

The Impact of Corporate Green Technological Innovation on Environmental, Social and Governance- An Empirical Analysis Based on Green Patent Data from Chinese A-Share Listed Companies

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Abstract:

Against the backdrop of China's dual carbon goals, green innovation has become a critical pathway for enterprises to achieve sustainable development. This study examines the impact of green patents on corporate Environmental, Social and Governance (ESG) performance using panel data from Chinese A-share listed companies between 2015 and 2023, further exploring the moderating effects of firm size and state-owned attributes. Employing a fixed-effects regression model with interaction terms to capture moderation effects, the findings reveal that: Regression results indicate that the quantity of green patents exerts a significant positive influence on corporate ESG scores, with green innovation activities enhancing overall performance across environmental, social, and governance dimensions. Further moderation analysis reveals that firm size exerts a significant negative moderating effect on the relationship between green patents and ESG performance, whereas state-owned enterprise status does not significantly impact this relationship. This study enriches empirical evidence on the linkage between green innovation and ESG performance, providing a reference for governments to formulate differentiated green policies and for enterprises to implement sustainable development strategies.

Keywords: Green patents; ESG performance; firm size; state-owned enterprises; moderating effect.

1. Introduction

Against the backdrop of increasingly reinforced global sustainability principles, ESG (Environmental, Social, and Governance) has become a crucial metric for assessing corporate long-term value and non-financial performance. Particularly under the guidance of the “dual carbon” strategy, green transition, and high-quality development objectives, how to drive enterprises to genuinely fulfil green responsibilities while avoiding “greenwashing” has become a widely debated topic in both academic and practical circles. Chinese regulators have successively introduced multiple policies to advance corporate ESG disclosure. Concurrently, green technological innovation has been incorporated into national strategic planning, with various policy initiatives and action plans setting explicit requirements for green patent and clean technology development. Although ESG rating systems have been refined in recent years and corporate ESG performance is now widely accepted by investors and the public, most existing research still relies on voluntarily disclosed information. This approach suffers from strong subjectivity in data and risks “formal compliance” without “substantive alignment”. This study attempts to introduce green patents as a quantifiable, verifiable objective metric representing companies’ genuine investment in environmental technological innovation, thereby assessing their relationship with overall corporate ESG scores. Utilising panel data and fixed-effects models, the paper not only examines the direct effects of green patents but also analyses the moderating roles of firm attributes (such as state-owned status) and scale factors. Compared to prior research, this study offers the following innovations and theoretical significance: First, it incorporates green technological innovation into the ESG performance research framework, constructing a causal model linking green patents and ESG. Second, it introduces moderating variables to identify the influence mechanisms on independent variables, examining the roles of state-owned enterprises and large firms in green development. Third, it matches ESG quantitative scores with China National Intellectual Property Administration (CNIPA) green patent data, enhancing the objectivity and verifiability of empirical evidence.

2. Literature Review

The relationship between corporate green technological innovation and ESG performance is underpinned by three core theoretical frameworks.

Ecological modernisation theory proposes, from a macro perspective, that technological progress and enhanced resource efficiency can address ecological crises. Empirical evidence shows a correlation between environmental technology development and reduced ecological footprints,

supporting the positive impact of green innovation on ESG. However, it remains necessary to examine whether this influence is more pronounced at the micro-level of individual enterprises [1]. Resource-Based Theory focuses internally, emphasising how scarce, non-imitable core resources confer competitive advantage. Green patents, as critical resources, reflect technological and innovative capabilities while serving as key factors in ESG evaluation, thereby illuminating the link between resource endowment and sustainable development [2]. Dynamic Capabilities Theory explains the transformation process, indicating that firms must strategically adjust, undergo organisational change, and engage in external collaboration to convert resources like green patents into ESG improvements and enhanced market value [3]. Together, these three theories form a multi-dimensional theoretical foundation, providing logical support for empirical analysis.

Macro-level research predominantly examines the relationship between R&D expenditure and sustainable development at the national level. Scholar’s utilising panel data methods and machine learning algorithms across 193 countries’ ESG data from 2011–2020 found that R&D expenditure as a proportion of Gross Domestic Product (GDP) exhibits significant positive correlations with greenhouse gas emissions and scientific paper output, while exhibiting a negative correlation with extreme climate indicators. This reveals the complex, multidimensional mechanisms linking innovation investment to environmental performance, providing theoretical grounding for the interplay between corporate green technological innovation and ESG performance. However, this research primarily utilises national-level data without distinguishing between types of corporate green technologies or innovation pathways, making it difficult to elucidate the specific linkages between green patents and ESG performance at the micro level [4]. Separately, scholars incorporating the ease of doing business (EDB) into the ESG framework analysed data from 193 countries spanning 2011–2020. Findings indicate that EDB levels exhibit significant positive correlations with internet usage rates and government effectiveness, while showing negative correlations with agricultural value-added and forest area. Through clustering and machine learning, they predicted an overall improvement trend in EDB, highlighting the importance of institutional environments and governance factors within ESG models. This provides a macro-level institutional context for understanding the relationship between corporate green innovation and ESG performance, yet similarly remains confined to the national level, failing to elucidate the micro-level mechanisms through which institutional and governance environments influence corporate technological innovation [5].

At the financial level, some scholars, adopting a financial intermediation perspective, employ systematic literature

reviews and cluster analysis to highlight banking's pivotal role in ecological transition and sustainable investment. Integrating ESG factors into credit decisions can channel capital towards green projects, bolstering financial stability and economic growth. While risks and challenges persist, they present opportunities for banks to enhance competitiveness and build resilient financial systems. While these studies provide theoretical underpinnings for understanding the relationship between financial resource allocation and corporate ESG performance, they focus on macro-level credit supply mechanisms and lack analysis of the micro-level processes through which corporate green technological innovation translates into ESG performance via capital markets or credit channels [6]. At the market level, investor-perspective research based on surveys and portfolio data reveals that most retail investors anticipate lower long-term returns from ESG investments compared to the overall market. Investment motivations exhibit heterogeneity (moral considerations, climate hedging, or return expectations), with these motivations closely linked to holding behaviour. Those with ethical motivations exhibit higher ESG investment proportions, yet even among those pursuing ethics or hedging, investment remains limited without belief in ESG generating excess returns. This highlights finance considerations as decisive in ESG investment decisions, offering behavioural finance insights into market participants' perceptions and preferences. However, these studies do not delve into how corporate green innovation impacts ESG investment value and performance evaluation [7].

At the corporate level, scholars analysing environmental patent data from 35 countries between 1982 and 2016 found a significant correlation between environmental technological innovation and reduced per capita ecological footprint. This validates the positive impact of technological progress on environmental performance, though its marginal effect is limited, indicating that technological innovation alone cannot achieve comprehensive ecological sustainability. This provides theoretical support for the relationship between green technological innovation and ESG performance, while underscoring the importance of exploring the mechanism through which corporate green patents influence ESG performance [8]. Separately, research utilising data from Chinese A-share listed companies reveals that strong ESG performance significantly stimulates corporate green technological innovation. This effect is more pronounced in eastern and western regions and among state-owned enterprises, with executive incentive mechanisms exerting a positive moderating influence. This provides empirical evidence for enterprises achieving green transformation and high-quality development through enhanced ESG performance, while illuminating the critical impact of corporate governance factors [9]. Regarding green patent commercialisation, one study an-

alysed the university-to-industry transfer of high-value invention patents in energy conservation and environmental protection across 34 Chinese "Double First-Class" science and engineering universities. It identified bottlenecks such as low conversion efficiency and insufficient corporate absorption capacity, emphasising the significance of green technology flows between academia, industry, and research for high-quality green economic development. However, while focusing on industry-academia-research collaboration and patent conversion, it did not delve into the enhancement mechanisms whereby autonomous corporate green innovation improves ESG performance [10]. Empirical research based on 2016–2023 panel data from A-share listed companies further demonstrates that strong ESG performance significantly enhances corporate value and stimulates green innovation. Green innovation plays a partial mediating role in this value-enhancement process, underscoring the critical position of green technological innovation within corporate sustainability strategies. This provides practical guidance for developing integrated ESG-value enhancement strategies. However, while focusing on the ESG-enterprise value pathway, there remains a lack of in-depth discussion on the reverse effect of green innovation shaping ESG performance [11]. Accordingly, this paper proposes the following hypotheses.

H1: Green technological innovation significantly influences corporate ESG performance

H2: Firm characteristics and firm size moderate the relationship between green technological innovation and corporate ESG performance.

3. Research Design

3.1 Methodology and Sample

This study examines A-share listed companies in China, utilising data from 2015 to 2023 to construct firm-level panel data for empirical analysis. The research aims to investigate the impact of green patent output on firms' overall ESG performance, further introducing firm size and state-owned status as moderating variables to explore their moderating mechanisms within this relationship.

Methodologically, a fixed effects model is employed to control unobservable individual heterogeneity, enhancing the robustness of estimation results. Interaction terms are constructed to analyse moderation effects. Data sources comprise: Corporate ESG ratings from SynTao Green Finance via the China Stock Market & Accounting Research Database (CSMAR) database - green patent and financial data primarily from Chinese Research Data Services (CNRDS) and CSMAR databases - Corporate ownership status referenced from the data platform availability in Fudan DMG: 2023 China Provincial Public Data Openness and

Utilisation Report

3.2 Variable Explanation

The dependent variable in this study is ESG_Score (corporate ESG composite score), reflecting a company's overall performance across environmental, social, and governance dimensions. This serves as a key indicator for measuring sustainable development capability, utilising raw scoring data from SynTao Green Finance's ESG rating system within the CSMAR database without logarithmic transformation.

The independent variable is Green_Patent (number of green patents), gauging corporate green technological innovation. Considering the quantifiability and objectivity of green patents, and following multidimensional disaggregation, the core explanatory variable selected is "number of green invention patents independently obtained in the current year".

The moderating variables include SOE_Dum (dummy variable for state-owned enterprise status, valued at 1 for SOEs and 0 for non-SOEs) and Log_Scale (firm scale, represented by the natural logarithm of total assets to mitigate outlier interference). These explore the moderating effects of state ownership and firm scale on the relationship between green innovation and ESG performance.

The interaction terms are interaction1 (Green_Patent $\times$ SOE_Dum) and interaction2 (Green_Patent $\times$ Log_Scale), both constructed after centring the variables to test moderation effects and mitigate multicollinearity.

The control variables comprise six items: Green_Share (proportion of green patents to total patents; smoothed as Green_Patent/10 when total patents = 0; data sourced from CNRDS); return on equity (ROE), reflecting profitability and Leverage (debt-to-equity ratio, measuring risk and capital structure), both using raw data; Log_Liquidity (logarithm of current ratio, measuring short-term solvency); Log_Herf (logarithm of industry Herfindahl index, controlling for industry competition). ROE, Leverage, Log_Liquidity, and Log_Herf data are sourced from CSMAR.

To examine whether the ownership background moderates

the effect of green innovation on sustainability scores, this paper constructs an interaction term between the number of green patents and the dummy variable for state-owned enterprises. Specifically, the green patent variable (green_patent) and the SOE dummy variable (soe_dum) were first globally mean-centred to mitigate multicollinearity and enhance the interpretability of the interaction term. Subsequently, the interaction variable interaction1 = c_green_patent $\times$ c_soe_dum was generated to capture the moderating role of SOE attributes in the relationship between green innovation and corporate sustainability.

Considering that large-scale enterprises may possess stronger resource allocation capabilities and green transition momentum, this study further introduces an interaction term between green patents and firm size (represented by the logarithm of total assets, log_scale). Similarly, both the green patent and firm size variables were centred before constructing the interaction variable interaction2 = c_green_patent $\times$ c_log_scale to examine the moderating effect of firm size on green innovation's impact on sustainability performance. This interaction term helps reveal the potential mechanism through which scale heterogeneity influences the utility of green patents.

Create a new smoothed variable green_share.

If total patents > 0: "green_share=green_patent / total_patent" (normal proportional calculation)

If total patents = 0: "green_share=green_patent / 10" (add a smoothing base value of 10 to the denominator to prevent 0/0)

3.3 Model Specification

$$ESG_{score} = \beta_0 + \beta_1 Green_{patent} + \beta_2 SOE_{dum} + \beta_3 Log_{scale} + \beta_4 interaction1 + \beta_5 interaction2 + \beta_6 Log_{liquidity} + \beta_7 ROE + \beta_8 Leverage + \beta_9 Green_{share} + \beta_{10} Log_{herf} \quad (1)$$

4. Regression Analysis Results

4.1 Descriptive Statistics

Table 1. Descriptive analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
green_patent	2367	3.319814	15.87747	0.0	347.0
soe_dum	2367	0.471905	0.499316	0.0	1.0
log_scale	2367	24.66878	1.370189	20.9704	28.69688
interaction1	2367	0.056514	7.769817	-162.1845	60.0339
interaction2	2367	5.219607	34.06647	-25.59501	775.5966
log_liquidity	2367	0.395534	0.71626	-2.240014	3.444528
ROE	2365	0.109485	0.183021	-5.547591	0.766921

leverage	2249	1.318167	1.898998	-6.364799	48.7388
green_share	2367	0.040329	0.126602	0.0	1.0
log_herf	2367	-1.843331	0.817149	-5.518964	-0.210717

This paper conducted descriptive statistical analysis on ten variables, including core explanatory variables, moderator variables, and control variables, with a total sample size of 2367 (Table 1). Results indicate that the mean value for corporate green patents (green_patent) is 3.32, yet the standard deviation is notably high at 15.88. The minimum value is 0, while the maximum reaches 347, demonstrating extremely uneven distribution of green innovation investment across enterprises. A substantial number of firms have yet to engage in green technology patent strategy, whereas a minority exhibit exceptionally high green invention output.

The dummy variable for state-owned enterprises (soe_dum) had a mean of 0.472, indicating approximately 47.2% of the sample comprised state-owned enterprises, suggesting overall balance in ownership structure. The enterprise scale variable (log_scale), expressed as the natural logarithm of total assets, had a mean of 24.67 and a standard deviation of 1.37, indicating relatively concentrated enterprise scale within the sample, though some variation persisted.

Two interaction variables were also included in the analysis. The meaning of the interaction term between green_

patent and soe_dum (interaction1) was 0.056, yet its standard deviation reached 7.77, with a maximum value of 60 and a minimum of -162. This indicates significant variation in the moderating effect of SOE status on green innovation across firms. The meaning of the interaction term between green_patent and log_scale (interaction2) was 5.22, with a standard deviation of 34.07 and a maximum value of 775.6. This similarly indicates substantial variation in the amplifying effect of enterprise scale on green patent outcomes across the sample.

The mean green patent share (green_share) stands at merely 0.040, indicating green patents constitute only approximately 4% of total patents. This suggests green technological innovation has yet to become the predominant direction for corporate patent applications. The mean industry concentration (log_herf) is -1.84, reflecting a relatively fragmented market structure and intense competition across most sectors.

Collectively, these statistical findings suggest significant heterogeneity in corporate green innovation behaviour within the sample, while also providing preliminary groundwork for subsequent regression analysis.

4.2 Analysis of Regression Results

Table 2. Regression results

Variable	Coefficient	Standard Error	t	P > t	[95% Conf. Interval] (Lower)	[95% Conf. Interval] (Upper)
green_patent	0.3943123	0.0937524	4.21	0.0	0.2101314	0.5784932
soe_dum	-0.933846	2.758803	-0.34	0.735	-6.353639	4.485947
log_scale	32.06941	1.296471	24.74	0.0	29.52244	34.61639
interaction1	1.1458436	0.0952058	1.53	0.126	-0.0411926	0.3328798
interaction2	-0.0776867	0.0388354	-2.0	0.046	-0.1539805	-0.0013928
log_liquidity	7.293835	1.59928	4.56	0.0	4.151977	10.43569
ROE	-12.71233	6.867876	-1.85	0.065	-26.20459	0.7799201
leverage	-0.251544	0.1875979	-1.34	0.181	-0.6200886	0.1170007
green_share	1.577283	3.808934	0.41	0.679	-5.905541	9.060108
log_herf	-8.417286	2.441215	-3.45	0.001	-13.21316	-3.621408

As shown in Table 2, the coefficient for green_patent (number of green patents) is 0.3943, significant at the 1% level. Each additional green patent increases the firm's ESG score by approximately 0.394 on average, indicating that green technological innovation has a positive and statistically significant impact on corporate sustainability performance, thereby validating Hypothesis 1.

The coefficient for soe_dum (SOE dummy variable) is -0.9338, not significant (P = 0.735). This indicates that, controlling for other variables, state-owned enterprises do not exhibit significantly higher or lower ESG scores than non-state-owned enterprises, suggesting that ownership attributes themselves do not directly influence ESG performance.

The coefficient for $\log_scale$ (firm size) is 32.0694, significant at the 1% level ($P = 0.000$). This indicates that for each natural logarithm unit increase in firm size, the ESG score rises by approximately 32 points, suggesting larger firms are more likely to exhibit superior ESG performance, thereby validating Hypothesis 2.

The coefficient for interaction1 ($green_patent \times soe_dum$) is 1.1458, not significant ($P = 0.126$), but directionally positive. This suggests green patents may yield marginally higher ESG effects in SOEs, though inconclusive due to non-significance.

The coefficient for interaction2 ($green_patent \times \log_scale$) is -0.0779, significant at the 5% level ($P = 0.046$). This indicates that the marginal improvement of green patents on ESG weakens as firm size increases, reflecting diminishing marginal returns. This suggests that green innovation yields greater marginal benefits in small and medium-sized enterprises.

5. Discussion and Recommendations

Regression results demonstrate that the volume of green patent grants ($green_patent$) significantly and positively influences corporate ESG performance. This indicates that green technological innovation receives positive recognition within ESG evaluation frameworks, with environmentally friendly corporate behaviour contributing to sustainable development ratings. This aligns with Gu and Yang's findings that green technological innovation enhances environmental performance alongside non-financial dimensions such as social responsibility and governance structures [2].

Interaction term results reveal that the interaction between green patents and state-owned enterprise status (interaction1) is insignificant, whereas the interaction with firm size (interaction2) exhibits a significant negative correlation. This indicates diminishing marginal ESG benefits from green innovation in large enterprises, with SMEs deriving more pronounced advantages. Future ESG institutional design should therefore strengthen innovation incentives for SMEs.

The state-owned enterprise dummy variable (soe_dum) exhibits no significant impact on ESG scores ($p=0.735$), with no discernible positive spillover effect even when controlling for green patent levels. This aligns with Xing Miao's research, indicating that under market-oriented policy frameworks, private enterprises demonstrate comparable green innovation activity and ESG performance to SOEs, even exhibiting greater advantages in innovation efficiency and market adaptability. This reflects the weakening of traditional resource advantages held by SOEs, with ESG frameworks and green subsidies now facilitating innovation opportunities across all market participants [3].

Based on this, policy recommendations are proposed. Firstly, develop simplified green ESG cost-benefit assessment tools for SMEs to lower participation barriers. Secondly, promote synergy between ESG and green finance by incorporating ESG performance into green credit subsidy evaluations and linking it to financing costs. Thirdly, enhance ESG disclosure by refining green technology indicators to improve assessment accuracy.

6. Conclusion

This study empirically analyses the impact of corporate green patent output on comprehensive ESG scores using 2015–2023 panel data from Chinese listed companies, further examining the moderating effects of state-owned status and firm size on this relationship. Regression results reveal a significant positive correlation between green patent output and ESG scores, indicating green innovation positively enhances corporate sustainability performance. Regarding moderating effects, the interaction term between firm size and green patents exhibits significant negativity, indicating that green patents yield weaker marginal improvements in ESG scores for larger enterprises. Conversely, the interaction term between state-owned status and green patents shows no significance, suggesting that the impact mechanism of green innovation on ESG may be similar or masked by other factors across state-owned and non-state-owned enterprises.

This study enriches empirical evidence on the relationship between green innovation and sustainable development, while providing decision-making references for policymakers and corporate management: firms should be encouraged to invest in green technologies, particularly unlocking greater potential within small and medium-sized enterprises. Future research may further incorporate heterogeneity analysis or consider additional moderation mechanisms to deepen understanding of the causal relationship between green innovation and ESG.

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