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Cost and quality priorities, technological uncertainty, and green innovation: an empirical study of manufacturing firms in South Korea

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ABSTRACT

Firms have been driven to adopt eco-friendly advancements due to regulatory pressures and consumer expectations. This research explores the impact of operation strategies, cost and quality priority strategies, on the introduction of green innovations and the moderator role of technological uncertainty in South Korea. Results show that prioritizing cost hinders the introduction of green innovation, whereas emphasizing quality enhances it. Therefore, firms must understand their competitive edges and develop customized strategies to promote green innovation. Based on the results of this study, policymakers need to consider the specific competitive context of companies and develop tailored strategies to promote green innovation across various sectors.

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1. Introduction

Firms face tremendous pressure to comply with environmental regulations and meet the expectations of environmentally conscious customers. On the regulatory side, following the Paris Agreement in 2015, firms have ramped up their efforts to reduce greenhouse gas emissions. However, from the customer perspective, growing environmental awareness has led consumers to support the purchase of green products (Wang, Kai Chan, and Li 2015). Thus, manufacturers have started offering a variety of green products, and one straightforward way to address this challenge is by introducing or adopting green innovations.

Green innovation, also known as eco-innovation, environmental innovation, or sustainable innovation, refers to innovations associated with green products or processes, encompassing technical advancements and new administrative practices (Carrillo-Hermosilla, Del Río, and Könnölä 2010; Chen, Lai, and Wen 2006). As it becomes essential for businesses and society, green innovation emerges as a key aspect of the broader innovation landscape (Galindo-Rueda 2018; Takalo, Sayyadi Tooranloo, and Shahabaldini Parizi 2021).

Previous research has dealt with both the factors driving green introduction and the impact of green innovation on firm performance. For instance, firm-specific factors (e.g. R&D expenditure) and external factors (e.g. government regulations and subsidy) lead to green

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innovations (Horbach and Rammer 2018; Mothe, Nguyen-Thi, and Triguero 2018; Peñasco, Del Río, and Romero-Jordán 2017), and such green innovations affect firm performance (Le 2022; Montabon, Sroufe, and Narasimhan 2007; Wong, Wong, and Boon-Itt 2020; Zhou et al. 2023). However, while many studies investigate the determinants and outcomes of green innovation, there remains a need for more in-depth understanding of the determinants and conditions for introducing green innovation (Siedschlag, Meneto, and Tong Koeckling 2019; Song and Yu 2018; Zameer and Yasmeen 2022). Specifically, we identify a research gap in the literature that there is a lack of studies examining the relationship between operations strategies, cost or quality leadership, and the introduction of green innovations. To bridge this research gap, we investigate how these operations strategies influence the introduction of green innovation.

However, the introduction of green innovation often requires the appropriate technologies such as energy-saving, resources and material, climate and emission reduction, and cleaner production technologies (Vrchota et al. 2020). Additionally, green innovation sometimes involves changes in technological processes, which can introduce technological uncertainty. This uncertainty is likely to influence the relationship between operations strategies and the introduction of green innovation (Jabbour et al. 2012; Noci and Verganti 1999). Thus, while previous studies have primarily focused on how priorities such as flexibility affect various forms of innovation, our research explores a previously understudied area: how technological uncertainty moderates the relationship between a company's operational strategy and the adoption of green innovation.

Overall, we investigate the following two research questions:

Research Question 1: Do the operation strategies, specifically cost and quality priorities, influence the introduction of green innovation?

Research Question 2: Does technological uncertainty moderate the relationship between operations strategy and the introduction of green innovation?

This study is organized as follows. Section 2 outlines the theoretical background of cost and quality priority strategies, green innovation, technological uncertainty, and hypotheses development. Section 3 describes the empirical methods, including data and variables, followed by section 4, which presents the results of the analysis. Finally, section 5 provides the conclusion and suggestions for the future research.

2. Theoretical background and hypotheses development

2.1. Determinants of green innovation introduction

Studies have explored the factors influencing the introduction of green innovation, which can be divided into two categories: firm-specific factors and external factors. First, firm-specific factors that positively influence the introduction of green innovation include technological capabilities developed through R&D investment and employee training (Cainelli, De Marchi, and Grandinetti 2015; Ketata, Sofka, and Grimpe 2015), a firm's external collaborations (Mothe and Nguyen-Thi 2017; Mothe, Nguyen-Thi, and Triguero 2018), ownership (Cainelli, Mazzanti, and Montresor 2012), and firm size (Horbach and Rammer 2018; Peñasco, Del Río, and Romero-Jordán 2017). However, external factors include environmental policies such as taxes and subsidies

(Ketata, Sofka, and Grimpe 2015; Peñasco, Del Río, and Romero-Jordán 2017), competition with other firms (Horbach and Rammer 2018), public funding (Cainelli, De Marchi, and Grandinetti 2015; Ketata, Sofka, and Grimpe 2015), and market scope (Horbach 2008).

2.2. Competitive priorities and green innovation

Competitive priorities are key drivers of organizational changes, affecting a firm's culture, processes, and beliefs (Jitpaiboon, Gu, and Truong 2016). They represent the strategic focus areas that firms choose to emphasize to gain a competitive advantage in the marketplace (Wheelwright 1984). According to the process model of manufacturing strategy, firms establish competitive priorities to support business strategies, set goals, and carry out activities to achieve these priorities (Kim and Arnold 1996). There are four types of competitive priorities: cost, quality, delivery, and flexibility (Leong, Snyder, and Ward 1990).

Cost priority refers to the emphasis on offering products or services at a lower cost than competitors through efficient operations, economies of scale, and supply chain optimization (Chavez et al. 2016). Quality priority focuses on providing superior products or services compared to competitors through the implementation of a quality management systems (Kharub and Sharma 2020). Delivery priority focuses on providing products or services precisely when customers want them, achieved through efficient supply chain management and optimized production planning (Chavez et al. 2016). Flexibility priority highlights the ability to respond swiftly to market changes or customer demands through a flexible organizational structure and rapid decision-making processes (Jain et al. 2013).

However, the mechanisms linking environmental performance to firm performance can be classified into two categories (Montabon, Sroufe, and Narasimhan 2007). First, cost-based mechanisms, where adopting environmental practices helps reduce operational costs through efficiency gains. Second, demand-based mechanisms, where environmental practices meet customer demands for sustainability, leading to increased sales and market share. These mechanisms correspond to cost and quality priorities, respectively. Cost priority relates to internal efficiency and cost reduction, aligning with cost-based mechanisms. Quality priority aligns with demand-based mechanisms by meeting external customer expectations for sustainability. By focusing on these two priorities, we can better understand how firms balance internal cost considerations with external quality demands when introducing green innovations. Additionally, cost and quality priorities are fundamental dimensions of competitive strategy and are often perceived to have a trade-off relationship (Gray, Roth, and Tomlin 2009), making their simultaneous pursuit challenging (Boyer and Lewis 2002). Lastly, while extensive research investigates competitive priorities, the impact of cost and quality priorities on green innovation remains underexplored. Understanding how these specific priorities influence green innovation introduction can offer valuable insights into aligning competitive strategies with environmental sustainability goals.

2.3. Cost priority, quality priority, and green innovation

Firms with cost priority focus on minimizing expenses and maximizing operational efficiency to offer lower-priced products or services (Chavez et al. 2017). This emphasis on cost reduction can make firms cautious about introducing green innovations, which often require significant upfront investments in eco-friendly materials, new technologies, and process changes (Xie, Zhu, and Wang 2019). The introduction of green innovation can also be perceived as conflicting with immediate cost-saving objectives because it can increase operating costs in the short term (Chavez et al. 2016; Wong, Wong, and Boon-Itt 2020).

Moreover, the economic benefits of green innovation are typically realized over a longer horizon, making it challenging for cost-focused firms to justify immediate expenditures (Song and Yu 2018). Organizational resistance to change can further hinder the introduction of green innovations, as employees and managers may be reluctant to alter established processes that currently contribute to cost efficiency (Chang and Chen 2013).

Given these considerations, firms with a cost priority strategy may be less inclined to introduce green innovations due to concerns about increased costs, uncertain returns on investment, and potential disruptions to their cost-efficient operations. Therefore, we propose:

H1a: Cost priority is negatively associated with green innovation introduction.

In contrast, quality priority tends to positively influence the introduction of green innovation. Firms focusing on quality prioritize meeting or exceeding customer expectations, which increasingly include environmental considerations due to rising consumer awareness and demand for sustainable products (Deming 1986; Martin, Elg, and Gremyr 2024). Implementing green innovations can enhance product quality by incorporating eco-friendly materials and sustainable practices, leading to improved customer satisfaction and brand reputation (Horbach and Rennings 2013). By integrating environmental sustainability into their quality management systems, firms can differentiate themselves from competitors and tap into new market opportunities (Makadon et al. 2010). Environmental improvements often align with high-quality standards, further strengthening a firm's competitive position (Reiss-Brennan et al. 2010).

Therefore, firms with a quality priority are more likely to introduce green innovations as a means to enhance product quality and meet evolving customer demands. Based on this, we propose:

H1b: Quality priority is positively associated with green innovation introduction.

2.4. Green innovation and technology uncertainty

Technological uncertainty refers to the uncertainty associated with technological changes, such as its complexity, unpredictability, and rapid advancement (Bolli, Seliger, and Woerter 2020; Bstieler 2005). This uncertainty can lead to rapid technology obsolescence (Bstieler 2005; Zhao, Cavusgil, and Tamer Cavusgil 2014), potentially causing significant investment losses if technologies fails to meet expectations (Ye, Paulson, and Khanna 2022). Consequently, firms often delay introducing new technologies, until they stabilize (Ye, Paulson, and Khanna 2024).

Firms prioritizing cost (price leadership) are particularly sensitive to the risks associated with technological uncertainty because the financial implications of adopting unproven technologies is substantial (Porter 1985; Ragatz, Handfield, and Petersen 2002). Technological uncertainty can discourage these firms from investing in green technologies, especially when the costs are high and the return on investment is uncertain (Bolli, Seliger, and Woerter 2020). Under high technological uncertainty, the fear of sunk costs associated with quickly outdated green technologies may outweigh the perceived benefits (Bstieler 2005; Ye, Paulson, and Khanna 2024). Consequently, firms with a strong cost focus are likely to postpone or avoid the introduction of green innovation when faced with significant technological uncertainty. This leads to the hypothesis:

H2a: Technological uncertainty negatively moderates the negative relationship between cost priority and the introduction of green innovation.

In contrast, firms that prioritize quality are primarily concerned with the performance and reliability of new technologies (Benerjee and McCleer 1997). Technological uncertainty raises questions about the market feasibility and the technology's ability to meet stringent quality standards (Gupta and Wilemon 1990). For these firms, the uncertainty often requires pursuing multiple technological paths simultaneously, posing a significant barrier to introducing green innovation due to potential performance variability and customer dissatisfaction (German 2009; Greene, German, and Delucchi 2009). The unpredictability of whether a new technology will perform as expected or meet the standard leads to hesitation (Darvishmotevali, Altinay, and Ali Köseoglu 2020). Therefore, firms with quality priority are likely to delay introduction until the technology matures and becomes reliable. Thus, technological uncertainty is likely to reduce their willingness to introduce green innovation, leading to the following hypothesis:

H2b: Technological uncertainty negatively moderates the positive relationship between quality priority and the introduction of green innovation.

3. Empirical methods

3.1. Sample and data

We examine the effects of cost and quality priorities on green innovation introduction and the moderating role of technological uncertainty in South Korean manufacturing firms. We have obtained the latest firm-level latest data from the Korean Innovation Survey (KIS), KIS 2022 (STEPI 2022), conducted by the Science and Technology Policy Institute (STEPI), a government-funded research institution, based on the OECD's Oslo manual. This survey, similar to the Community Innovation Survey (CIS) in other countries, collected firm-level data on operational strategies (cost and quality priorities), technological uncertainty, and innovation activities (Galindo-Rueda 2018; Mothe and Nguyen-Thi 2017; Mothe, Nguyen-Thi, and Triguero 2018). STEPI provides the refined and processed data from their 2022 KIS. KIS is the nationally approved statistics in South Korea and has been studied by several researchers in established journals (Castellacci and Mee Lie 2017; Seo et al. 2016). Our sample consists of 3,964 manufacturing firms, after excluding 36 firms from a total of 4,000 observations. These 36 firms are from an industry categorized as miscellaneous manufacturing, where none of the firms introduced green innovation. Our sample covers 23 industries as described in Table A1 in the Appendix. We use data released in 2022, which covers a three-year period from 2019 to 2021. We note that the survey instrument is designed to gather responses based on this three-year timeframe. We describe variables and provide summary statistics in Table 1, because green innovation introduction was not recorded in previous surveys.

Table 1. Description of variables and summary statistics.

Variable	Description (n = 3,964)	Mean	SD	Min	Max
Dependent Variable					
Green Innovation (GI) Introduction	1 if a firm introduces any green innovation, otherwise 0	0.311	0.463	0	1
Independent Variables and a Moderator					
Cost Priority	Degree of focusing on low-price	1.623	1.541	0	5
Quality Priority	Degree of focusing on high-quality	3.204	1.326	0	5
Technological Uncertainty	1 if technological uncertainty is moderate to high, otherwise 0	0.614	0.487	0	1
Controls					
Size	Natural logarithm of the number of employees	4.011	1.375	2.398	11.068
Age	Natural logarithm of a firm's age	2/873	0.659	1.099	4.489
Union	1 if a firm has a union, otherwise 0	0.206	0.404	0	1
Public	1 if a firm is publicly traded, otherwise 0	0.118	0.322	0	1
Group Affiliation	1 if a firm belongs to a group enterprise	0.187	0.390	0	1
Graduate Ratio	Ratio of employees with a master's or higher degree to total number of employees	0.038	0.069	0	0.950
Innovation Expenditure Ratio	Ratio of total innovation expenditures (including both R&D and non-R&D spending) to total sales revenue	0.024	0.057	0	1.328
Export Ratio	Proportion of export market sales to total market sales	0.124	0.222	0	1

3.2. Variables

3.2.1. Dependent variable: green innovation introduction

We define innovations with environmental benefits as green innovations. Firms report their introduction of these innovations at either the production or consumption stages in KIS 2022 (Mothe and Nguyen-Thi 2017; Siedschlag, Meneto, and Tong Koeckling 2019). Green innovation at the production stage relates to internal operational improvements that reduce the firm's environmental footprint, such as replacing a portion of fossil energy with renewable energy sources. On the other hand, green innovation at the consumption stage pertains to the environmental benefits experienced by end users (consumers), such as extending product life through more durable products from the consumer's perspective. Overall, green innovation in consumption is related to the environmental benefits realized by consumers, while green innovation in production is associated with internal changes that reduce the company's environmental impact. The survey incorporates ten items on green innovation introduction: six in production and four in consumption (See Table A2 and A3 in the Appendix). We treat the dependent variable, indicating whether a firm has introduced any green innovation, as binary: coded as 1 for introduction and 0 otherwise. This approach aligns with previous studies using the CIS data (Siedschlag, Meneto, and Tong Koeckling 2019).

3.2.2. Independent variables: cost and quality priorities

Skinner (1985) argues that firms must assign weight to competitive priorities such as cost, quality, flexibility, responsiveness, reflecting the degree of emphasis to achieve their business goals. Our study focuses on cost and quality priorities to assess the operational strategy, similar to the previous studies (Gray, Roth, and Tomlin 2009).

3.2.2.1. Cost priority. Cost priority represents the firm's emphasis on developing low-cost capabilities for its primary products in target markets, establishing its competitive edge in cost-efficiency over its competitors (Gray, Roth, and Tomlin 2009). While some studies measure cost priority using multiple items, such as capacity utilization, labour productivity, inventory cost, and production cost (Gray, Roth, and Tomlin 2009; Kroes and Ghosh 2010), we use a single-item similar to other studies (Peng et al. 2011; Rosenzweig and Roth 2004). Specifically, we measure cost priority using the item in KIS 2022 that describes the perceived importance of focusing on low-price for the economic performance of the firm, scaled from 0 to 5.

3.2.2.2. Quality priority. Quality is defined as the ability to meet or exceed conformance standards (Gray, Roth, and Tomlin 2009). Consistent with several studies using a single-item measure of quality priority, we assess quality priority using one item (Gray, Roth, and Tomlin 2009; Peng et al. 2011). The item in KIS 2022 evaluates the perceived importance of focusing on high quality to improve the firm's economic performance, scaled from 0 to 5.

3.2.3. Moderator: technological uncertainty

Technological uncertainty arises from difficulties in evaluating key specifications of the technology to be developed. It can also occur if the technology's performance capabilities are not fully proven (Cantarello et al. 2011). In this context, we use an item to measure technological uncertainty, specifically how difficult it is for a firm to predict future technological developments. Similar to the study that measured technological uncertainty using CIS data, we constructed a dummy variable. This variable indicates a value of 1 if technological uncertainty is moderate to high (3, 4, or 5) and 0 otherwise (0, 1, or 2) (Bolli, Seliger, and Woerter 2020).

3.2.4. Control variables

We incorporate key control variables, firm characteristics, from previous literature that use CIS and studies innovation (Mothe and Nguyen-Thi 2017; Mothe, Nguyen-Thi, and Triguero 2018; Parrilli, Balavac-Orlić, and Radicic 2023; Siedschlag, Meneto, and Tong Koeckling 2019).

3.2.4.1. Size. Previous studies argue that larger firms are more likely to introduce green innovation (Parrilli, Balavac-Orlić, and Radicic 2023). To control for the size of firms, we create a measure by computing the natural logarithm of the number of employees.

3.2.4.2. Age. Horbach and Rennings (2013) concede that younger firms appear to be more innovative. To account for the impact of firm age on innovation, we measure firm age using the natural logarithm of the firm's age.

3.2.4.3. Union. Unionization would interrupt firm innovation by reducing R&D expenditures and productivity and discouraging innovative inventors in the firm (Bradley, Kim, and Tian 2017). To incorporate the firm's unionization, we create a dummy variable that indicates whether the firm has a union or not.

3.2.4.4. Public. Gao, Hsu, and Li (2018) find that public firms are more likely to engage in exploitative innovation, while private firms in exploratory innovation. To control for the ownership of each firm, we create a dummy variable indicating whether the focal firm is publicly traded or not.

3.2.4.5. Group Affiliation. Previous studies suggest that a firm's affiliation status to group enterprise may affect its tendency to introduce green innovations, because firms within a group can access to more financing options and external knowledge from the other firms in the group (Figueiredo, Patrício, and Reis 2024; Mothe, Nguyen-Thi, and Triguero 2018). To account for this, we control for firm's group affiliation by coding the variable as 1 if a firm belongs to a group enterprise and 0 otherwise.

3.2.4.6. Graduate Ratio. We control for graduate ratio by computing the ratio of employees with a master's or higher degree to total number of employees, because firms with more resources tend to hire more highly educated employees, which can influence their potential capacity for innovation.

3.2.4.7. Innovation Expenditure Ratio. We control for innovation expenditure ratio, calculated as the ratio of total innovation expenditures (including both R&D and non-R&D spending) to total sales revenue. This ratio is a common proxy for a firm's absorptive capacity, reflecting how much of its revenue is allocated to innovation activities (van Beers and Zand 2014).

3.2.4.8. Export ratio. Exporting firms would pursue green innovation more aggressively because they need to compete with firms in other countries where regulatory standards are higher (Choo, Chandrasekaran, and Chinaprayoon 2020). In this regard, we control for the export ratio by calculating the proportion of export market sales to total market sales.

3.2.4.9. Industry fixed effects. Some industries such as utility industries are more likely to introduce green innovation (Ozusaglam, Kesidou, and Yew Wong 2018; Siedschlag, Meneto, and Tong Koeckling 2019). As such, we control for the types of industries using dummy variables.

3.3. Empirical strategy

Our analyses investigate two research questions: whether cost and quality priorities and green innovation introduction are associated, and when their relationships are strengthened or weakened by technological uncertainty. We construct logistic regression models to test the main effects of the priorities and the moderation effect of technological uncertainty (TU). This approach is appropriate because the dependent variable is a binary outcome, whether to introduce green innovation (GI). Across all models, we include control variables and employ robust standard errors clustered at the industry-level. Equation 1 describes our model, where priorities refer to either cost or quality priority, and variables are constructed for a firm i at industry j. Cost and quality priorities are demeaned before creating interaction terms.

$$\log\left(\frac{P(GI_{ij}=1)}{1-P(GI_{ij}=1)}\right)=\beta_1 Priority_{ij}+\beta_2 TU_{ij}+\beta_3 Priority_{ij}\times TU_{ij}+\gamma Contols_{ij}+\delta Industr\,y_j+\varepsilon_{ij} \tag{1}$$

However, a major concern of this study is the potential for endogeneity due to reverse causality, where the introduction of green innovation would influence the levels of cost and quality priorities. Although the cross-sectional data are limited in addressing the issue, we employ a control function method to mitigate it (Ketokivi and McIntosh 2017; Wooldridge 2015). In the first stage (Equation 2), we regress each potentially endogenous variable (cost priority and quality priority) on the instrument variable *z* and control variables, respectively. We then create a predicted variable from the residual term in the Equation 2 for both priorities. Next, in the second stage (Equation 3), we adjust Equation 1 by including the fitted residual term.

$$Priority_{ij}=\beta_1 TU_{ij}+\beta_2 Z_{ij}+\gamma Contols_{ij}+\delta Industry_j+\varepsilon_{ij} \tag{2}$$

$$\log\left(\frac{P(GI_{ij}=1)}{1-P(GI_{ij}=1)}\right)=\beta_1 Priority_{ij}+\beta_2 TU_{ij}+\beta_3 Priority_{ij}\times TU_{ij}+\gamma Contols_{ij}+\delta Industr\,y_j+\eta\hat{\varepsilon}_{ij}+\pi \tag{3}$$

One of major challenges in implementing the control function method is to find the appropriate instruments that are directly associated with independent variables (instruments relevance) but dependent variables (exclusion restriction). We use two steps to construct instrument variables. We first consider the average levels of priorities in the same industry (Li et al. 2023; Palit, Hora, and Ghosh 2022). According to institutional theory, firms mimic the behaviours and strategies of their competitors within the same industry (DiMaggio and Powell 1983). The instrument satisfies the key assumptions of relevance and exclusion restriction, because the industry-level average of priorities does not directly influence the likelihood of green innovation introduction in the focal firm. In our data, the correlations between cost priority and the industry average (r = 0.604, p < 0.01) and between quality priority and the industry average (r = 0.406, p < 0.01) are both positive and significant. However, given the moderately high values and the limitation of using a single instrument per endogenous variable, we also include generated instruments suggested by other studies (Lagzi et al. 2023; Lewbel 2012).

We consider the control function approach as our main model to test hypotheses.

4. Results

A correlation matrix table in Table 2 suggests that each priority is weakly associated with the dependent variable, green innovation introduction.

We report the main analyses testing H1 and H2 in Table 3, using Equations 2 and 3. Models 1 to 2 correspond to Equation 2, which is based on the first-stage of the control function approach, where dependent variables are cost priority and quality priority,

Table 2. Correlation matrix.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) *GI Introduction*	1											
(2) *Cost Priority*	−0.215***	1										
(3) *Quality Priority*	0.083***	0.256***	1									
(4) *Technological Uncertainty*	0.033**	0.145***	0.139***	1								
(5) *Size*	0.401***	−0.016	0.228***	0.059***	1							
(6) *Age*	0.202***	−0.008	0.086***	0.030*	0.380***	1						
(7) *Union*	0.334***	−0.048***	0.122***	0.029*	0.647***	0.289***	1					
(8) *Public*	0.279***	−0.017	0.118***	0.052***	0.538***	0.288***	0.395***	1				
(9) *Group Affiliation*	0.267***	−0.061***	0.106***	0.024	0.583***	0.255***	0.461***	0.384	1			
(10) *Graduate Ratio*	0.308***	−0.089***	0.044***	−0.000	0.276***	0.121***	0.178***	0.191***	0.121***	1		
(11) *Inno. Expenditure Ratio*	0.262***	−0.049***	0.070***	0.031**	0.075***	0.022	0.034**	0.093***	0.028*	0.252***	1	
(12) *Export Ratio*	0.325***	−0.049***	0.108***	0.003	0.406***	0.205***	0.273***	0.240***	0.271***	0.203***	0.123***	1

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

respectively. We then examine the hypotheses in the second stage using Equation 3. Accordingly, in Models 3 through 7, we include the fitted residual terms to address endogeneity. Model 3 examines H1a, which includes cost priority along with technological uncertainty and control variables. Model 5 concerns H1b by considering quality priority. We then analyse the interaction effects between each priority and technological uncertainty in Models 4 and 6, corresponding to H2a and H2b, respectively. Model 7 incorporates all the variables.

Table 3. Control function approach green innovation introduction.

	1st stage: OLS regression		2nd stage: Logistic regression				
DV:	CP	QP	Green Innovation Introduction				
	Model	Model	Model	Model	Model	Model	Model
	1	2	3	4	5	6	7
Cost Priority (Industry-level mean)	1.174 (1.032)		–	–	–	–	–
Quality Priority (Industry-level mean)		1.207 (0.942)	–	–	–	–	–
Tech Uncertainty (TU)	0.319*** (0.005)	0.235*** (0.020)	0.330** (0.130)	0.263* (0.147)	0.054 (0.124)	0.042 (0.129)	0.236 (0.154)
Cost Priority (CP)			−0.590** (0.230)	−0.481* (0.250)			−0.654*** (0.246)
*CP*TU*				−0.116* (0.065)			−0.058 (0.059)
Quality Priority (QP)					0.304* (0.156)	0.341** (0.163)	0.390*** (0.142)
*QP*TU*						−0.115 (0.081)	−0.073 (0.078)
Size	−0.005 (0.006)	0.170*** (0.017)	0.593*** (0.118)	0.593*** (0.118)	0.542*** (0.118)	0.546*** (0.119)	0.543*** (0.109)
Age	0.031*** (0.004)	0.006 (0.008)	0.213*** (0.072)	0.212*** (0.072)	0.186*** (0.062)	0.186*** (0.064)	0.215*** (0.067)
Union	0.073*** (0.012)	−0.006 (0.020)	0.604*** (0.162)	0.608*** (0.166)	0.560*** (0.175)	0.560*** (0.176)	0.624*** (0.167)
Public	0.074*** (0.008)	0.025 (0.022)	0.257* (0.153)	0.248* (0.151)	0.192 (0.171)	0.198 (0.171)	0.256 (0.175)
Group Affiliation	−0.169*** (0.019)	−0.120*** (0.031)	−0.069 (0.161)	−0.070 (0.161)	0.111 (0.158)	0.107 (0.160)	−0.060 (0.147)
Graduate Ratio	0.278*** (0.037)	0.238*** (0.035)	1.450*** (0.306)	1.446*** (0.304)	1.249*** (0.304)	1.258*** (0.304)	1.354*** (0.326)
Inno. Exp. Ratio	0.094** (0.037)	0.735*** (0.175)	4.089*** (1.284)	4.161*** (1.297)	3.886*** (1.386)	3.965*** (1.383)	4.248*** (1.364)
Export Ratio	0.129*** (0.014)	1.300*** (0.124)	13.243*** (3.275)	13.166*** (3.314)	13.171*** (3.417)	13.157*** (3.430)	12.972*** (3.497)
Fitted Residual (Cost)			0.809*** (0.269)	0.764*** (0.268)			0.953*** (0.284)
Fitted Residual (Quality)					0.076 (0.172)	0.119 (0.186)	0.052 (0.171)
Constant			−7.034*** (0.882)	−6.997*** (0.867)	−7.545*** (0.925)	−7.497*** (0.928)	−6.983*** (0.908)
Generated Instruments	Yes	Yes	–	–	–	–	–
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,964	3,964	3,964	3,964	3,964	3,964	3,964
R^2 or Pseudo R^2	0.441	0.368	0.419	0.419	0.430	0.431	0.438

Industry-cluster robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Notes. Without including the generated instruments, the industry-level mean of cost priority is significantly associated with firm-level cost priority ($b = 0.976$, $p < 0.01$) after accounting for control variables. Similarly, the industry-level mean of quality priority is significantly associated with firm-level quality priority ($b = 0.954$, $p < 0.01$) after accounting for control variables. However, to examine the validity of instruments (overidentification), we additionally include generated instruments to provide more robust results.

We find that the effect of cost priority on green innovation is negative and significant ($b_1 = -0.590$, $p < 0.05$, Model 3), thus strongly supporting H1a. However, quality priority positively influences the introduction of green innovations, supporting H1b ($b_1 = 0.304$, $p < 0.10$, Model 5). These effects are statistically robust in other models – specifically, Models 4, 6, and 7.

Next, we evaluate the moderation effect of technological uncertainty on the relationship between priorities and green innovation introduction. For cost priority, technological uncertainty significantly intensifies the negative relationship with green innovation introduction in Model 4 but Model 7 ($b_3 = -0.116$, $p < 0.10$, Model 4; $b_3 = -0.058$, $p > 0.10$, Model 7), partially supporting H2a. In contrast, no significant moderation effect is observed for quality priority, not supporting H2b ($b_3 = -0.115$, $p > 0.1$, Model 6; $b_3 = -0.073$, $p > 0.1$, Model 7). To illustrate these results, Figure 1 displays the relationships among cost priority, technological uncertainty, and green innovation introduction based on Model 4. The result highlights the moderating effect where the combination of cost priority and technological uncertainty leads to decreases in green innovation introduction.

4.1. Robustness check and post-hoc analysis

We conduct robustness checks using alternative dependent variables and post-hoc analysis to further investigate green innovation intensity. First, we consider two alternative dependent variables for green innovation introduction. The OECD distinguishes two categories of green innovation benefits: one occurring at the production stage for manufacturers and another at the consumption stage for end-users (Galindo-Rueda 2018). Accordingly, we create two alternative dependent variables, whether to introduce green innovation at each stage respectively. Table A2 in the Appendix describes six innovations for production and four for consumption. The new variables indicate whether a firm introduce any green innovation for benefits at production or consumption respectively. We also use the control function method to mitigate the endogeneity issues. We find that the results are robust compared to main results in Table 3, but some contingencies exist

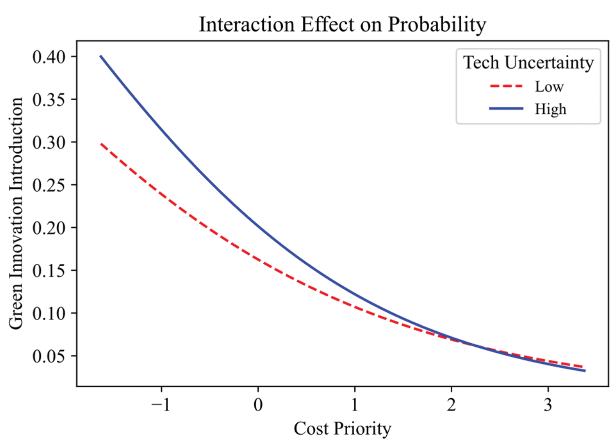

Figure 1. Interaction effects of technological uncertainty: cost priority.

for the moderation effect (See Table B1 in the Appendix). In the context of green innovation introduction at the production stage, cost and quality priorities are significantly associated with the green innovation introduction, supporting H1a ($b_1 = -0.534$, $p < 0.05$, Model 1) and H1b ($b_1 = 0.348$, $p < 0.05$, Model 2). We also observe that technological uncertainty significantly intensifies the negative relationship between cost priority and the green innovation introduction at production in Model 1 but Model 3 ($b_3 = -0.129$, $p < 0.10$, Model 1; $b_3 = -0.076$, $p > 0.10$, Model 3), partially supporting H2a. In contrast, the moderation effect between quality priority and technological uncertainty is insignificant ($b_3 = -0.072$, $p > 0.10$, Model 2). At the consumption stage, however, results are consistent except for the moderation effects. While the main effects of cost priority ($b_1 = -0.633$, $p < 0.01$, Model 4) and quality priority ($b_1 = 0.322$, $p < 0.10$, Model 5) remain significant, the moderation effect between cost priority and technological uncertainty is mixed ($b_3 = 0.115$, $p > 0.10$, Model 4; $b_3 = 0.151$, $p < 0.05$, Model 6). Next, the moderation effect between quality priority and technological uncertainty is also mixed significant ($b_3 = -0.150$, $p < 0.10$, Model 4). However, this result is no longer significant in the comprehensive model that include all variables (Model 6). Overall these results suggest that depending on the types of green innovation, either at production or consumption, technological uncertainty would be contingent. Thus, technological uncertainty may play different roles as a moderator. However, due to the mixed results, they call for future research.

In the post-hoc analysis, we investigate the intensity of green innovation introduction among firms that have already introduced such innovations. Previously, we focus solely on whether a firm introduce any green innovation, ignoring the extent of each firm's dedication to green innovation. Using the ten measure items of green innovation in Table A2, we count the number of innovations each firm introduced. We build negative binomial regression models for those 1,221 firms that introduced at least one green innovation, because the dependent variable is a non-zero count variable. We employ the control function method with robust standard errors clustered at industry level. From the result reported in Table B2 in the Appendix, we find that while the main effects remain significant, the moderation effects are not. The result suggests that cost priority is negative associated with introduction intensities ($b_1 = -0.108$, $p < 0.05$, Model 1), and that quality priorities is positively associated with the intensities ($b_1 = 0.089$, $p < 0.10$, Model 2), aligned with the main result.

5. Discussion

5.1. Theoretical implications

First, this study advances our understanding of the determinants of green innovation by revisiting the impact of competitive priorities, specifically cost and quality priorities. While much of previous literature has focused on priorities such as flexibility that influence various forms of innovation, we find that cost and quality priorities also significantly influence 'green' innovation introduction, an area that has not been thoroughly explored before.

Second, we examine the role of technological uncertainty in green innovation introduction. We find that technological uncertainty typically exacerbates the negative impact of cost priority on green innovation introduction, making firms more risk averse. This effect, however, is context dependent. Specifically, when green innovation benefits manufacturers directly, technological uncertainty discourages introduction by intensifying the negative association between cost priority and green innovation introduction. However, when the benefits of green innovation are aligned with customer interests, manufacturers are more likely to assume risks, with technological uncertainty unexpectedly mitigating the negative impacts of cost priority and promoting green innovation introduction. However, future research is necessary because our results are not robust across models.

Overall, these insights highlight the nuanced interplay between competitive priorities and technological uncertainty that influence green innovation, offering valuable implications for both theory in sustainable operations management.

5.2. Practice implications

As green innovation becomes more salient globally, it is crucial for policy makers to understand these dynamics and foster an environment for sustainable practices. This study quantifies the impact of cost and quality priorities on green innovation: a one-scale increase in cost priority leads to a 44.6% ($b_1 = -0.590$, Model 3 in Table 3, 0.446 = 1 - exp (−0.590)) decrease in the likelihood of introducing green innovation, whereas a one-scale increase in quality priority results in a 35.5% ($b_1 = 0.304$, Model 5 in Table 3, 0.355 = exp (0.304) − 1)) increase. Our findings indicate that firms emphasizing price competitiveness (cost leadership) are less likely to introduce green innovations, while those prioritizing quality are more inclined to do so. Furthermore, the influence of technological uncertainty on green innovation introduction varies depending on whether the benefits are targeted towards manufacturers or consumers. These results suggest that there is no one-size-fits-all policy solution. Instead, policymakers should consider the specific competitive context of firms and develop tailored strategies to promote green innovation across different sectors.

5.3. Limitations and future directions

First, one of the major limitations of this study is using cross-sectional data. However, prior to KIS 2022, the survey did not contain any measure of green innovation introduction. As ESG continue to gain importance, If consistent measurements of green innovation are maintained continuously, longitudinal analysis will be possible in future research. This will allow future research to infer how the impact of cost and quality priority strategies on the introduction of green innovation changes over the long term.

Second, another limitation arises from the self-assessment methods used for data collection, which could introduce social desirability and common method biases. However, our dependent variable is a binary measure of whether a firm introduce any green innovation or not. Additionally, common method bias can significantly deflate interaction effects rather than inflate them, making it more difficult for them to be significant (Siemsen, Roth, and Oliveira 2010). Thus, we have fewer concerns about common method bias. However, as mentioned earlier, future research could benefit from using a longitudinal approach (time-lagged) to mitigate these biases.

Third, the generalizability of our findings may be restricted due to the specific context of our sample, which reflects only the situation during the COVID-19 pandemic in Korea. Future studies could expand the scope to different geographical and institutional settings to determine the applicability of our results in other contexts. As CIS data also capture green innovation, researchers are encouraged to utilize these resources to explore how various factors might influence green innovation introduction in different countries. This could provide a more robust understanding of the dynamics at green innovation introduction.

6. Conclusion

In this study, we examine the effects of competitive priorities – cost and quality priorities – on green innovation introduction and the moderation role of technological uncertainty in the context of Korean manufacturing firms. We use KIS 2022 data from the STEPI and then employ the control function method to address endogeneity issues to examine these effects. The results show the negative association between cost priority and green innovation introduction and the positive association between quality priority and the introduction. We further show that technological uncertainty intensifies the negative association between cost priority and green innovation. Additionally, we further differentiate the effects on green innovation introduction at the production and consumption stages. When green innovation benefits manufacturer, technological uncertainty intensifies the negative association between cost priority and green innovation introduction. In contrast, when benefits are at consumption, technological uncertainty may weaken this negative association. This suggests that firms are more willing to embrace associated risks when the benefits of green innovations are directly perceived by end-users. This observation aligns with literature indicating that firms are willing to introduce green innovation under technological uncertainty, when customers recognize the benefits (Wang, Kai Chan, and Li 2015). As the post-hoc analysis, we explore the extent of green innovation introduction among firms that have introduced at least one innovation. The significance of main effects in this result confirms that the mechanism influencing both the decision to introduce green innovation and the extent of its introduction are consistent.

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Appendices

Appendix A. Survey questions

Table A1. List of industries (n = 3,964).

Type of industry	# of firms
Food manufacturing	293
Beverage manufacturing	24
Textiles manufacturing (excl. clothing)	102
Clothing, accessories, and fur products manufacturing	79
Leather, bags, and footwear manufacturing	20
Wood and wood products (excl. furniture)	32
Pulp and paper products manufacturing	99
Printing and reproduction of recorded media	43
Coke, coal, and refined petroleum products manufacturing	17
Chemical products manufacturing (excl. pharmaceuticals)	250
Medical substances and pharmaceutical manufacturing	100
Rubber and plastic products manufacturing	306
Non-metallic mineral products manufacturing	149
Basic metals manufacturing	210
Fabricated metal products (excl. machinery, furniture)	383
Electronic components and communication equipment manufacturing	317
Medical, precision, and optical instruments manufacturing	157
Electrical equipment manufacturing	275
Other machinery and equipment manufacturing	527
Motor vehicles and trailers manufacturing	422
Other transport equipment manufacturing	93
Furniture manufacturing	42
Repair of industrial machinery and equipment	24

Table A2. Green innovation introduction measures items.

Whether your firm introduced innovations with the following environmental benefits:	
At production	(1) reduced material or water use per unit of output.
	(2) reduced energy use or CO_2 footprint.
	(3) reduced soil, noise, water or air pollution.
	(4) replaced a share of materials with less polluting or hazardous substitutes.
	(5) replaced a share of fossil energy with renewable energy sources.
	(6) recycled waste, water, or materials for own use or sale.
At consumption	(7) reduced energy use or CO_2 footprint.
	(8) reduced air, water, soil or noise pollution.
	(9) facilitated recycling of product after use.
	(10) extended product life through longer-lasting, more durable products.

Table A3. Competitive priorities and technology uncertainty measures items.

Competitive priorities: How important were the following strategies to the economic performance of your firm?	
Cost	Focus on low-price (price leadership)
Quality	Focus on high-quality (quality leadership)
Flexibility	Focus on a broad range of goods or service
To what extend do the following characteristics describe the condition faced by your firm?	
Technological uncertainty	Future technological developments are difficult to predict.

Appendix B. Robustness checks

Table B1. Green innovation introduction for production and consumption.

DV: *Green Innovation*	Production			Consumption		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Tech Uncertainty (TU)	0.290*	0.059	0.268*	−0.199	−0.510***	−0.230
	(0.156)	(0.133)	(0.161)	(0.131)	(0.118)	(0.145)
Cost Priority	−0.534**		−0.724***	−0.633***		−0.784***
	(0.235)		(0.242)	(0.202)		(0.192)
*Cost Priority*TU*	−0.129*		−0.076	0.115		0.151**
	(0.071)		(0.064)	(0.074)		(0.069)
Quality Priority		0.348**	0.404***		0.322*	0.370**
		(0.158)	(0.133)		(0.172)	(0.167)
*Quality Priority*TU*		−0.072	−0.025		−0.150*	−0.113
		(0.089)	(0.089)		(0.088)	(0.094)
Size	0.628***	0.576***	0.573***	0.475***	0.419***	0.421***
	(0.122)	(0.127)	(0.117)	(0.111)	(0.105)	(0.099)
Age	0.226***	0.197***	0.230***	0.072	0.054	0.073
	(0.078)	(0.066)	(0.072)	(0.104)	(0.097)	(0.099)
Union	0.582***	0.532***	0.602***	0.279	0.224	0.282
	(0.157)	(0.165)	(0.155)	(0.318)	(0.318)	(0.318)
Public	0.211	0.154	0.217	−0.017	−0.089	−0.004
	(0.160)	(0.175)	(0.184)	(0.151)	(0.148)	(0.161)
Group Affiliation	−0.065	0.125	−0.055	−0.082	0.068	−0.094
	(0.134)	(0.124)	(0.115)	(0.241)	(0.256)	(0.234)
Graduate Ratio	2.664**	2.403*	2.676**	3.516***	3.451***	3.601***
	(1.219)	(1.252)	(1.237)	(1.089)	(1.078)	(1.148)
Inno. Exp. Ratio	12.912***	12.927***	12.769***	5.105***	4.550***	4.744***
	(3.020)	(3.177)	(3.259)	(1.496)	(1.688)	(1.620)
Export Ratio	1.410***	1.205***	1.310***	1.108***	0.936***	1.021***
	(0.300)	(0.304)	(0.323)	(0.247)	(0.239)	(0.246)
Fitted Residual (Cost)	0.826***		1.042***	0.856***		1.041***
	(0.255)		(0.285)	(0.226)		(0.233)
Fitted Residual (Quality)		0.094	0.021		−0.018	−0.040
		(0.184)	(0.166)		(0.195)	(0.195)
Constant	−6.973***	−7.539***	−6.963***	−6.064***	−6.235***	−5.912***
	(0.808)	(0.903)	(0.856)	(0.716)	(0.703)	(0.689)
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,964	3,964	3,964	3,605	3,605	3,605
Pseudo R^2	0.412	0.424	0.433	0.273	0.272	0.285

Industry-cluster robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table B2. Negative binomial regression analysis: green innovation intensities.

DV: Green Innovation (Counts)	Model 1	Model 2	Model 3
Tech Uncertainty (TU)	−0.031	−0.100***	−0.097**
	(0.040)	(0.037)	(0.043)
Cost Priority	−0.108**		0.021
	(0.045)		(0.024)
*Cost Priority*TU*	0.052		0.042
	(0.034)		(0.033)
Quality Priority		0.089*	0.103**
		(0.046)	(0.045)
*Quality Priority*TU*		0.002	0.019
		(0.032)	(0.035)
Size	0.049**	0.029	0.026
	(0.023)	(0.022)	(0.022)
Age	−0.031	−0.032	−0.037
	(0.033)	(0.033)	(0.033)
Union	−0.012	−0.009	−0.014
	(0.067)	(0.069)	(0.071)
Public	−0.052	−0.067*	−0.062
	(0.043)	(0.037)	(0.039)
Group Affiliation	0.084	0.114	0.128*
	(0.074)	(0.079)	(0.073)
Graduate Ratio	−0.948***	−0.973***	−0.959***
	(0.250)	(0.267)	(0.253)
Inno. Exp. Ratio	−0.500**	−0.683***	−0.692***
	(0.222)	(0.261)	(0.249)
Export Ratio	0.054	0.017	−0.001
	(0.073)	(0.073)	(0.078)
Constant	1.550***	1.693***	1.625***
	(0.237)	(0.162)	(0.143)
Industry Fixed Effects	Yes	Yes	Yes
Fitted Residual	Yes	Yes	Yes
Observations	1,221	1,221	1,221
Pseudo R^2	0.0320	0.0282	0.0324

Industry-cluster robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.