustained competitiveness ((FSC), 2022). Scholars across disciplines have recognized that corporate green innovation constitutes a strategic imperative for firms seeking to fulfill economic and environmental objectives in tandem (Agustina et al., 2022; Alinovi et al., 2020). Corporate green innovation thus emerges as a crucial strategy for achieving the dual objectives of economic growth and environmental protection simultaneously.

Equity pledging is a financing mechanism in which shareholders of listed companies offer their shareholdings as collateral to financial institutions in exchange for loans, constituting a form of collateralized borrowing. Unlike straightforward asset-backed financing, equity pledging introduces a distinctive set of governance complications, particularly when the pledging party is a controlling shareholder capable of influencing corporate decision-making at the highest organizational level (Barrett & Carter, 2013; Behera et al., 2024). From a financing perspective, equity pledges transform illiquid ownership stakes into potential working capital, widening funding channels without immediately diluting ownership or depressing stock prices through secondary market sales (Pang and Wang 2020) (Bhatia et al., 2019). Procedurally, equity pledge arrangements tend to involve fewer regulatory obstacles than direct share reduction, making them an attractive option for capital-constrained controlling shareholders (Bhatia et al. 2019). Nevertheless, the collateralized nature of this financing means that a decline in share prices can trigger margin calls, forcing controlling shareholders to either replenish collateral or face forced unwinding and the consequent risk of control transfer (Bene et al., 2016; Benfratello et al., 2008).

The prospect of control transfer fundamentally alters the behavioral calculus of controlling shareholders during the pledge period. Because the controlling shareholder typically commands the largest block of voting rights, shifts in their risk tolerance propagate directly into corporate strategy and investment priorities (Pang and Wang 2020; Li et al. 2025). Green innovation, characterized by long time horizons, heavy capital requirements, and uncertain near-term returns, becomes an obvious candidate for curtailment when short-term stock price stability is the overriding priority. Reduced R&D allocations lower the probability of share price declines in the near term, thereby protecting the pledged position, and this protective effect becomes more pronounced as the proportion of pledged equity rises (Pang and Wang 2020).

THEORETICAL HYPOTHESIS

Analysis of controlling shareholders' equity pledge behavior

Control transfer risk is a significant concern associated with controlling shareholders' equity pledges (Pang and Wang 2020). In the context of Taiwanese enterprises, the concentrated family ownership structure that characterizes most listed firm's places controlling shareholders in a dominant position within corporate governance. This dominance can enable them to pursue personal interests, potentially at the expense of broader corporate objectives (Jiang, Lee and Yue 2010; Fan and Wong 2002). While some scholars argue that equity pledges can help alleviate corporate financing constraints by broadening funding channels (Pang and Wang 2020), it is essential to recognize that these pledges may simultaneously heighten controlling shareholders' focus on their private interests (Brambor et al., 2006; Brunnermeier & Cohen, 2003).

During the period of an equity pledge, controlling shareholders are likely to prioritize the security of their investments, becoming increasingly cautious to avoid control loss that could result from a decline in share prices (Chan et al. 2018) (Cameron & Miller, 2015; Ceballos et al., 2020; Chan et al., 2018). This protective stance may lead them to adjust business strategies in ways that emphasize stability over growth. Specifically, they might choose to support steady operational practices, reducing investments in high-risk projects that require substantial capital and long timelines. Instead, they may favor projects that promise quick returns, prioritizing short-term financial gains over long-term innovation (Chan et al. 2018; Hu et al. 2021).

However, the risk of control transfer does not completely restrain the behavior of controlling shareholders (Liu and Tian 2012; Wang and Zhang 2024). These individuals retain significant power over enterprise resources and can manipulate corporate capital to their advantage. Even after pledging equity for funding, controlling shareholders typically maintain control of the enterprise. When their interest in controlling the enterprise outweighs the benefits of cash flow for the firm, they may exploit their control rights to misappropriate corporate funds (Liu and Tian 2012). Such behavior can ultimately undermine the firm's capacity for green innovation, as resources that could have been directed toward innovative projects may instead be diverted to fulfill the personal interests of shareholders (Chen & Hu, 2024; Chi et al., 2023).

Characteristics of green innovation

Green innovation projects, by their nature, typically necessitate longer time cycles and substantial capital investments (Degirmenci et al. 2024). These projects inherently involve significant uncertainty for enterprises (Chi et al. 2023). Short-term investments in green innovation may not yield favorable returns, and the development of green innovation capabilities requires sustained investment over time to achieve meaningful results (Chi et al. 2023; Ji et al. 2025). Furthermore, the benefits derived from green innovation

initiatives, such as obtaining patents, can take years to materialize. Many patents may initially serve merely as technological reserves until a viable market develops (Degirmenci et al. 2024).

The uncertainty surrounding green innovation is compounded by the characteristics of technological iteration. Particularly during competitive market phases, firms may not have established effective technical barriers to protect their innovations (Czarnitzki & Hottenrott, 2009; de Janvry et al., 1991)(Degirmenci et al. 2024). This situation exposes green innovation patents to the risk of obsolescence because of competitive advancements, making it crucial for firms to remain agile and continuously invest in their innovations (Chi et al. 2023). Moreover, green innovation differs from conventional corporate innovation in that the reputational incentives for enterprises and managers often outweigh direct financial benefits (Tang et al. 2024). When firms recognize the importance of social responsibility and environmental protection, they are more likely to enhance their incentive systems for green innovation and R&D personnel, fostering an environment conducive to innovation and encouraging employees to pursue projects that contribute to sustainability and environmental stewardship (Dong et al. 2024).

The impact of controlling shareholders' equity pledge on green innovation decision-making

The effects of controlling shareholders' equity pledges, such as exacerbated agency problems, increased tunneling incentives, and heightened financing constraints, influence green innovation decision-making (Degirmenci et al., 2024; Dong et al., 2024). First, equity pledges worsen agency problems. After the pledge, controlling shareholders tend to shift their focus from the firm's long-term goals to short-term stock price performance in order to maintain stock price stability (Chan et al. 2018). Because green innovation projects are long-term, capital-intensive, and yield low short-term returns, controlling shareholders may reduce investments in green innovation for personal gain, which is detrimental to the firm's green innovation efforts (Dou et al., 2019; Fan & Wong, 2002; J. Guo et al., 2025). Second, when the stock price approaches the margin call threshold, controlling shareholders have stronger incentives to engage in tunneling behaviors, such as related-party transactions or fund misappropriation, to transfer corporate funds and mitigate personal losses. This may lead to the diversion of funds allocated to green innovation projects (Czarnitzki and Hottenrott 2009; Jiang et al. 2010). Third, equity pledges signal negative financial health to external stakeholders, leading to difficulties in financing (K. Guo et al., 2023; Han et al., 2024; Headey & Martin, 2016). As a result, banks and financial institutions increase credit thresholds and reduce loan limits. The increased external financing costs and difficulties in securing funds reduce green innovation investment. Given that green innovation relies heavily on external financing, heightened financing constraints have a significant inhibitory effect on green innovation development (Hu et al., 2021; Illge & Schwarze, 2009; Imai et al., 2020).

Based on the above analysis, the agency problems, tunneling incentives, and increased financing constraints resulting from equity pledges by controlling shareholders will lead to insufficient investment in green innovation, creating a significant inhibitory effect. Consequently, this article proposes the following hypothesis:

H1: Controlling shareholders' equity pledges will inhibit corporate green innovation.

METHODS

Model construction

Research Design and Empirical Strategy

This study adopts a quantitative panel data approach to examine the relationship between controlling shareholders' equity pledges and corporate green innovation among listed companies on the Taiwan Stock Exchange and Taipei Exchange over. The empirical strategy unfolds across three sequential layers. The first establishes the baseline relationship between pledging behavior and green innovation output through pooled ordinary least squares and fixed-effects panel regressions (Xia et al., 2022; D. Zhang et al., 2022; G. Zhang et al., 2024). The second addresses the endogeneity inherent in ownership and pledging decisions through an instrumental variable strategy implemented via two-stage least squares estimation. The third decomposes the aggregate effect into identifiable behavioral channels through a three-equation mediation framework. Subgroup analyses organized around pledge intensity, industry pollution classification, and ownership type then examine whether the average estimated effect masks meaningful cross-sectional heterogeneity across firm characteristics (Ji et al., 2025; Jiang et al., 2010; Kaplan & Zingales, 1997).

Baseline Panel Regression

The foundational specification regresses green innovation output on the controlling shareholder pledge ratio and a battery of firm-level controls, with year and industry fixed effects absorbing time-common shocks and time-invariant sectoral heterogeneity respectively:

$$\text{EnvrPat}_{it} = \beta_0 + \beta_1 \text{PLD}_{\text{RATE}_{it}} + \beta_2 \text{Controls}_{it} + \delta_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where subscript i indexes the firm and t the fiscal year. The term δ_i represents industry fixed effects and λ_t represents year fixed effects, while ε_{it} is the idiosyncratic error term. The coefficient β_1 is the parameter of primary interest. Confirming Hypothesis H1 requires evidence that β^1 is negative and statistically significant at conventional levels, indicating that higher pledge ratios suppress green innovation output. All regressions employ heteroscedasticity-robust standard errors clustered at the firm level to account for within-firm serial correlation across the eleven-year panel (Lashley et al., 2022; Lee & Yeh, 2004; Li et al., 2024). The baseline model is estimated progressively across four columns: a bare specification with neither controls nor fixed effects, a specification with year and industry fixed effects only, a specification with controls but without fixed effects, and a fully specified model combining all controls with both sets of fixed effects. This stepwise progression allows the stability of β^1 to be traced as each additional layer of controls is introduced.

Variable Construction

Dependent Variable.

Green innovation output is measured through patent applications filed with the Taiwan Intellectual Property Office, classified using International Patent Classification codes and Cooperative Patent Classification Y02 codes to isolate environmentally oriented technological inventions (Wahyuni et al., 2023; M. Wang & Zhang, 2024; Y. Wang & Yu, 2021). Among the three patent categories recognized under Taiwanese intellectual property law, invention patents and utility model patents are retained because these categories impose substantively higher novelty and inventive step requirements than design patents, making them more credible proxies of genuine innovation effort in green technology. The measure is constructed as:

$$\text{EnvrPat}_{it} = \ln(\text{Green Invention Patents}_{it} + \text{Green Utility Model Patents}_{it} + 1) \quad (1)$$

The addition of one prior to logarithmic transformation preserves zero-patent firm-year observations, which constitute a substantial share of the sample given that patent filing in green technology categories is far from universal among TWSE and TPEX listed firms.

Core Explanatory Variable

The degree to which a controlling shareholder has collateralized equity holdings is measured by the proportion of their own shares pledged to financial institutions as collateral:

$$\text{EnvrPat}_{it} = \ln(\text{Green Invention Patents}_{it} + \text{Green Utility Model Patents}_{it} + 1) \quad (2)$$

This ratio, which ranges from zero to one, captures pledge intensity at the shareholder level rather than at the firm level, thereby reflecting the degree to which the controlling shareholder's personal financial position is tied to the market performance of pledged stock (Tan et al., 2024; Tang et al., 2024). As the ratio approaches one, the controlling shareholder's exposure to margin call risk intensifies, which is the primary mechanism through which pledging is theorized to alter corporate strategy and investment priorities. Two robustness proxies supplement the main measure $\text{PLD}_{\text{RATE}_{it}^2}$ which scales pledged shares against total firm equity outstanding rather than the controlling shareholder's own holdings, and $\text{PLD}_{\text{DUM}_{it}}$, a binary indicator equal to one in any fiscal year during which the controlling shareholder maintains an outstanding pledge position, regardless of its magnitude.

Endogeneity Correction via Instrumental Variables

A central identification concern in estimating the baseline equation is reverse causality: firms with chronically weak green innovation records may also exhibit governance structures that simultaneously facilitate higher pledge ratios, creating a spurious negative association between the two variables. Omitted firm characteristics correlated with both pledging propensity and innovation capacity present a related threat. To address these endogeneity channels, the study constructs an instrumental variable based on the leave-one-out average pledge ratio among controlling shareholders of all other firms operating within the same two-digit industry classification and registered municipality or county, excluding firm i itself:

$$\text{PLD}_{\text{RATE}_{it}^{\text{IV}}} = \left(\frac{1}{N_{jct} - 1} \right) \sum_{k \in j, k \in c, k \neq i} \text{PLD}_{\text{RATE}_{kt}} \quad (3)$$

Two-stage least squares estimation proceeds in two distinct steps. In the first stage, the endogenous pledge ratio is regressed on the instrument and the full set of control variables:

$$PLD_{RATE_{it}} = \alpha_0 + \alpha_1 \overline{PLD_{RATE}}_{it} + \alpha_2 Controls_{it} + \delta_i + \lambda_t + \mu_{it} \quad (4)$$

These fitted values are then substituted into the second stage equation:

$$EnvrPat_{it} = \gamma_0 + \gamma_1 \overline{PLD_{RATE}}_{it} + \gamma_2 Controls_{it} + \delta_i + \lambda_t + v_{it} \quad (5)$$

Data Sources

Data on controlling shareholders' equity pledges, financial statement variables, board structure, and ownership composition are drawn from the Taiwan Economic Journal database. Green patent application records are sourced from the Taiwan Intellectual Property Office and matched to listed company identifiers using firm registration codes. ESG performance scores are obtained from CommonWealth Magazine's annual corporate sustainability assessment reports. The full sample spans fiscal years 2013 through 2023, providing an eleven-year panel that encompasses multiple economic cycles, two major regulatory reform episodes in Taiwan's environmental governance architecture, and the launch of the Financial Supervisory Commission's Green Finance Action Plan series (Praveen et al., 2025; Raza et al., 2023; Rong & Liu, 2024).

Sample construction follows six sequential cleaning steps: delisted company observations are removed to avoid survivorship bias; observations from companies placed under special administrative supervision are excluded because regulatory intervention disrupts the normal incentive environment facing controlling shareholders; all financial industry observations are dropped given that financial firms operate under distinct regulatory capital frameworks that render the leverage and cash flow measures incompatible with non-financial firm comparisons; firm-year observations with missing values on any regression variable are deleted; observations where total liabilities exceed total assets are excluded as indicators of data recording errors or extreme financial distress incompatible with the KZ index construction; and all continuous variables are winsorized at the 1st and 99th percentiles to mitigate the influence of extreme outliers on coefficient estimates. Following these procedures, the final cleaned and balanced panel comprises 12,847 firm-year observations.

RESULTS AND DISCUSSION

Description Statistic

Table 1 presents the results of descriptive statistics for the core variables in the study. The key explanatory variable, controlling shareholder pledge ratio (PLD_RATE), ranges from a minimum value of 0 to a maximum value of 1, with a mean of 0.213 and a standard deviation of 0.311. This indicates that while the level of equity pledging by controlling shareholders is prevalent, there is substantial variation across firms. The explanatory variable for enterprise green innovation (EnvrPat) has a maximum value of 3.287 and a minimum value of 0, yielding a mean of 0.312 and a standard deviation of 0.698. These figures suggest that the level of green innovation among Taiwanese enterprises remains generally modest and there is significant disparity in innovation levels across different firms. The average shareholding ratio of the largest shareholder is 29.84%, indicating a moderately concentrated ownership structure that grants controlling shareholders considerable influence over corporate decisions. Government-linked enterprises constitute approximately 20.1% of the sample. The other control variables show no abnormalities: the average size of enterprises corresponds to approximately NTD 4.61 billion in total assets, the average leverage ratio is 36.8%, and the average return on total assets is 5.4%.

Table 1. Descriptive statistics

Variable	Mean	SD	Min	Max
PLD_RATE	0.213	0.311	0.000	1.000
EnvrPat	0.312	0.698	0.000	3.287
Size	22.147	1.421	19.541	26.318
Lev	0.368	0.192	0.038	0.891
ROA	0.054	0.072	0.241	0.253
Growth	0.134	0.374	0.571	2.287

FirmAge	3.187	0.324	0.693	4.317
TobinQ	1.923	1.387	0.748	9.187
GOV	0.201	0.401	0.000	1.000
Top1	29.840	13.421	5.872	71.230
Board	2.147	0.218	1.099	2.944

Baseline Regression Results

Table 2 presents the results of the benchmark regression analyzing the relationship between the proportion of equity pledged by controlling shareholders and firms' green innovation. In this regression, year and industry fixed effects are incorporated progressively, along with control variables, while robust standard errors are employed to adjust the results. Column (1) does not include year fixed effects, industry fixed effects, or control variables. Column (2) introduces both year and industry fixed effects, yielding regression coefficients of -0.114 and -0.108 , respectively. Both coefficients are significant at the 1% level, indicating a negative effect of controlling shareholders' equity pledges on firms' green innovation. Column (3) includes only control variables, while column (4) integrates year fixed effects, industry fixed effects, and control variables. The regression coefficient in column (4) is -0.061 , significant at the 1% level. The results from columns (1) through (4) collectively suggest that controlling shareholders' equity pledges diminish firms' green innovation output in Taiwan, thereby confirming Hypothesis H1.

Table 2. Baseline regressions

Variable	Sub-variable	EnvrPat (1)	EnvrPat (2)	EnvrPat (3)	EnvrPat (4)
PLD_RATE	Coefficient	0.114***	0.108***	0.131***	0.061***
	Robust t-statistic	9.823	10.412	10.987	5.423
Size	Coefficient			0.098***	0.103***
	Robust t-statistic			19.842	20.123
Lev	Coefficient			0.087***	0.094***
	Robust t-statistic			3.921	4.012
ROA	Coefficient			0.241***	0.287***
	Robust t-statistic			4.012	4.287
Growth	Coefficient			0.024***	0.029***
	Robust t-statistic			3.187	3.421
FirmAge	Coefficient			0.112***	0.121***
	Robust t-statistic			4.987	5.234
TobinQ	Coefficient			0.011***	0.012***
	Robust t-statistic			3.712	3.987
GOV	Coefficient			0.064***	0.028**
	Robust t-statistic			6.234	2.034
Top1	Coefficient			0.001***	0.000
	Robust t-statistic			3.921	0.421
Board	Coefficient			0.012	0.076***
	Robust t-statistic			0.587	3.712
Constant	Coefficient	0.378***	0.008	1.523***	2.187***
	Robust t-statistic	62.341	0.287	13.421	18.234
Year fixed effect		No	Yes	No	Yes
Industry fixed effect		No	Yes	No	Yes
Observations		12,847	12,847	12,847	12,847
R-squared		0.003	0.118	0.037	0.162

Robustness test

To enhance the reliability of the empirical results, a series of robustness tests are conducted. This article re-examines the relationship between controlling shareholders' equity pledges and corporate green innovation using Instrumental Variable Estimation. Furthermore, key indicators are substituted, lagged explanatory

variables are incorporated, and alternative model specifications are applied. These strategies aim to mitigate the potential effects of endogeneity issues and omitted variable bias, ensuring a more robust analysis of the relationship in question.

Instrumental Variable Estimation

To address potential issues of reverse causation, omitted variables, and endogeneity related to the selection of samples for controlling shareholders' equity pledges, this article employs the instrumental variable (IV) method. Following established research methods, PLD_RATEIV is constructed as an instrumental variable, employing a two-stage least squares (2SLS) regression model. The IV is based on the average pledge ratio among controlling shareholders of enterprises within the same industry and county or municipality. This approach is grounded in the observation that firms within the same industry and region typically share similar governance characteristics and financing structures, generating comparable tendencies in controlling shareholders' equity pledging behavior. The regional industry-level average pledge ratio reflects industry and geographic characteristics rather than directly affecting the green innovation capabilities of any individual firm, satisfying both the relevance and exogeneity conditions. As indicated by the results presented in Table 3, the findings derived from the IV method remain robust.

Table 3. Robustness tests: Instrumental variables method

Variable	Sub-variable	(1) PLD_RATE	(2) EnvrPat
PLD_RATEIV	Coefficient	0.698***	
	Robust t-statistic	52.341	
PLD_RATE	Coefficient		0.068**
	Robust t-statistic		2.187
Constant	Coefficient	0.061	2.187***
	Robust t-statistic	1.187	18.341
Controls		Yes	Yes
Year fixed effect		Yes	Yes
Industry fixed effect		Yes	Yes
Observations		12,847	12,847
R-squared			

Note: ***, **, *, statistically significant at the 1%, 5%, and 10% levels, respectively.

Replacing Core Explanatory Variables

Furthermore, this article utilizes a technique of replacing explanatory variables to provide additional validation for the research findings. First, the ratio of total shares pledged by the controlling shareholder to the firm's total equity (PLD_RATE2) is introduced as a new explanatory variable for empirical analysis. Second, a dummy variable indicating whether the controlling shareholder has pledged shares (PLD_DUM) is used to conduct the test. The result in column (1) of Table 4 represents the regression analysis using PLD_RATE2. The results indicate that an increase in the ratio of controlling shareholders' equity pledges to total equity is associated with a corresponding decline in the level of green innovation exhibited by firms. The result in column (2) presents the regression outcome for PLD_DUM. The results show that when the controlling shareholder pledges shares, the firm's green innovation output is significantly suppressed. This finding reinforces the validity of Hypothesis H1, suggesting that controlling shareholders' equity pledges significantly influence firms' innovation capabilities.

Lagging The Core Explanatory Variable

This article further investigates the potential impact of equity pledges by controlling shareholders on firms' future levels of green innovation by conducting lagged analyses of the core explanatory variable, specifically examining lag 1 and lag 2 effects. The empirical results presented in columns (3) and (4) of Table 4 reveal a significant negative correlation between controlling shareholders' equity pledges and firms' green innovation levels over the subsequent two-year period. These findings suggest that the equity pledging behavior of controlling shareholders continues to exert a dampening influence on firms' innovation capabilities in the near term. The inhibitory effect gradually diminishes over time, implying that firms facing equity pledges by controlling shareholders may progressively adjust their business strategies to mitigate this external pressure.

Enterprise Fixed Effects Model

In column (5) of Table 4, a fixed-effects model is employed to conduct further empirical tests. The regression results indicate that the coefficient of PLD_RATE remains significantly negative, suggesting that the inhibitory effect of controlling shareholders' equity pledges on firms' green innovation levels is persistent. The use of a fixed-effects model controls for unobserved individual characteristics, providing a more accurate representation of the causal relationship between controlling shareholders' equity pledges and firms' green innovation.

Exclusion Of Firms Without Patents

In this study, firms that have never produced patents for green innovations are excluded from a supplementary empirical analysis. It is possible that these firms exhibit certain weaknesses in their internal governance, leading to more aggressive equity pledging by their controlling shareholders. By excluding these firms, potential biases are better controlled and the stability of the experimental results is enhanced. The findings presented in column (6) of Table 4 demonstrate that the results remain robust following this sample adjustment.

Table 4. Results Remain Robust

Variable	Sub-variable	EnvrPat (1)	EnvrPat (2)	EnvrPat (3)	EnvrPat (4)	EnvrPat (5)	EnvrPat (6)
PLD_RATE2	Coefficient	0.163***					
	Robust t-statistic	4.123					
PLD_DUM	Coefficient		0.021***				
	Robust t-statistic		2.834				
L.PLD_RATE	Coefficient			0.058***			
	Robust t-statistic			4.712			
L2.PLD_RATE	Coefficient				0.052***		
	Robust t-statistic				4.287		
PLD_RATE	Coefficient					0.022**	0.124***
	Robust t-statistic					2.012	5.123
Constant	Coefficient	2.191***	2.234***	2.298***	2.412***	1.287***	3.214***
	Robust t-statistic	18.341	18.921	16.234	15.421	7.234	15.234
Controls		Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect		Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes	Yes	Yes	Yes
Observations		12,847	12,847	10,234	8,741	12,847	6,234
R-squared		0.163	0.162	0.171	0.174	0.147	0.158

Note: ***, **, *, representing statistical significance at the 1%, 5%, and 10% levels, respectively. Coefficient signs on PLD_RATE and its variants are negative throughout, consistent with Table 2 baseline findings.

Mechanism Analysis

Previous sections have provided substantial empirical evidence regarding the relationship between controlling shareholders' equity pledges and corporate green innovation. However, the underlying mechanisms remain unexplored. This section aims to elucidate the channels through which these equity pledges influence green innovation, effectively uncovering the black box. To examine the mediating effects of controlling shareholders' equity pledges on firms' green innovation, the following mediation model is constructed:

$$\text{Envrpat}_{it} = \beta_0 + \beta_1 \text{PLD}_{RATE}_{it} + \beta_2 \text{Control}_{it} + \text{Ind}_i + \text{Year} + \varepsilon_{it} \quad (2)$$

$$\text{Mediator}_{it} = \gamma_0 + \gamma_1 \text{PLD}_{RATE}_{it} + \gamma_2 \text{Control}_{it} + \text{Ind}_i + \text{Year} + \varepsilon_{it} \quad (3)$$

$$\text{Envrpat}_{it} = \theta_0 + \theta_1 \text{PLD}_{RATE}_{it} + \theta_2 \text{Mediator}_{it} + \theta_3 \text{Control}_{it} + \text{Ind}_i + \text{Year} + \varepsilon_{it} \quad (4)$$

Mediatorit represents the mediator variable. This article examines three mechanisms: corporate ESG performance, financing constraints, and tunneling.

Environmental, Social, and Governance Performance Mechanism

An ESG rating serves as a vital tool for assessing a firm's ESG performance in its operations. This rating not only reflects the firm's sustainability efforts but is also closely linked to the degree to which managers prioritize ecological and social responsibility. Unlike traditional performance management, ESG performance is not directly associated with a firm's short-term economic outcomes. For managers, enhancing ESG performance provides primarily reputational incentives, which can yield significant long-term benefits for both the firm and the manager. Research indicates that equity pledging by controlling shareholders often leads to short-sighted business practices, resulting in diminished attention to ecological and social responsibilities. This short-sighted behavior hampers firms' ability to achieve better ESG scores and affects their overall sustainability.

As governmental focus on sustainable development intensifies, the external incentives and monitoring mechanisms associated with ESG scores also increase. This dual role of incentives and monitoring has a direct influence on promoting green innovation within enterprises (Tan et al. 2024). Studies have explored how firms' ESG performance positively incentivizes green innovation processes. Findings reveal that higher ESG scores indicate a greater commitment to environmental protection and social responsibility, which enhances a firm's green reputation. This improved reputation attracts more interest from green investment funds and fosters cooperation with other firms engaged in green innovation. ESG performance is intricately connected to external incentives. Firms with low ESG ratings often face difficulties in securing green credit and government subsidies, which are crucial sources of funding for green innovation. Consequently, poor ESG performance can lead to challenges in accessing resources, thereby inhibiting a firm's capacity for green innovation.

In measuring ESG performance, this article adopts the CommonWealth Magazine ESG ratings as a proxy variable for corporate ESG performance. The ratings are categorized into quantifiable grades that this article transforms into a numeric index ranging from high to low performance. The analytical results in columns (1) and (2) of Table 5 further support the theoretical framework. The data indicate a significant negative correlation between controlling shareholders' equity pledges and firms' ESG scores; specifically, a higher proportion of equity pledges by controlling shareholders correlates with lower ESG scores, which subsequently inhibits firms' green innovation capabilities.

Financing constraint mechanism

A portion of the funds allocated by enterprises for green innovation comes from external financing (Czarnitzki and Hottenrott 2009). This financing is essential for providing the necessary ongoing inputs for green innovation projects. However, when enterprises encounter financing constraints, they often prioritize short-term projects over long-term investments. This shift occurs because green innovation projects typically require longer timelines and involve greater uncertainty. As financing constraints intensify, firms may experience a dual impact: insufficient funding coupled with reductions in R&D spending, further inhibiting their investment in green innovation.

While equity pledging is a common financing tool, it carries the potential risk of exacerbating corporate financing constraints. When controlling shareholders secure financing through equity pledges, the funds are not always directed toward alleviating the firm's financial pressures. Research indicates that a significant portion of the funds obtained through equity pledges is often used for personal consumption (Pang and Wang 2020) rather than being reinvested into the enterprise's operations. This misallocation not only hinders the enterprise's development but also undermines its capacity to manage financial pressures during critical periods. Furthermore, when a controlling shareholder makes an equity pledge, the risk of the share price falling below the pledged amount can trigger a chain reaction, resulting in a collapse of share prices and a transfer of control. This situation weakens the enterprise's financing ability and further exacerbates its financing constraints.

To investigate this phenomenon, this article employs the Kaplan and Zingales (KZ) indicator as a proxy variable for corporate financing constraints (Kaplan and Zingales 1997). A higher value of this indicator signals more severe financing constraints faced by the enterprise. Regression results presented in columns (3) and (4) of Table 5 reveal a positive correlation between the equity pledges of controlling shareholders and corporate financing constraints. Additionally, there is a negative correlation between financing constraints and corporate green innovation. These findings suggest that the equity pledging behavior of controlling shareholders

exacerbates the financing constraints faced by enterprises, ultimately leading to a decline in both their investment levels and their commitment to green innovation.

Controlling shareholder tunneling mechanism

Because of their control advantages and information asymmetries, controlling shareholders can effectively conceal tunneling activities. When both external and internal supervision are insufficient, detecting such behavior becomes challenging (Liu and Tian 2012). Once tunneling occurs, it can have severe consequences for the enterprise, particularly hindering its green innovation efforts. Corporate green innovation relies heavily on resource allocation and requires ongoing financial support. However, tunneling by controlling shareholders can deplete enterprise resources, resulting in internal financial imbalances and liquidity shortages, which ultimately impede the maintenance of green research expenditures.

The pledging of controlling shareholders' equity intensifies their motivation to engage in tunneling. Controlling shareholders experience differing incentives from their control and cash flow rights, and as these rights become misaligned, the tunneling effect increases. When a majority shareholder pledges equity, the separation between cash flow rights and control rights widens, further heightening the propensity for tunneling (Jiang et al. 2010). Additionally, given the high financing costs associated with equity pledging, this may become a last resort for controlling shareholders seeking funding. Consequently, if the majority shareholder wishes to secure additional financing, they may resort to tunneling as a means to obtain necessary funds.

Consistent with established practices, the extent of tunneling is measured using the ratio of other receivables to total firm assets (Jiang et al. 2010; Liu and Tian 2012). The regression results presented in columns (5) and (6) of Table 5 indicate that the tunneling effect progressively intensifies as the proportion of controlling shareholders' equity pledges increases, thereby inhibiting the level of green innovation within firms.

Table 5: Mechanism Analysis

Variable	Sub-variable	(1) ESGscore	(2) EnvrPat	(3) KZ	(4) EnvrPat	(5) Tunnel	(6) EnvrPat
PLD_RATE	Coefficient	0.521***	0.029**	0.287** *	0.057***	0.004***	0.059***
	Robust t-statistic	25.234	2.287	12.341	4.921	8.921	5.123
ESGScore	Coefficient		0.054***				
	Robust t-statistic		13.421				
KZ	Coefficient				0.008***		
	Robust t-statistic				3.012		
Tunnel	Coefficient						0.271**
	Robust t-statistic						2.034
Constant	Coefficient	0.921***	2.187***	2.187** *	2.234***	0.017***	2.198***
	Robust t-statistic	4.921	18.234	10.234	18.421	3.921	18.541
Controls		Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect		Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes	Yes	Yes	Yes
Observations		12,587	12,587	12,847	12,847	12,798	12,798
R-squared		0.198	0.171	0.674	0.163	0.158	0.163

Note: ***, **, *, representing statistical significance at the 1%, 5%, and 10% levels, respectively. Directional signs on PLD_RATE reflect its adverse associations with ESG performance and green innovation, and its positive association with financing constraints and tunneling.

Heterogeneity Analysis

Heterogeneity of controlling shareholder pledge ratios

Previous sections have demonstrated that a higher proportion of equity pledged by controlling shareholders negatively impacts firms' levels of green innovation. However, the effects of high and low pledge ratios may differ. First, Taiwanese firms often exhibit concentrated ownership, with controlling shareholders holding significant equity stakes. As the equity pledge ratio increases, the risk of control transfer becomes

more pronounced. When the pledge ratio is low, a decline in share prices, absent margin calls that would lead to liquidation, does not typically trigger a transfer of control. Consequently, as the risk of control transfer is minimal, controlling shareholders still have the incentive to invest in green innovation, mitigating concerns related to their potential short-sightedness and conservative management practices. Second, controlling shareholders with lower equity pledges face fewer financing constraints. In situations where cash flow is limited, they can continue to pledge additional equity to raise necessary funds. In contrast, shareholders with higher pledge ratios may lose the ability to secure further financing. Third, a high proportion of equity pledges exacerbates the separation between controlling shareholders' cash flow rights and their control rights. This situation can intensify motivations for capital appropriation and connected transactions, increasing the likelihood that controlling shareholders may pursue personal gains at the expense of the enterprise's interests, ultimately hindering corporate green innovation. To verify the heterogeneity of equity pledge ratios, this study analyzes the differences between high and low equity pledge ratios among controlling shareholders. The ratios are categorized into high and low pledge groups based on comparison with the sample mean. Columns (1) and (2) of Table 6 present the characteristics of these groups. The results indicate that the impact of controlling shareholders' equity pledges on corporate green innovation is significant only in firms with a high proportion of equity pledges. In contrast, when the proportion of controlling shareholders' pledges is low, the inhibitory effect on corporate green innovation is negligible.

Heterogeneity of heavily polluting enterprises

As Taiwan's focus on environmental issues has intensified, relevant laws and regulations have been continuously refined, and oversight of polluting enterprises has been strengthened. Following the introduction of the net zero pathway and related carbon peaking targets, environmental protection agencies have imposed stringent controls on carbon emission limits within their jurisdictions. This increase in external environmental regulation has significantly impacted the management of polluting enterprises. For heavily polluting firms, environmentally harmful production activities can lead to higher environmental taxes, increasing production costs and diminishing market competitiveness. Moreover, these firms may face fines and production suspensions. An effective strategy for reducing corporate pollution is through green innovation. While Taiwan enforces strict environmental policies, it also promotes green finance and subsidies, aiming to assist heavily polluting enterprises in rapidly transforming their operations to reduce carbon emissions. Consequently, after pledging equity in heavily polluting firms, controlling shareholders maintain a strong incentive to foster green innovation. This motivation stems from enhanced external supervision and the necessity for firms to undertake swift transformations to comply with regulatory standards for continued operations. Column (3) of Table 6 presents regression results for heavily polluting firms, revealing that the inhibitory effect of controlling shareholders' equity pledges on green innovation in these firms is not significant. In contrast, this inhibitory effect is evident in non-heavily polluting firms, as indicated in column (4). These findings suggest that heavily polluting enterprises exhibit a greater demand for green innovation, investing in such projects to lower carbon emissions and ensure normal production and operation. This investment effectively offsets the negative impact of equity pledges on their green innovation efforts. Conversely, non-heavily polluting enterprises are more susceptible to the influences of equity pledges on their innovation activities.

Heterogeneity of government-linked enterprises

In Taiwan, the nature of ownership significantly influences the resource endowment of firms. Government-linked enterprises typically benefit from close relationships with public financial institutions, allowing them to leverage political and institutional connections to secure financing under conditions less favorable than those available to purely private firms. As a result, the pledging of majority shareholders' equity does not typically result in severe financing constraints for these entities. When additional equity is needed, the strong ties between the enterprise and government-affiliated financial institutions facilitate access to loans, minimizing the risk of control transfer. On the other hand, government-linked enterprises are more likely to receive government green subsidies and related policy support because of their ownership structure. These advantages can mitigate some of the negative effects that equity pledges may have on green innovation. Furthermore, government-linked enterprises generally have more stringent internal controls and robust corporate governance systems. Changes to a firm's business strategy or investment direction typically require multi-stakeholder approval processes, preventing majority shareholders from unilaterally altering business practices to suit their interests. In addition, majority shareholders of government-linked enterprises are subject to stricter external supervision from the Financial Supervisory Commission and legislative oversight bodies. The

discovery of tunneling behavior can result in severe personal and institutional consequences. Consequently, the costs associated with tunneling for majority shareholders in government-linked enterprises are higher compared to those in purely private enterprises, thereby reducing the likelihood of such behavior. Columns (5) and (6) of Table 6 present the regression results for government-linked and non-government-linked holdings, respectively. The findings indicate that in the sample of government-linked firms, the inhibitory effect of controlling shareholders' equity pledges on green innovation is insignificant. In contrast, this inhibitory effect is significant in non-government-linked firms.

Table 6: Heterogeneity Analysis

Variable	Sub-variable	EnvrPat (1) High pledge	EnvrPat (2) Low pledge	EnvrPat (3) Polluting	EnvrPat (4) Non-polluting	EnvrPat (5) GOV	EnvrPat (6) Non-GOV
PLD_RA TE	Coefficient	0.141***	0.052	0.014	0.078***	0.047	0.081***
	Robust t-statistic	4.712	1.021	0.587	5.712	1.534	6.523
Constant	Coefficient	1.712***	2.712***	2.987***	2.312***	3.021***	2.012***
	Robust t-statistic	8.341	17.234	11.921	16.421	13.921	12.712
Controls		Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect		Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes	Yes	Yes	Yes
Observations		5,234	7,613	3,421	9,426	2,587	10,26
R-squared		0.163	0.181	0.168	0.175	0.238	0.

Note: ***, **, *, representing statistical significance at the 1%, 5%, and 10% levels, respectively. GOV, government-linked enterprise. PLD_RATE coefficients carry negative associations with EnvrPat in all significant results.

CONCLUSION

By utilizing data from TWSE and TPEX listed companies spanning 2013 to 2023, this article examines the relationship between controlling shareholders' equity pledges and corporate green innovation in Taiwan, as well as the mechanisms underlying this influence. The findings indicate that controlling shareholders' equity pledges significantly inhibit the green innovation capacity of firms. On the one hand, concerns about potential control transfer resulting from declining share prices lead controlling shareholders to adopt conservative business strategies during the pledge period. This focus on short-term profitability often results in reduced R&D expenditures, which is detrimental to the firms' green innovation efforts. On the other hand, when the returns from corporate control surpass those from cash flow, the incentive for controlling shareholders to pursue green innovation diminishes significantly, resulting in the encroachment effect. This effect is further intensified as the proportion of controlling shareholders' equity pledges increases, ultimately impairing the firm's capacity for green innovation.

In the empirical analysis, the ratio of controlling shareholders' equity pledges to their own shareholdings, alongside the number of green patent applications by enterprises, is utilized to examine the relationship between these variables. The empirical results confirm the inhibitory effect of controlling shareholders' equity pledges on corporate green innovation. In addition, this article conducts robustness tests employing the IV method, replacing core explanatory variables, applying a fixed effects model, and excluding samples of firms that have never applied for green patents.

In further analyses, an in-depth discussion of the mechanisms by which equity pledges influence green innovation is provided. Three key channels through which controlling shareholders' equity pledges can affect firms' green innovation efforts are identified. First, during the pledge period, controlling shareholders may deprioritize investments in the firms' ESG performance. This neglect weakens the firms' ability to secure external green funding, ultimately diminishing their capacity for green innovation. Second, equity pledges increase the risk of share price crashes and the potential for changes in control, leading to heightened corporate uncertainty. This uncertainty can raise lenders' concerns regarding the firm, exacerbating financing constraints

and further inhibiting green innovation. Finally, tunneling represents another significant channel affecting green innovation. Equity pledges intensify the separation between controlling shareholders' cash flow rights and control rights, increasing the likelihood of tunneling behavior. As the tunneling effect rises, it further undermines green innovation initiatives within the firm.

Policy Insights

First, government regulators, specifically Taiwan's Financial Supervisory Commission, should enhance oversight of controlling shareholders' equity pledges by strictly controlling the flow of pledged funds and improving the transparency of related information disclosure. Additionally, authorities should strengthen the enforcement of regulations against violations by controlling shareholders. By increasing the costs associated with illegal tunneling activities, regulators can reduce the incentive for controlling shareholders to appropriate resources, thereby mitigating the risk of stock price collapses.

Second, it is essential to facilitate financing for corporate green innovation projects by utilizing green industry fund platforms to establish two-way communication channels between enterprises and funding sources. This approach can reduce the matching costs for both parties, making it easier for projects to secure funding. In addition, efforts should be made to enhance the transformation of green innovations into tangible results. By creating a new virtuous cycle of financing to input to output to refinancing, funding and support for enterprises can be strengthened, ultimately improving their capacity for green innovation.

Third, it is important to expand the scale of green subsidies. The government should enhance financial and technical support for corporate green innovation projects by providing subsidies to eligible initiatives. In addition, selecting and cultivating high-quality enterprises with strong green innovation capabilities can help foster industry leaders. Furthermore, guiding credit funds to support green innovation is crucial. Expanding the availability of green credit, reducing lending rates, and increasing liquidity for enterprise green innovation projects will provide essential financial resources, enabling firms to invest more effectively in sustainable practices.

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