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Research article

Environmental innovation for competing firms: Key ESG dimension shaping strategies and profitability

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ABSTRACT

We integrate a game-theoretic model with an empirical analysis using system GMM model to provide a holistic approach in studying ESG (Environment, Social, and Governance) issues and to clarify the ongoing debate surrounding the impact of ESG initiatives on firm performance. Specifically, we focus on environmental innovation to examine whether such activities are associated with improved financial outcomes, while accounting for moderating roles of market and firm characteristics. We also incorporate firms' environmental reputation stocks, recognizing their critical influence on long-term financial performances. Our findings show that financial returns of environmental innovation are shaped by market and firm-level factors underscoring the importance of competitive dynamics and strategic decision-making. At the market level, the intensity of competition and the environmental innovation efforts of peer firms significantly affect individual firms' performances. At the firm level, we find that companies with stronger existing reputations in environmental innovation and greater innovation effectiveness and efficiency are better positioned to realize financial gains from their investments. Moreover, we differentiate the distinct effects of product-based versus price-based competition, highlighting their comparable influence. Overall, our study emphasizes the need for firm-specific capabilities, stakeholder alignment, and favorable market conditions to achieve sustainable competitive advantage through environmental innovation.

1. Introduction

Socially responsible investments (SRI) started in the 1960's and evolved into ESG (Environment, Social, and Governance) considerations when the term was first coined by the United Nations in 2004 (Bernoville, 2024). NAVEX Global study (including management and senior level executives in the U.S., U.K., France, and Germany) showed that 88 % of publicly traded companies, 79 % of venture and private equity-backed companies, and more than two-third of privately-owned companies have ESG initiatives (NAVEX, 2021). As the co-founder of Plan A, Nathan Bonnisseau stated: "*ESG will likely play a more significant role in how companies are assessed by investors, consumers, and stakeholders*." (Bernoville, 2024) Sustainability considerations related to ESG investments encompass ecological impact toward the environment, social impact toward the community and stakeholders, and organizational impact via systems, protocols and structures for planning, implementing, and monitoring good business practices. Khaw et al. (2024) aggregated the key factors to influence ESG performance including digital transformation, financial strategies, corporate social responsibility (CSR) strategy and dedicated committee, regulatory and policy mechanisms, governance approach, board diversity, and organizational excellence. Hence, ESG initiatives and their impact are not only important for companies but also for investors, consumers, governments, and any other stakeholders that have interest in the company. To illustrate, 89 % of investors consider ESG funds critical investment decisions according to the asset management *Capital Group's ESG Global Study 2022*. Various eco-friendly initiatives are being implemented such as SolarCity, part of Tesla, to enhance the adoption of solar energy, Interface Inc. implementing closed-loop recycling system, and Ecovative Design using sustainable packaging plant-based materials.

Asset management firms often advocate for ESG investments to achieve superior financial returns. However, the veracity of these claims

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remains uncertain. While numerous studies have endeavored to establish a definitive link between high ESG ratings and equity returns, the findings have been mixed with positive results (e.g., Danso et al., 2019; Chen et al., 2023), negative results (e.g., Pomarici et al., 2015; Jaeger and Upadhyay, 2020), and even U-shaped relationship by having a changing effect over time (Franco et al., 2020). This ambiguity within the literature suggests a need for a more nuanced examination, perhaps focusing on specific dimensions of ESG rather than its entirety as suggested by Taddeo et al. (2024). They studied companies listed in the Euro Stoxx 300 index and used a combination of qualitative metrics related to ESG standards with quantitative metrics and a dynamic panel model. The results indicate that ESG initiatives are associated with increased profits and each ESG dimension plays a different role which may explain the inconsistencies of results in previous literature. They showed that firms that implement all ESG practices simultaneously may see their profits decrease. Hence, it is better to focus strategically on one ESG dimension.

The literature on organizational innovation underscores the significant impact of innovation on firms' financial performance. Notably, environmental innovation driven by stakeholders' growing concern over environmental footprints has garnered substantial attention from firms in various industries. For instance, in the agriculture field, Stonyfield Organic aims to achieve a 30 % reduction in emissions by 2030 through optimized energy usage, waste conservation, and integration of sustainable packaging and logistics. In the auto industry, Toyota designed Prius as the first mass-market hybrid car. In the travel industry, Lyft is known for its carbon neutral-ride, and United Airlines invested more than $16 billion for more fuel-efficient airplanes. In the hospitality/restaurant industry, Taco Bell is a leader in meatless menus and eco-friendly ingredients. In the retail industry, Patagonia uses at least 75 % of its materials from sustainable places and donates 1 % of profits to environmentally friendly groups (Morgan, 2019). Consequently, our paper directs its attention toward environmental innovation, aiming to ascertain whether these innovation activities are associated with higher financial returns while also considering the moderating effects of market and firm characteristics to include important external determinants as debated by Martiny et al., (2024). By delving into the financial implications of environmental innovation investment, rather than the broader concept of ESG investment, this study seeks to redirect focus toward more productive pursuits.

Moreover, our paper includes the importance of the company's environmental reputation, which also could play a critical role in the impact of ESG initiatives on financial performance over a long period of time. To illustrate, Whelan et al. (2021) concluded in their meta-analysis that ESG impact on financial performance is more significant over longer time horizons.

An additional contribution of our paper is to merge two big streams of research on ESG practices, namely game theoretical research and empirical research to enhance the robustness of our results and create synergy between two major perspectives of analyzing the impact of ESG practices.

Our empirical investigation primarily examines the direct impact of firms' environmental innovation on profitability using Tobin's Q as a dependent variable reflecting the investor's evaluation of firm's profitability. Such a measure has been widely used in previous literature (e.g., Dalal and Thaker, 2019; Aydoğmuş et al., 2022; Giannopoulos et al., 2022; Bissoondoyal-Bheenick et al., 2023; Hwang et al., 2024).

Dong et al. (2014) demonstrated the significant impact of various types of eco-innovation activities on performance and competitiveness. Hence, we include the moderating effects of two market characteristics namely peers' environmental innovation and market competition, and two firm characteristics namely environmental innovation efficiency/effectiveness and prior environmental reputation. Broadstock et al. (2020) explained that the conflicting results in the literature may be due to the missing links between CSR practices and firms' performance. These links are explained as the indirect effects of CSR on firms' performance generating an indirect value creation (Lioui and Sharma, 2012). Hence, we intend to fill the gap by incorporating the firm's environmental reputation that boosts the consumer baseline market and has an indirect effect on enhancing performance. Consequently, our research questions are as follows.

(1) What is the effect of firms' investments in environmental innovation on their respective financial performances (i.e., profits in both models, analytical one and empirical one)?
(2) How do peers' environmental innovation investments and market competition intensity (measured by the HHI index in the empirical model and price competition in the analytical model) moderate the relationship between firms' innovation efforts and their financial performances?
(3) What are the moderating effects of firms' environmental innovation efficiencies and prior environmental reputations on this relationship?

Our analytical analyses show that investing in environmental innovation is profitable for the firm while it is detrimental for the competing firm that does not invest in such innovation. The result illustrates the importance of environmental innovation as an asset for competitive advantage. The peer's innovation would motivate the focal firm to invest more in environmental innovation to keep such competitive advantage. However, there is a moderating influence of market-level innovation undertaken by peers which entails that a heavy investment in environmental innovation by the peer's firm diminishes the financial returns of the focal firm from its own environmental investment. Our analytical findings also show that a lack of effectiveness in environmental innovation's investment implies a loss of competitive advantage or even an exit from the market. However, a higher firm's prior reputation in environmental innovation boosts customers' trust in the firm, which ultimately increases its profit. Finally, our analytical model demonstrates that price-based market competition negatively moderates the effect of environmental innovation effort on the firm's financial performance due to customers' sensitivity to price. Our empirical result focusing on product-based competition demonstrates similar results reflecting the importance of a strategic choice by companies on what type/intensity level of competition to compete on (either using product or price competition). In addition, our empirical results indicate that the financial benefits (measured using Tobin's Q) associated with environmental innovation are most pronounced in markets with moderate levels of competition and where peer firms engage in comparable levels of innovation. The result is consistent with our analytical findings showing a curvilinear moderating influence of market-level environmental innovation undertaken by peers. On the firm level, companies with strong pre-existing environmental reputations and greater innovation effectiveness and efficiency are better equipped to leverage these initiatives, in line with our analytical insights.

The rest of the paper is organized as follows. Section 2 reports the literature review related to ESG practices and strategic initiatives using analytical and empirical methodologies. Section 3 describes the game theoretic model and analytical results. Section 4 illustrates the data and methodology used in the GMM model and discusses the empirical results. Section 5 summarizes and discusses the main findings and describes the theoretical and managerial implications. Section 6 concludes with potential future research directions.

2. Literature review

A group of studies performed a meta-analysis and extensive literature reviews to understand the relationship between ESG practices and financial performance from different perspectives (e.g., Whelan et al., 2021; Gillan et al., 2021; Khan, 2022; Martiny et al., 2024). In some studies, the bibliometric analysis is specific to an industry (e.g., Trotta et al., 2024 in the FinTech industry, and Legendre et al., 2024 in the

hospitality industry). We summarize below some of the main conclusions of Whelan et al. (2021) who reviewed more than 1000 papers published between 2015 and 2020.

- The ESG impact on financial performance is more significant over longer time horizons.
- ESG adoption as a strategic integration performs better than marginal or limited initiatives.
- Better innovation and risk management play a mediating role in the impact of sustainability initiatives on financial performance.
- The simple disclosure of ESG initiatives is not sufficient to drive financial performance.

The meta-analysis also showed that close or above 60 % of studies found a positive relationship between ESG and financial performance. Mixed, neutral and negative results were also shown in several studies but at lower rates (e.g., 8 % of corporate studies found a negative relationship compared to 14 % of investment studies). While over two-thirds of previous studies indicate at least a non-negative correlation between ESG and financial returns (e.g., Danso et al., 2019; Franco et al., 2020; Chen et al., 2023), none have conclusively demonstrated that ESG directly causes higher returns. Some research studies have even cast doubt on the purported connection between ESG and outperformance and showed a neutral relationship (e.g. Ortiz-de-Mandojana and Aragon-Correa, 2015; Zou et al., 2015). Martiny et al. (2024) highlighted the major use of internal determinants (e.g., financial characteristics in addition to resources and corporate structure) rather than external determinants (e.g., regulations in addition to country and industry characteristics) of ESG performance which could lead to an incomplete understanding of the factors affecting long-term sustainable performance.

Following the extensive literature review findings, we include the company's reputation as an important component of our models to consider the long-term effect of environmental innovation. To illustrate, Chen et al. (2021) considered the return on total assets (ROA) and showed that ESG investments have a substitution effect in the short term (i.e., negative effect on firm's performance due to high costs) mainly for small and mid-sized firms and a promotional effect in the long term. The study highlights the role of building an ESG reputation over time to reinforce the positive effect on the firm's performance. In addition, we incorporate ESG investments as a strategic decision variable and consider internal and external factors to have an exhaustive view of ESG impact on profitability.

Various studies tackled the topic of ESG initiatives using game theory or empirical methodologies as explained next.

2.1. Game theoretic literature

Multiple studies looked at the ESG topic from a supply chain perspective including consumer's level. Khosroshahi et al. (2019) examined the impact of manufacturer's transparency on the profits of the supply chain members and customer satisfaction. They also proposed a new consumer satisfaction index as a corporate social responsibility (CSR) metric. They analyzed a centralized supply chain, a decentralized supply chain without CSR concerns, and a decentralized supply chain with CSR concerns. They found that a higher transparency of the manufacturer leads to higher demand and supply chain profit. Katsamakas and Sanchez-Cartas (2023) proposed an agent-based computational model using the Hotelling model and competitive firms where firms could educate consumers to alter their perception about brands based on their investment in ESG initiatives. In addition, the model considers various effects related to marginal costs and product value. The results show that ESG investment lowers prices and increases product value but may erode profits in an intense competitive context. Ultimately, it could lead to market exit under asymmetric competition. Zhu et al. (2024) investigated the joint emission reduction (JER) of a supply chain using a dynamic game and including green technology, remanufacturing, low-carbon promotion, consumer environmental awareness, and mixed carbon policies (carbon tax and cap-and-trade). They found that the noncooperative case in the supply chain generates a loss of efficiency in JER. They also found that the bilateral cost sharing scenario is more attractive than the unilateral cost scenario to improve low carbon goodwill when the profit distribution ratio is controlled within a certain interval. The retailer plays a key moderating role in controlling low-carbon goodwill and consumer demand in cooperative cases. Other studies considered the perspective of investors to enhance ESG investments (e.g., Kruitwagen et al., 2017; Wang et al., 2023), and finally, another group of studies investigated the strategic interaction between the government and firms investing in green technology innovation (e.g., Li and Wang, 2022; Giannarakis et al., 2018; Li and Gao, 2022; Wu et al., 2024).

Our paper focuses on the supply chain perspective with consumer's level. Following Zhu et al. (2024) using a differential game analysis with low-carbon goodwill, our analytical model incorporates the firm's environmental reputation as a key component reflecting consumers' awareness and evolving perception over time regarding the firm's ESG initiatives. While Zhu et al. (2024) examined a dynamic game, our paper includes the environmental goodwill in a static game as a contribution to static studies and considers horizontal firm's competition. Such goodwill increases the connection of consumers to the firm, keeps them loyal, and generates long-term benefits. Our model also includes price competition to represent the intensity of market competitiveness. Furthermore, we use empirical data to examine consistency with our analytical model and add robustness to our findings.

2.2. Empirical literature

Various studies used empirical models to investigate topics related to ESG investments such as the relationship between sustainable institutional investors and environmental performance (e.g., Sariannidis et al., 2013; Kordsachia et al., 2022), the impact of ESG performance on stock returns (e.g., Yin et al., 2023), the role of business segments and geographical diversification on ESG performance (Barros et al., 2024), and the mediating role of ESG practices on geopolitical risks associated with stock price crash events (e.g., Fiorillo et al., 2024). We summarize empirical literature by classifying the studies into three motivation categories: the first group highlights the effect of ESG practices on peer competitivity, the second group connects ESG initiatives to digital innovation, and the third group examines the impact of ESG practices on financial performance.

2.2.1. Effect of ESG practices on peer competitivity

Li et al. (2023a,b) used China's A-share listed enterprises and modeled the green innovation level of peer enterprises (i.e., green patent applications) dependent on ESG performance of focal enterprises. The results showed that ESG practices have significant green innovation spillover effects in the industry by reducing financing constraints and improving corporate environmental awareness. Zhu and Yang (2024) studied the spillover effect of ESG initiatives on peer-green innovation within the industry. The study focused on Shanghai Stock Exchange and Shenzhen Stock Exchange and showed that superior ESG performance has a significant and positive impact on peer-green innovation activities in terms of quantities and qualities. The effect is mediated by higher levels of R&D investments and enhanced green consciousness. The spillover effect varies depending on the industry (e.g., non-state-owned firms, small-sized firms, etc.). Wang et al. (2024) studied 1536 firms in the United States and showed a negative relationship between ESG performance and technological peer pressure (i.e., threat of competitive innovations) that could be explained by *resource constraint* view (e.g., Xu and Kim, 2022), and *agency concerns* view (e.g., Hsu et al., 2021). The effect is weaker for firms with high efficiency of innovation and varies depending on the industry (e.g., high-tech, green industries, etc.).

Hence, this stream of research demonstrates the key role of peer pressure in firms' sustainability investments (Li and Wang, 2022). We include this peer competitivity in our models (i.e., analytical and empirical).

2.2.2. ESG practices and digital innovation

Broadstock et al. (2020) used a nonparametric frontier analysis (i.e., estimation of production efficiency levels), analyzed 320 Japanese firms over the period 2008–2016, and showed the nonlinear relationship between ESG investments and the innovation capacity of companies. The result highlights the indirect value-creation process which translates into better operational performance. Huang et al. (2023) studied the effect of digital innovation on ESG performance using data from China's A-share listed companies from 2011 to 2021. They found that the positive impact of digital innovation on ESG performance is weakened by corporate financial stability and enhanced by institutional investors' shareholdings. Wang and Wang (2024) studied the effect of ESG investments on corporate innovation measured in terms of patents and using a sample of Chinese-listed companies from 2009 to 2021. They showed that ESG investments are positively correlated with the quantity and quality of companies' innovation leading to a reduction of agency problems, improvement of information disclosure, and enhancement of corporate governance. Wang and Tang (2024) examined the role of substantive versus symbolic digital innovation and their effectiveness in influencing ESG performance. They showed that substantive digital innovation can restrain corporate greenwashing (i.e., symbolic activities to achieve higher ratings), while symbolic innovation cannot. More recent studies are investigating the role of digital innovation, specifically artificial intelligence, in improving the achievement of sustainable goals such as green productivity (e.g., Xie and Lin, 2025) and renewable energy generation and transition towards cleaner energy (e.g., Behera et al., 2025). Following this stream of research, we include environmental digital innovation as an important component of our models. Such innovation is defined as "new environmental technologies and processes or eco-designed products" according to Refinitiv Eikon Database (Thomson Reuters, 2017).

2.2.3. Financial performance as a measure of ESG impact

Lin et al. (2019) studied the case of the auto industry (163 international automotive firms) and used the dynamic panel data system (i.e., the Generalized Method of Moment (GMM) method) to assess the relationship between the corporate green innovation strategy GIS and financial performance. The latter is measured using various metrics (e.g., Return on Assets ROA, Return on Equity ROE, and Return on Sales ROS). They found that the correlation between GIS and financial performance is moderated by the size of the firm. Aydoğmuş et al. (2022) focused on 1720 publicly listed companies from Bloomberg database and used Tobin's Q and ROA as measures of profitability. They found a positive and highly significant relationship between ESG scores (i.e., social, governance, and combined ESG score) and the firm financial performance except the environmental score that has no relationship, probably due to a longer effect to generate financial results or due to high costs. Garcia and Orsato (2020) compared emerging and developed countries and showed a negative relationship between ESG practices and financial performance in emerging markets. Bissoondoyal-Bheenick et al. (2023) investigated the case of G20 countries and analyzed the relationship between ESG scores and firm performance (using Tobin's Q and excess returns). They highlighted the role of firm's size to capitalize on economies of scale and media coverage to reduce information asymmetry regarding ESG investments with respect to stakeholders. They found that the dependent variable is critical in determining the effect of ESG scores. While a positive relationship was demonstrated using Tobin's Q (a result consistent with the *stakeholder theory*), a negative effect was shown when market performance is represented in excess returns (a result consistent with *risk-return trade-off theory*). In addition, the effect is dependent on the industry level. As an example, Behl et al. (2022) showed the negative impact of ESG dimensions on financial performance of companies using the *trade-off theory*. D'Amato et al. (2024)examined 400 companies constituting the EuroStoxx-600 index and compared usual statistical technique such as generalized linear models to machine learning models (e.g., decision trees and ensemble methods such as Bagging, Random Forest, and Gradient Boosting). They found that the ESG score has a significant influence on firms' profitability measured using EBIT (earnings before interest and taxes). They also found that companies should be highly socially responsible rather than relying only on partial socially responsible investments. Hwang et al. (2024) focused on 1383 observations of the hospitality industry and found that the more economically developed a country is, the higher is the engagement in ESG initiatives and the better is the financial performance. They used ROA, as an accounting-based metric, which reflects short-term profitability and efficiency with indication toward resource allocation compared to the market-based measure, Tobin's Q, that represents the investor's evaluation of firm's profitability. They also found varying effects of ESG metrics on financial performance in terms of short and long-term effects.

Given the mixed results contingent on the choice of the dependent variable, we consider profits as an important variable for companies. Following the recommendation of Taddeo et al. (2024) to focus on each ESG dimension separately rather than the overall ESG score, we center attention on environmental innovation as a key variable for our empirical model. We also consider the interplay between the focal firm and peer pressure and consider the market competition to reflect the characteristics of the industry. The firm's environmental reputation is a novel contribution to a static game theory approach that reflects the stock of goodwill built over time. The innovation efficiency represents a tradeoff between costs and impact on financial performance which is aligned with the *tradeoff theory* highlighted in various studies. In addition, we consider internal and external factors to fill the gap as debated by Martiny et al. (2024).

The above studies focus solely on empirical data analysis and don't consider analytical models. The game theoretical model has been widely used in different fields such as economics, operations management, supply chain management among others, and does reflect real business practices (e.g., Cotterill and Putsis, 2000; Amrouche et al., 2008). Game theory provides a structured framework to analyze competitive market dynamics and determine optimal strategies for business efforts (e.g., pricing, advertising, production quantities, market entry) which help companies maximize performance in a competitive context.

3. Analytical model

3.1. Benchmark model with no environmental innovation (symmetric case)

First, we analyze two symmetric firms selling competitive products to the market while having the same baseline demand. Customers can purchase products either from firm 1 with a price p_1 or from firm 2 with a price p_2. The baseline demand of each firm is a. The demand functions are assumed to be linear in direct price and differential price. When customers buy competitive products, they not only need to consider the product's price but also need to compare the prices of two competitive products. As a result, we have the demand functions below. D_1 and D_2 are defined as the demands of firms 1 and 2, respectively:

$$D_1 = a - b_1 p_1 + c_1(p_{2-} p_1) \tag{1}$$

$$D_2 = a - b_2 p_2 + c_2(p_1 - p_2) \tag{2}$$

Following Raju and Roy (2000), b_1 and b_2 are normalized to 1, and c_1 and c_2 equal to c. Thus, we have:

$$D_1 = a - p_1 + c(p_{2-} p_1) \tag{3}$$

$$D_2 = a - p_2 + c(p_1 - p_2) \tag{4}$$

The parameter $c(0 < c < 1)$ reflects the degree of price competition between firms. As products are more substitutable, the market becomes more competitive which leads to closer prices and less demand for each product. This assumption, supporting the linear demand function in direct price effect and price differential effect, has been widely used in previous game-theoretic literature (e.g., Tsay and Agrawal, 2000; Yan, 2011). Thus, the profit functions for both firms are:

$$R_1 = (p_1 - s_1)D_1 \tag{5}$$

$$R_2 = (p_2 - s_2)D_2 \tag{6}$$

Where R_1 is profit for firm 1; R_2 is profit for firm 2, s_1 is unit production cost for product of firm 1, and s_2 is unit production cost for product of firm 2. Since s_1 and s_2 are not considered decision variables, we normalize them to zero to simplify the expressions. Both firms follow the Bertrand mode to make optimal decisions since no party likes to be left behind. Given the above equations, we have the results in Table 1 (see proofs in Appendix 1).

The result shows that optimal prices and profits are increasing in baseline demand but decreasing in price competition. Hence, a higher baseline demand provides leverage for both firms to boost their respective profits. However, a higher intensity in price competition is disadvantageous in profit for both firms in a symmetrical market. Such price competition intensity could degenerate into a price war that has been shown to be detrimental to businesses such as the 1992 airline price war (e.g., American Airlines and Northwest Airlines among others) that resulted in record losses for the air travel industry (Rao et al., 2000).

3.2. Model with asymmetric innovation

In this scenario, firm 1 invests in environmental innovation for its product. When the product is more environmentally friendly and safe, more customers would like to buy it. Moreover, there is a spillover effect of the firm's innovation to the peer-firm as shown in previous empirical literature (e.g., Li et al., 2023a,b; Zhu and Yang, 2024). Thus, we have the following demand functions:

$$D_1 = a - p_1 + c(p_2 - p_1) + fg_1 \tag{7}$$

$$D_2 = a - p_2 + c(p_1 - p_2) + rg_1 \tag{8}$$

Where g_1 is the firm 1's investment in environmental innovation, f $(0 < f < 1)$ is the effectiveness of environmental innovation on customers' purchases, and r $(0 < r < f)$ is the spillover effect to the peer-firm. Following Banker et al. (1998) and Chen et al. (2015), the green innovation related costs are assumed to have a quadratic function. Thus, the profit functions for firms 1 and 2 are:

$$R_1 = p_1 D_1 - \frac{{g_1}^2}{2} \tag{9}$$

$$R_2 = p_2 D_2 \tag{10}$$

Given the above profit functions, we have the results in Table 2 (see proofs in Appendix 2).

Based on the results, we have proposition 1 below (see proofs in Appendix 3).

Table 1
Results in benchmark model.

Firm 1's price, p_1	$\frac{a}{2+c}$
Firm 2's price, p_2	$\frac{a}{2+c}$
Firm 1's profit, R_1	$\frac{a^2(1+c)}{(2+c)^2}$
Firm 2's profit, R_2	$\frac{a^2(1+c)}{(2+c)^2}$

Table 2
Results in model with asymmetric innovation.

Firm 1's price, p_1	$\frac{a(2+3c)}{4-2f^2+c(8+3c-f(2f+r))}$
Firm 2's price, p_2	$\frac{a(2+3c+f(-f+r))}{4-2f^2+c(8+3c-f(2f+r))}$
The level of firm 1's innovation, g_1	$\frac{a(2+3c)f}{4-2f^2+c(8+3c-f(2f+r))}$
Firm 1's profit, R_1	$\frac{a^2(2+3c)^2\left(2+2c-f^2\right)}{2\left(-4-3c^2+2f^2+c\left(-8+2f^2+fr\right)\right)^2}$
Firm 2's profit, R_2	$\frac{a^2(1+c)\left(2+3c-f^2+fr\right)^2}{\left(-4-3c^2+2f^2+c\left(-8+2f^2+fr\right)\right)^2}$

Proposition 1: *Compared to non-investment in environmental innovation, investment in such innovation leads to higher financial performance (profit) for both firms. However, if the peer-firm is not investing in such innovation and leveraging the benefit from the spillover effect, then it risks falling behind the firm investing in innovation.*

Proposition 1 shows that it is beneficial for firms to invest in environmental innovation. The reason is that such innovation in product offering is attractive to customers who are conscious about sustainability and thus stimulates customers to buy the product. This result is consistent with the recent study of McKinsey & Company in joint with NielsonIQ showing that 78 % of US consumers consider sustainable products important for their lifestyle and purchases (McKinsey & Company, 2023). This result also illustrates that investing in such innovation is a valuable investment and can help firms obtain competitive advantage. Managers should view such investments not only as a response to regulatory pressures but as a strategic leverage for differentiation and long-term value creation. Additionally, the results suggest that peer firms cannot afford to remain passive. If competitors introduce successful environmental innovations, firms that delay similar investments risk losing their competitive viability and ultimately their market share, a conclusion consistent with the findings of Katsamakas and Sanchez-Cartas (2023). **In practice, this implies that managers should:** (1) integrate sustainability considerations early in product development processes; (2) monitor and respond to shifts in consumer trends and attitudes toward sustainable products; and (3) track proactively peer innovation activities and be prepared to react quickly to avoid strategic disadvantages.

3.3. Model with symmetric innovation

In this scenario, both firms 1 and 2 invest in environmental innovation for their products. More innovation would bring more customers to buy the products. Thus, we have the demand function as follows:

$$D_1 = a - p_1 + c(p_2 - p_1) + fg_1 + rg_2 \tag{11}$$

$$D_2 = a - p_2 + c(p_1 - p_2) + fg_2 + rg_1 \tag{12}$$

Where g_2 is the firm 2's invested environmental innovation. Thus, the profit functions for firms 1 and 2 are:

$$R_1 = p_1 D_1 - \frac{{g_1}^2}{2} \tag{13}$$

$$R_2 = p_2 D_2 - \frac{{g_2}^2}{2} \tag{14}$$

Given the profit functions above, we have the results in Table 3 (see proofs in Appendix 4).

Based on our results, we have proposition 2 below (see proofs in Appendix 5).

Proposition 2: *Peer's environmental innovation investment positively moderates the effect of innovation effort on all firms' financial performances.*

Table 3
Results in model with symmetric innovation.

Firm 1's price, p_1	$\frac{a}{2+c-f(f+r)}$
Firm 2's price, p_2	$\frac{a}{2+c-f(f+r)}$
The level of firm 1's innovation, g_1	$\frac{af}{2+c-f(f+r)}$
The level of firm 2's innovation, g_2	$\frac{af}{2+c-f(f+r)}$
Firm 1's profit, R_1	$\frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$
Firm 2's profit, R_2	$\frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$

Proposition 2 **underscores the profitability-enhancement effect of environmental innovation, particularly in competitive settings.** For managers, this implies that when a competitor introduces environmental innovation, it is not only a threat but also a signal, prompting the need to respond strategically. Rather than falling behind, the focal firm should view the competitor's action as a motivation to increase its own investment in environmental innovation.

This competitive dynamic creates a positive feedback loop. **As firms invest more to maintain or regain their advantage, overall profits increase for all active participants.** Managers should recognize that environmental innovation is not a zero-sum game but rather a leverage to the entire industry. **In practical terms, managers should:** (1) continuously monitor peer innovation activity to anticipate competitive shifts; (2) allocate flexible resources for sustainable innovation in response to market movements; and (3) develop internal capabilities to sustain long-term competitive advantage in environmentally conscious markets. By adopting a forward-looking approach, managers can turn competitive pressure into growth and strengthened strategic position.

Next, we investigate how environmental innovation effectiveness impacts decisions and profits. We have proposition 3 below (see proofs in Appendix 6).

Proposition 3: *Environmental innovation effectiveness positively moderates the effect of innovation effort on firm's financial performance.*

Proposition 3 **highlights that while environmental innovation can significantly boost firm profitability, the effectiveness of its implementation is critical to achieving optimal returns.** For managers, this means that simply investing in environmental initiatives is not enough. **How** to execute the investment matters as well.

Effective innovation processes allow firms to accelerate time-to-market and maximize return on investment. Conversely, ineffective implementation due to poor planning, misaligned resources, or lack of technological capabilities can erode potential benefits and even lead to market exit. **To enhance decision-making, managers should: (1)** prioritize innovative projects with scalable outcomes; (2) invest in operational capabilities, including data analytics and automation, to improve innovation effectiveness; and (3) benchmark internal innovation processes against industry best practices to identify performance gaps. By focusing on quality execution and resource optimization, managers can ensure that environmental innovation supports sustainability goals, positively impacts consumers' perception and trust, and delivers long-term financial gains.

Finally, we examine the effect of price competition. Thus, we have proposition 4 below (see proofs in Appendix 7).

Proposition 4: *Price-based competition negatively moderates the effect of environmental innovation effort on the firm's financial performance.*

Proposition 4 **reveals a critical trade-off for managers operating in highly price-competitive markets. As price competition intensifies, environmental innovation becomes increasingly necessary to maintain competitive parity, but its financial returns may diminish.** In such environments, innovation is less about gaining advantage and more about *avoiding obsolescence*.

For managers, investing in environmental innovation remains strategically important but the **rising costs associated with intensified innovation efforts may erode profitability due to shrinking profit margins. To make informed decisions in these settings, managers should:** (1) carefully assess the cost-effectiveness of innovation projects before committing significant capital; (2) explore non-price-based value creation to offset margin pressure; (3) seek collaborative innovation opportunities to share costs and reduce duplication; and (4) monitor market saturation to avoid overinvestment in fading innovations. Ultimately, managers must balance the strategic necessity of environmental innovation with a realistic view of its financial implications.

3.4. Model with prior environmental innovation reputation

Following dynamic game-theory approach (e.g., Chintagunta and Jain, 1992; Nair and Narasimhan, 2006; Amrouche et al., 2008; Zhu et al., 2024), we incorporate the reputation (in this case environmental innovation's reputation) as a stock growing over time. The reputation stock affects baseline sales by boosting its level given the stronger goodwill of the firm for consumers.

$$D_1 = k_1 + a - p_1 + c(p_2 - p_1) + fg_1 + rg_2 \tag{15}$$

$$D_2 = k_2 + a - p_2 + c(p_1 - p_2) + fg_2 + rg_1 \tag{16}$$

Where k_1 is firm 1's prior credit for environmental innovation and k_2 is firm 2's prior credit for environmental innovation. To simplify our computations, we let $k_1 + a = e_1$ and $k_2 + a = e_2$. Given that firms invest different amounts in innovation (g_1 for firm 1 and g_2 for firm 2), the credit stock is not the same for firms 1 and 2. The difference is also due to the varied capabilities of each firm to maintain strong goodwill in the mind of consumers. Thus, we have:

$$D_1 = e_1 - p_1 + c(p_2 - p_1) + fg_1 + rg_2 \tag{17}$$

$$D_2 = e_2 - p_2 + c(p_1 - p_2) + fg_2 + rg_1 \tag{18}$$

The profit functions for firms 1 and 2 are given as:

$$R_1 = p_1 D_1 - \frac{{g_1}^2}{2} \tag{19}$$

$$R_2 = p_2 D_2 - \frac{{g_2}^2}{2} \tag{20}$$

Given the above functions, we have the results in Table 4 (see proofs in Appendix 8).

We have proposition 5 below on the effect of firm's prior credit on environmental innovation (see proofs in Appendix 9).

Proposition 5: *Firm's prior environmental reputation positively*

Table 4
Results in model with prior environmental reputation.

Firm 1's price, p_1	$\frac{e_1\left(2+2c-f^2\right)+e_2(c+fr)}{(2+3c+f(-f+r))(2+c-f(f+r))}$
Firm 2's price, p_2	$\frac{e_1\left(2+2c-f^2\right)+e_2(c+fr)}{(2+3c+f(-f+r))(2+c-f(f+r))}$
The level of firm 1's innovation, g_1	$\frac{f\left(e_1\left(2+2c-f^2\right)+e_2(c+fr)\right)}{(2+3c+f(-f+r))(2+c-f(f+r))}$
The level of firm 2's innovation, g_2	$\frac{f\left(c(e_1+2e_2)-e_2\left(-2+f^2\right)+e_1fr\right)}{(2+3c+f(-f+r))(2+c-f(f+r))}$
Firm 1's profit, R_1	$\frac{\left(2+2c-f^2\right)\left(e_1\left(2+2c-f^2\right)+e_2(c+fr)\right)^2}{2\left(2+3c-f^2+fr\right)^2\left(-2-c+f^2+fr\right)^2}$
Firm 2's profit, R_2	$\frac{\left(2+2c-f^2\right)\left(c(e_1+2e2)-e_2\left(-2+f^2\right)+e_1fr\right)^2}{2\left(2+3c-f^2+fr\right)^2\left(-2-c+f^2+fr\right)^2}$

moderates the effect of innovation effort on firm's financial performance.

Proposition 5 **highlights the strategic value of building a strong prior reputation for environmental innovation.** For managers, this finding emphasizes that a firm's historical credibility in sustainability enhances customer trust and goodwill, which in turn reinforces the effectiveness and market impact of future innovative efforts. Customers are more likely to believe in and support a firm's environmental initiatives when they perceive it as genuinely committed and competitively resilient. **From a managerial standpoint, this suggests that: (1)** visible commitment to environmental innovation builds long-term reputational capital; (2) transparent communication and consistent performance in sustainability efforts strengthen customer perception; (3) and early investments in reputation may reduce future marketing costs and increase the likelihood of successful green product launches.

As we now transition to the empirical analysis to validate our analytical results, it is important for managers to recognize that **while analytical models simplify real-world complexity, they offer valuable frameworks to identify key relationships and guide strategic decisions.** By leveraging both theoretical insights and empirical evidence, managers can craft more effective, data-driven strategies for sustainable innovation and long-term value creation.

4. Empirical analysis

Game-theory models are a simplified mathematical representation of reality. Specifically, our game-theoretical model derives analytical results representing conjectures that need to be tested empirically using data to prove their validity and realistic contribution to real-world interactions and behaviors. Empirical models are intended to use closer proxies to the variables and parameters used in game-theory models. Aligned with the analytical framework, our empirical investigation examines the direct impact of firms' environmental innovation on profitability, alongside the moderating effects of two market characteristics (peers' environmental innovation and product-based competition), and two firm characteristics (environmental innovation efficiency and prior environmental reputation). Our empirical analysis answers the following questions: (1) What is the effect of firms' investment in environmental innovation on financial performance (i.e., profit)? (2) How do peers' innovation investment and market competition intensity (i.e., HHI index) moderate the relationship between firms' innovation effort and their financial performance? (3) What are the moderating effects of firms' innovation efficiency and prior environmental reputation on this relationship?

4.1. Data and measurements

We collected the data from multiple sources including Refinitiv and Compustat. Refinitiv offers one of the most comprehensive ESG databases in the industry covering over 85 % of the global market cap across more than 630 different ESG metrics with a history dating back to 2002. After merging the Refinitiv data with Compustat, which offers firms' financial characteristics, the final sample involves 432 publicly traded companies from 56 2-digit industry SICs from 2003 to 2020.

We summarize the variables in Table 5.

We report the descriptive analysis in Table 6.

Specifically, the outcome variable about firms' financial performance is measured by firm value (i.e., Tobin's Q). The firm's environmental innovation is measured by Refinitiv's environmental innovation scores, which reflect "a company's capacity to reduce the environmental costs and burdens for its customers, thereby creating new market opportunities through new environmental technologies and processes or eco-designed products" (Thomson Reuters, 2017). The peer's environmental innovation is measured as the average innovation scores of all firms except the focal firm in the same 2-digit SIC industry, following the common practice of calculating the industry average in literature (e.g., Angrist and Krueger, 2001).

Table 5
Variable measurements and sources.

Variable	Measurement	Source
Profitability	Tobin's Q (Peters and Taylor, 2017)	Compustat
Environmental innovation	The environmental innovation score reflects a company's capacity to create new market opportunities through new environmental technologies and processes or eco-designed products	Refinitiv
Environmental innovation efficiency	The ratio of the firm's environmental innovation score relative to the firm's cost of goods (COG)	Refinitiv and Compustat
Environmental reputation	The reversed measure of ESG controversy rating. The value equals 1 if there is no ESG controversy, and 0 otherwise	Refinitiv
Peers' environmental innovation	The average of all other companies' environmental innovation scores in the same industry (2-digit SIC code)	Refinitiv
Product market competition	The average market-wide change in the use of the given firm's 10-K product description vocabulary by all other firms	10-K product description vocabulary (Hoberg and Phillips, 2016)
Firm asset	The log value of firms' total assets	Compustat
Advertising expense	The ratio of advertising expenses relative to the total assets	Compustat
R&D expense	The ratio of R&D expenses relative to the total assets	Compustat
ROA	Return on Asset (net income by the average of its total assets in year *t*-1)	Compustat
Financial leverage	Total debt/total equity	Compustat

Table 6
Descriptives analyses.

	Mean	Std	Min	Max
Profitability	2.269	1.740	.588	35.805
Environmental innovation	25.570	31.935	.000	99.438
Environmental innovation efficiency	.808	6.851	.000	416.287
Environmental reputation	.976	.153	.000	1.000
Peers' environmental innovation	25.553	13.950	.000	91.262
Product market competition	6.330	3.490	.585	36.277
Firm asset	9.561	1.766	2.171	14.804
Advertising expense	.256	.462	.000	13.283
R&D expense	.062	.280	.000	11.354
ROA	.058	.102	−2.075	.503
Financial leverage	.158	.133	.000	.799

The market competition intensity is proxied by the average market-wide change in the use of the given firm's 10-K product description vocabulary by all other firms (Hoberg and Phillips, 2016). More frequent new product introductions at the market level signals stronger competition.

The firm's prior environmental reputation is measured based on the previous year's ESG controversy scores provided by Refinitiv. The value equals 1 if there is no ESG controversy, and 0 otherwise. The firm's environmental innovation efficiency is measured as the ratio of the firm's innovation score relative to the firm's cost of goods (COG). As the innovation score reflects the output in creating new environmental technologies and eco-designed products and the cost of goods reflects the input, this ratio could suggest a firm's innovation efficiency. We also controlled other firm characteristics, including the asset size, advertising spending, ROA, and financial leverage that could affect firm profits.

Return on Assets (ROA) is a direct measure of a company's profitability in relation to its assets (including debt and equity). Hence, using ROA as a control variable helps isolate the impact of other independent variables on the dependent variable by controlling better the profitability assessment (e.g., Ali et al., 2022), improving the measurement of operational efficiency, and offering a more standardized analysis to compare companies with different financial leverage and capital structure (e.g., Laghari et al., 2023).

4.2. Empirical method

We use a two-step system GMM approach (Generalized Method of Moments) to estimate the dynamic panel data. System GMM is designed for situations where independent variables are not strictly exogenous and when heteroskedasticity and autocorrelation exist within groups. It also eliminates firm-specific fixed effects by first-differencing, and it alleviates concerns about endogeneity by employing lagged values of regressors as instrument variables (Roodman, 2009). System GMM is especially robust and efficient when some regressors have poor variability, while the difference GMM model may have weak instrument problems if the value of the outcome variable is persistent (Uotila et al., 2009).

Following earlier research (Blundell and Bond, 1998), we also included the lagged dependent variable (Tobin's Q in Year *t*-1) in the system GMM equation. Peter and Taylor (2017) demonstrated empirically how Tobin's Q reflects physical and intangible investments at equal level and how it explains total investment even better.

We treat the year dummies and industry (SIC) dummies as exogenous variables, the independent variables as endogenous variables, and the lagged term of the outcome variable and the firm size as the predetermined variables. In addition, we test the validity of instrument assumptions for model estimation using the Hansen tests of over-identifying restrictions and the autocorrelation test. The Arellano-Bond test for autocorrelation (i.e., AR(II)) shows no second-order serial correlation in errors, indicating the validity of using the dependent variable lags as instruments. The estimations reported by Hansen's J statistic from over-identifying restrictions tests suggest the instruments' validity.

The empirical model is written as follows:

$$\text{Profitabiltiy}_{\text{it}} = \beta_0 + \beta_1\ \text{Profitabiltiy}_{\text{it-1}} + \beta_2\ \text{Env\_innovation}_{\text{it}} + \beta_3\ \text{Env\_innovation\_efficiency}_{\text{it}} + \beta_4 \text{Env\_reputation}_{\text{it}} + \beta_5\ \text{Peers\_env\_innovation}_{\text{it}} + \beta_6\ \text{Peers\_env\_innovation}^2_{\text{it}} + \beta_7\ \text{Product\_market\_competition}_{\text{it}} + \beta_8\ \text{Env\_innovation*Env\_innovation\_efficiency}_{\text{it}} + \beta_9\ \text{Env\_innovation*Env\_reputation}_{\text{it}} + \beta_{10}\ \text{Env\_innovation*}\ \text{Peers\_env\_innovation}_{\text{it}} + \beta_{11}\ \text{Env\_innovation*}\ \text{Peers\_env\_innovation}^2_{\text{it}} + \beta_{12}\ \text{Env\_innovation*}\ \text{Product\_market\_competition}_{\text{it}} + \sum\beta_{\text{mit}}\ \text{Year dummy}_{\text{mit}} + \sum\beta_{\text{nit}}\ \text{Industry dummy}_{\text{nit}} + \varepsilon_{\text{it}}$$

The correlation analysis is summarized in Table 7.

4.3. Empirical results

We summarized the regression results in Table 8. Our analysis reveals a statistically significant direct effect of a firm's environmental innovation on its profitability ($b = .0010$, $p < .001$). Our study specifically considers environmental innovation, demonstrating that such innovation strategies can substantially benefit a firm's shareholders financially. The result is consistent with proposition 1 of our analytical results. This focus on specific ESG efforts may help clarify the mixed findings in the literature considering overall ESG efforts and financial returns.

Additionally, our analysis of firm characteristics shows positive moderating effects of prior environmental reputation ($b = .0003$, $p <$

Table 8
Regression results.

	Main effect model		Interaction effect model	
	Coefficient	Std. Err.	Coefficient	Std. Err.
Profitability (t-1)	.8274***	.0008	.8190***	.0015
Environmental innovation	.0010***	.0000	.0010	.0006
Environmental innovation efficiency	.0002**	.0001	.0158***	.0005
Environmental reputation	.1488***	.0076	.1395	.0845
Peers' environmental innovation	.0023***	.0002	.0098***	.0004
Peers' environmental innovation (Squared)	−.0001***	.0000	−.0001	.0000
Product market competition	.0084***	.0003	.0094***	.0005
Environmental innovation * Environmental innovation efficiency			.0003***	.0000
Environmental innovation * Environmental reputation			.0010**	.0005
Environmental innovation * Peers' environmental innovation			.0000**	.0000
Environmental innovation * Peers' environmental innovation Squared			−.0000***	.0000
Environmental innovation * Product market competition			−.0000**	.0000
Firm asset	−.0562***	.0007	−.0621***	.0013
Advertising expense	.1107***	.0034	.1053***	.0045
R&D expense	.1000	.0720	.0060	.0062
ROA	1.2330***	.0137	1.2759***	.0119
Financial leverage	.7607***	.0066	.8110***	.0141
Time fixed effect	Yes		Yes	
Industry fixed effect	Yes		Yes	
N	3688		3688	
F-statistic	1.04e+10		1.30e+11	
AR(II) Test	−.47		−.45	
Hansen Overid. Test (J-statistic)	408.80		398.41	

*** Significant at $p < .01$; ** Significant at $p < .05$; * Significant at $p < .1$.

Table 7
Correlation matrix.

	1	2	3	4	5	6	7	8	9	10	11
1.Profitabiltiy	1										
2.Environmental innovation	.0716*	1									
3.Environmental innovation efficiency	.0093	.1119*	1								
4.Environmental reputation	.0068	−.1370*	.011	1							
5.Peers' environmental innovation	−.0856*	.3372*	.0378*	−.1210*	1						
6.Product market competition	−.1454*	−.0710*	−.0098	.0014	−.0983*	1					
7.Firm asset	−.3196*	.3404*	−.1044*	−.1434*	.1876*	.3091*	1				
8.Advertising expense	.1247*	−.0767*	.0322*	.0431*	−.0649*	−.1345*	−.3175*	1			
9.R&D expense	.1004*	−.0845*	.0592*	.0164	−.0580*	.0013	−.2164*	.2903*	1		
10.ROA	.1914*	.0325*	−.2446*	.0119	−.0002	−.1247*	−.0245	−.01	−.1387*	1	
11.Financial leverage	−.3383*	.0583*	−.0409*	−.0544*	.0366*	.0862*	.1188*	−.0641*	−.0387*	−.2036*	1

* Significant at $p < .05$.

.001) and innovation efficiency ($b = .0010$, $p < .05$) which is consistent with propositions 3 and 5 of our analytical results. Consumers are more likely to trust products of a firm with a more established reputation for environmental responsibility. Firms with higher efficiency and effectiveness in implementing such innovations are more capable of developing and launching new eco-friendly products to market more quickly and cost-effectively.

4.3.1. ESG innovation efficiency and ESG reputation

We identified a curvilinear moderating influence of market-level environmental innovation undertaken by peers on the impact of a focal firm's innovation on its profitability (linear term interaction $b =$ 2.18e-05, $p < .05$, and square term interaction $b = -1.85e\text{-}06$, $p < .01$). Specifically, when competitors within an industry invest a low or a moderate amount in environmental innovation, the presence of peer innovation enhances the focal firm's profitability stemming from its own environmental initiatives. This can cultivate market preference for products with enhanced environmental features, thereby generating momentum in favor of environmentally innovative products. From a managerial perspective, this suggests that firms should strategically coordinate their environmental innovation investments by monitoring industry peers' activities to optimize their competitive positioning and profitability. However, when market peers heavily invest in environmental innovation, it diminishes the financial returns of the focal firm from its own environmental initiatives. This could be attributed to intensified competition for attention and resources within the market, leading to diminished returns for individual firms. Managers should therefore carefully evaluate market saturation in environmental innovations to avoid overinvestment that could result in profitability erosion. For example, in the electric vehicle market, when several companies introduce electric vehicles with varying environmental features, consumer interest and demand for such vehicles increase, benefiting all companies involved in the market. This result reinforces the proposition 2 of our analytical findings isolating the positive effect of peers' efforts in environmental innovation. However, companies should avoid aggressive levels of innovation that could be detrimental.

Moreover, our analysis uncovered a negative moderating effect of product-based competition on the relationship between a firm's innovation and its profitability ($b = 3.31e\text{-}05$, $p < .01$). Specifically, high competition intensity (i.e., high product market fluidity index), weakens the financial returns for firms investing in environmental innovation. This indicates that managers should consider adopting differentiated or niche environmental strategies when operating in highly competitive markets to maintain profitability. Although we explored the possibility of a curvilinear effect of market competition as a moderator, our findings did not support such a relationship. In addition, the empirical result of product-based competition is aligned with our analytical result focusing on price-based competition (see proposition 4) which reflects a different competition basis but similar effect.

Overall, our findings on the market-level influence suggest that firms investing in environmental innovation tend to benefit most in an environment characterized by moderate competition and peers investing similarly in environmental innovation. Regarding the effects of firm characteristics, firms with better prior environmental reputations and higher innovation efficiencies are better positioned to capitalize on the financial benefits of their innovation efforts due to increased consumer trust and streamlined operations.

5. Discussions

Our findings entail various theoretical implications by contributing to the existing academic knowledge and advancing theoretical understanding within the ESG paradigm. They also offer practical guidance for ESG managers and executives in real-world settings and inform their decision-making in organizational contexts.

5.1. Theoretical implications

While prior research primarily discussed value creation through operational improvements stemming from general ESG initiatives (e.g., Danso et al., 2019; Chen et al., 2023), our research distinctively investigates direct financial returns. Our results show a statistically significant direct effect of a firm's environmental innovation on its profitability and financial returns. However, more critically, our study uncovers the nuanced and conditional nature of such innovation's financial outcomes, demonstrating that they are significantly shaped by both market-level dynamics and firm-level characteristics and highlighting the importance of competitive context and strategic choices.

At the market level, we find that firms investing in environmental innovation achieve the greatest financial benefits in markets characterized by moderate competition (where the balance between differentiation and market pressure fosters innovation payoff) and when peers engage in similar levels of environmental engagement. This supports and extends the literature on competitive dynamics and strategic complementarity by showing that environmental investment effectiveness is co-determined by interfirm interactions and competitive intensity. By identifying the optimal conditions (i.e., moderate competitive environments and similar peer innovation levels), our study expands upon Zhu and Yang (2024) who emphasized spillover effects of ESG investments among peer firms and who detailed the nuanced curvilinear relationship with peer ESG activities' conditions to enhance or to diminish firm profitability.

Moreover, the type of competition matters. Both product-based and price-based competition introduce challenges. Our findings show that product-based competition exerts the same effect as price-based competition. Product-based competition leads to a negative moderating effect due to a high product market fluidity level that weakens the financial returns for firms investing in environmental innovation which ultimately dilutes firms' innovation advantages and increases consumer switching. Similarly, price-based competition poses risks by intensifying the likelihood of price wars, thereby eroding profit margins despite sustainability-driven differentiation. This comparison contributes to strategic management literature by clarifying how competitive bases affect ESG-related strategic outcomes. Our results align with Skordoulis et al. (2022) findings. In their study, they interviewed 225 managers overseeing environmental strategy of medium and large-sized firms in Greece and concluded with a mediating role of strategy choices on the relationship between environmental innovation and firms' competitiveness. They focused their questionnaire on diversification strategy versus cost leadership strategy which is respectively reflected in product-based competition versus price-based competition in this study.

At the firm level, we find that organizational attributes play a critical role. We reinforce and extend the findings of previous studies (e.g., Whelan et al., 2021) by confirming the critical positive moderating role of prior environmental reputation. Such result signals legitimacy and trust among stakeholders and better innovation effectiveness and efficiency. The findings emphasize the importance of building firm-specific capabilities and stakeholder alignment in achieving sustainable competitive advantages.

To summarize, our study contributes to several literature streams. First, while prior ESG-performance research often aggregates environmental, social, and governance indicators leading to mixed findings, we focus on environmental innovation and identify key boundary conditions. This aligns with and extends recent calls for dimension-specific analysis (Han et al., 2016; Taddeo et al., 2024). Second, building on *dynamic capabilities theory* (Teece et al., 1997), we show how innovation efficiency/effectiveness and environmental reputation act as strategic enablers by strengthening the link between innovation and financial outcomes. Third, we refine the understanding of peer effects by demonstrating a curvilinear effect of peers' environmental innovation. This nuanced insight helps reconcile conflicting results from prior research, where some studies suggest positive peer influences due to

innovation spillovers (Lieberman and Asaba, 2006), while others indicate negative outcomes stemming from competitive imitation pressures (DiMaggio and Powell, 1983). Finally, we complement Schumpeterian's innovation erosion perspectives by showing that market-level competition can dilute the financial returns of environmental innovations, underscoring the importance of timing and differentiation in ESG strategy.

Overall, this study challenges the prevailing notion that ESG adoption, particularly environmental innovation, is inherently value-accretive across all contexts. Instead, our results underscore the importance of strategic alignment, industry conditions, and internal capabilities in determining ESG success.

5.2. Managerial implications

By elucidating the roles of market and firm characteristics, this research offers actionable insights for practitioners aiming to navigate the intersection of sustainability and financial performance.

- **Prioritize strategic environmental innovation:** Managers should direct ESG investments towards high-impact areas, particularly environmental innovation, that resonate with shareholder priorities. This targeted approach enables more effective resource allocation, increases managerial control over outcomes, and enhances the likelihood of achieving superior financial returns. Our results confirm that focused environmental initiatives directly enhance firm profitability. Investments should align with firm-specific strengths and market conditions to optimize outcomes. For instance, Interface Inc. has invested in closed-loop carpet recycling systems (Interface, 2024), creating new eco-conscious product lines that align with both market demand and internal innovation capabilities. Similarly, consumer goods companies, such as Seventh Generation, have developed product portfolios with reduced environmental impact (PR Newswire, 2025) aligning product innovation with core sustainability objectives.
- **Monitor competitive landscape closely:** Managers must make deliberate strategic choices between competing on price or differentiating through non-price features (i.e., product-based competition). These choices should be aligned with the firm's ESG priorities, as they shape the firm's risk exposure and influence how ESG efforts translate into performance. Our results indicate that intense product/price-based competition diminishes the profitability of environmental innovation. Thus, managers should actively monitor competitive intensity and whether competitors are doing the same at scale, strategically aligning their innovation's investments to avoid overly saturated markets.
- **Select timing for environmental investments:** Managers should conduct ongoing analysis of industry competition and peer ESG activities when planning environmental innovation. Given the curvilinear relationship identified with peer innovation, managers should strategically time their environmental initiatives when peer investments are moderate. This approach capitalizes on collective market momentum without risking diminished returns due to excessive competition. For instance, in the packaging industry, companies have benefited from strategically timed innovation rollouts in renewable materials (e.g., Tetra Pak launching the Tetra Rex in 2015) entering markets with growing sustainability awareness but before it becomes hyper-competitive (Tetra Pak, n.d.).
- **Build and leverage environmental reputation:** Firms with established environmental reputations significantly benefit from their innovative efforts. Therefore, managers should prioritize consistent and transparent sustainability practices to strengthen reputation capital, which in turn amplifies financial gains from innovation. To illustrate, Patagonia maintains strong consumer trust and premium pricing power through ongoing transparent communication about sustainability initiatives (Torossian, 2024).
- **Enhance innovation efficiency/effectiveness:** Our study emphasizes innovation efficiency and effectiveness as a critical factor positively influencing profitability. Managers should focus on improving internal innovation processes, including efficient and effective resource allocation, designing streamlined operations, and integrating advanced technologies and effective R&D practices. This ensures that environmental innovation efforts are not only impactful but also cost-effective and scalable. Some companies, such as Danone, have focused on cross-functional collaboration between their sustainability and product development teams (Danone Research, n.d.) to ensure that environmental goals enhance speed to market and cost control.
- **Differentiate strategically:** In highly competitive markets, incremental innovations may offer limited financial gains. Managers should focus on distinctive environmental innovations that clearly differentiate their products or services, thereby ensuring sustained competitive advantage and higher financial returns.

6. Conclusion and future research

We combine a theoretical and an empirical model to have a holistic approach in studying ESG topics and to find insightful results that clarify the controversy around the ESG initiative's effect on firms' performances. Our study makes significant contributions to existing literature by addressing several research gaps. First, by focusing on environmental innovation as one of the ESG dimensions, our study clarifies the key positive role in firms' financial performances compared to contradictory previous research findings. Second, there are external determinants that must be considered for their moderating effects, namely market-level dynamics and firm-level characteristics, highlighting the complex competitive dynamics and necessity of strategic decision-making. Third, firms must consider the differential effect of product-based versus price-based competition to align their strategic choices to the overall corporate environmental vision and mission. Fourth, underscoring the peer competitiveness influence on financial performances and highlighting its spillover effect similar to previous studies, shed light on the complex dynamic between the intensity level of peer competition and financial outcomes. Finally, our study emphasizes the key role of innovation reputation, which is missing in previous ESG research, and demonstrates empirically and analytically how it leverages the competitive power of firms and presents a scalable asset for further pressure on competing firms.

This study opens several pathways for future inquiry. First, our analytical model could be extended by incorporating vertical competition (e.g., distributors such as wholesalers and retailers) and more granular forms of horizontal competition (e.g., multi-firm rivalry). Second, future work could adopt a dynamic modeling approach, treating environmental reputation and innovation capability as evolving stocks that interact with other marketing activities such as service (e.g., mobile service for repairs by Tesla, in-store repairs and assistance by Patagonia) and promotions (e.g., Luxe Cravings Boxes by Taco Bell, Transfer Miles Bonus by United Airlines). Third, longitudinal research tracking the progress of the reputational innovation of competing firms, within an industry and across multiple industries, could be very insightful to uncover the temporal dynamics of environmental innovation and its impact on strategies and profitability. Fourth, the empirical section of this study could be replicated in other geographic areas to assess the idiosyncrasy of the findings or their generality to various locations. Fifth, researchers could investigate how government regulations and stakeholders' activism act as a strategic force within ESG investment games. Introducing the state as a third-party player could yield insights into optimal policy interventions. Finally, future studies may broaden the lens by evaluating the societal welfare effect of environmental innovation, particularly in contexts where private gains and public benefits diverge. This could enhance the intersection between ESG, public policy, consumer welfare, and long-term value creation for

businesses.

CRediT authorship contribution statement

Zixia Cao: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Nawel Amrouche:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization. **Zhi Pei:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing interests that could influence the work reported in this article.

Appendices.

Appendix 1

$$D_1 = a - p_1 + c(p_{2-}p_1)$$

$$D_2 = a - p_2 + c(p_1 - p_2)$$

$$R_1 = (p_1 - s_1)D_1$$

$$R_2 = (p_2 - s_2)D_2$$

By taking the derivatives of R1 and R2 with respect to p1 and p2, respectively, we obtain the results below:

$$\mathrm{p1} = \frac{a}{2+c}$$

$$\mathrm{p2} = \frac{a}{2+c}$$

$$\mathrm{R1} = \frac{a^2(1+c)}{(2+c)^2}$$

$$\mathrm{R2} = \frac{a^2(1+c)}{(2+c)^2}$$

Appendix 2

$$D_1 = a - p_1 + c(p_2 - p_1) + fg_1$$

$$D_2 = a - p_2 + c(p_1 - p_2) + rg_1$$

$$R_1 = p_1 D_1 - \frac{{g_1}^2}{2}$$

$$R_2 = p_2 D_2$$

Following the same procedures as Appendix 1, we obtain:

$$\mathrm{p1} = \frac{a(2+3c)}{4 - 2f^2 + c(8 + 3c - f(2f+r))}$$

$$\mathrm{p2} = \frac{a(2+3c+f(-f+r))}{4 - 2f^2 + c(8 + 3c - f(2f+r))}$$

$$\mathrm{g1} = \frac{a(2+3c)f}{4 - 2f^2 + c(8 + 3c - f(2f+r))}$$

$$\mathrm{R1} = \frac{a^2(2+3c)^2\left(2+2c-f^2\right)}{2\left(-4-3c^2+2f^2+c\left(-8+2f^2+fr\right)\right)^2}$$

$$\mathrm{R2} = \frac{a^2(1+c)\left(2+3c-f^2+fr\right)^2}{\left(-4-3c^2+2f^2+c\left(-8+2f^2+fr\right)\right)^2}$$

Appendix 3

When firms invest in innovation, the profits are:

$$R1 = \frac{a^2(2+3c)^2\left(2+2c-f^2\right)}{2\left(-4-3c^2+2f^2+c\left(-8+2f^2+fr\right)\right)^2}$$

$$R2 = \frac{a^2(1+c)\left(2+3c-f^2+fr\right)^2}{\left(-4-3c^2+2f^2+c\left(-8+2f^2+fr\right)\right)^2}$$

When firms have no investment in innovation, the profits are:

$$R1 = \frac{a^2(1+c)}{(2+c)^2}$$

$$R2 = \frac{a^2(1+c)}{(2+c)^2}$$

By comparing the firm profits with innovation and without innovation, we prove the derived proposition 1.

Appendix 4

$$D_1 = a - p_1 + c(p_2 - p_1) + fg_1 + rg_2$$

$$D_2 = a - p_2 + c(p_1 - p_2) + fg_2 + rg_1$$

$$R_1 = p_1 D_1 - \frac{{g_1}^2}{2}$$

$$R_2 = p_2 D_2 - \frac{{g_2}^2}{2}$$

By taking the derivatives of R1 with respect to p1 and g1 and R2 with respect to p2, respectively, we obtain the results below:

$$p1 = \frac{a}{2+c-f(f+r)}$$

$$g1 = \frac{af}{2+c-f(f+r)}$$

$$p2 = \frac{a}{2+c-f(f+r)}$$

$$g2 = \frac{af}{2+c-f(f+r)}$$

$$R1 = \frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

$$R2 = \frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

Appendix 5

When firms invest in innovation, the profits are:

$$R1 = \frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

$$R2 = \frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

When firms have no investment in innovation, the profits are:

$$R1 = \frac{a^2(1+c)}{(2+c)^2}$$

$$R2=\frac{a^2(1+c)}{(2+c)^2}$$

By comparing firm 1's profits with innovation and without innovation and then taking the derivative of profits' difference with respect to g2, then we find a positive relationship between g2 and firm 1's profits' difference due to innovation investment. Similarly, we can prove that there is a positive relationship between g1 and firm 2's profits' difference due to innovation investment.

Appendix 6

When firms invest in innovation, the profits are:

$$R1=\frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

$$R2=\frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

When firms have no investment in innovation, the profits are:

$$R1=\frac{a^2(1+c)}{(2+c)^2}$$

$$R2=\frac{a^2(1+c)}{(2+c)^2}$$

By comparing firm 1's profits with innovation and without innovation and then taking the derivative of profits' difference with respect to f, then we find a positive relationship between f and firm 1's profits' difference due to innovation investment. Similarly, we can prove that there is a positive relationship between f and firm 2's profits' difference due to innovation investment.

Appendix 7

When firms invest in innovation, the profits are:

$$R1=\frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

$$R2=\frac{a^2\left(2+2c-f^2\right)}{2\left(-2-c+f^2+fr\right)^2}$$

When firms have no investment in innovation, the profits are:

$$R1=\frac{a^2(1+c)}{(2+c)^2}$$

$$R2=\frac{a^2(1+c)}{(2+c)^2}$$

By comparing firm 1's profits with innovation and without innovation and then taking the derivative of profits' difference with respect to c, then we find a negative relationship between c and firm 1's profits' difference due to innovation investment. Similarly, we can prove that there is a negative relationship between c and firm 2's profits' difference due to innovation investment.

Appendix 8

$$D_1=e_1-p_1+c(p_2-p_1)+fg_1+rg_2$$

$$D_2=e_2-p_2+c(p_1-p_2)+fg_2+rg_1$$

$$R_1=p_1D_1-\frac{{g_1}^2}{2}$$

$$R_2=p_2D_2-\frac{{g_2}^2}{2}$$

Following the same procedures as Appendix 1, we obtain:

$$p1=\frac{e_1\left(2+2c-f^2\right)+e_2(c+fr)}{(2+3c+f(-f+r))(2+c-f(f+r))}$$

$$p2=\frac{e_1\left(2+2c-f^2\right)+e_2(c+fr)}{(2+3c+f(-f+r))(2+c-f(f+r))}$$

$$g1=\frac{f\left(e_1\left(2+2c-f^2\right)+e_2(c+fr)\right)}{(2+3c+f(-f+r))(2+c-f(f+r))}$$

$$g2=\frac{f\left(c(e_1+2e_2)-e_2\left(-2+f^2\right)+e_1fr\right)}{(2+3c+f(-f+r))(2+c-f(f+r))}$$

$$R1=\frac{\left(2+2c-f^2\right)\left(e_1\left(2+2c-f^2\right)+e_2(c+fr)\right)^2}{2\left(2+3c-f^2+fr\right)^2\left(-2-c+f^2+fr\right)^2}$$

$$R2=\frac{\left(2+2c-f^2\right)\left(c(e_1+2e2)-e_2\left(-2+f^2\right)+e_1fr\right)^2}{2\left(2+3c-f^2+fr\right)^2\left(-2-c+f^2+fr\right)^2}$$

Appendix 9

When firms invest in innovation, profits are:

$$R1=\frac{\left(2+2c-f^2\right)\left(e_1\left(2+2c-f^2\right)+e_2(c+fr)\right)^2}{2\left(2+3c-f^2+fr\right)^2\left(-2-c+f^2+fr\right)^2}$$

$$R2=\frac{\left(2+2c-f^2\right)\left(c(e_1+2e2)-e_2\left(-2+f^2\right)+e_1fr\right)^2}{2\left(2+3c-f^2+fr\right)^2\left(-2-c+f^2+fr\right)^2}$$

When firms have no investment in innovation, profits are:

$$R1=\frac{a^2(1+c)}{(2+c)^2}$$

$$R2=\frac{a^2(1+c)}{(2+c)^2}$$

By comparing the firms' profits with innovation and without innovation and then taking the derivative of profits' difference with respect to e1 and e2 , respectively, we find a positive relationship between e_i ($i = 1,2$) and firms' profits' difference due to innovation investment.

Data availability

Data will be made available on request.

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