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Female CEOs and Green Innovation: Evidence from Asian Firms

Marwan Mansour [1,2,*], Mohammad Fawzi Shubita [1], Abdalwali Lutfi [3,4,5,*], Mohammed W. A. Saleh [6] and Mohamed Saad [7]

[1] Department of Accounting, Amman Arab University, Amman 11953, Jordan; m.shubita@aau.edu.jo
[2] Jadara Research Center, Jadara University, Irbid 21110, Jordan
[3] College of Business Administration, University of Kalba (UKB), Kalba 11115, United Arab Emirates
[4] Applied Science Research Center, Applied Science Private University, Amman 11931, Jordan
[5] MEU Research Unit, Middle East University, Amman 11831, Jordan
[6] Department of Accounting and Auditing, Palestine Technical University-Kadoorie, Tulkarm P.O. Box 7, Palestine; mohammed.w.saleh@ptuk.edu.ps
[7] Department of Accounting, College of Business, King Faisal University, Al-Ahsa 31982, Saudi Arabia; msoahmad@kfu.edu.sa
* Correspondence: m.mansour@aau.edu.jo (M.M.); abdalwale.lutfi@ukb.ac.ae (A.L.)

Abstract: This study aims to examine how female CEOs influence green innovation and whether firm size moderates this connection. Our paper focuses on CEOs, who are considered the strategic leaders of corporations, because of their crucial role in making important decisions. This research paper examines how female CEOs influence green innovation (GI) in the Asian industrial sector. The primary goal is to address these research questions: Do Asian industrial firms with female and male CEOs differ in their GI efforts? Is there a positive moderating influence of Asian industrial enterprises' size on the nexus between women in CEO positions and eco-innovation? Based on our research questions, firm size is likely a determining factor in the GI of female CEOs. This research employs rigorous econometric modeling to analyze a substantial dataset of listed Asian industrial companies from 2013 to 2022. We have found a significant positive correlation between female CEOs and GI in Asian industrial firms. It has been proven that female CEOs in the industrial sector are more inclined to promote environmentally friendly practices. Furthermore, the size of an industrial firm amplifies the beneficial influence of a female CEO on the firm's chances of engaging in GI initiatives. Regarding the moderating effect of size, the size of companies significantly magnifies the impact of female CEOs on GI. The effectiveness of female CEOs on environmentally friendly practices is more prominent in large corporations than in smaller ones. Our outcomes remain robust with respect to endogeneity issues using two-step GMM estimators. This study proposes that stakeholders, particularly in Asian countries, should promote the increased representation of females in CEO roles, particularly within large corporations. This is because women-led companies demonstrate superior performance in GI endeavors. Hence, regulators must establish policies that facilitate the participation of women in CEO positions within large-scale enterprises. These policies may strengthen the private sector's capacity to foster sustainable innovation.

Keywords: female CEOs; green innovation; industrial sector; GMM

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1. Introduction

Environmental concerns have intensified the pressure to conserve and maintain natural resources [1]. Businesses increasingly realize they must be involved in accomplishing these greening objectives [2]. Modern corporations encounter a multitude of environmental challenges and pressures. Firm managers know that GI is critical for sustainable development and gaining a competitive edge. GI is a vital and efficient solution for firms to address a changing environment and mounting pressure [3]. Business innovations driven by sustainability models have revolutionized manufacturing strategies, considering ecological risks such as GI [4]. While the innovation issue has been extensively studied in the

finance literature, little attention has been given to the effect of CEO gender on GI [5,6]. Past studies suggest that female CEOs exhibit higher levels of risk aversion than their male counterparts, making this issue especially important [2,7]. Additionally, firms must prioritize GI to stay ahead, but this endeavor is hazardous and prone to failure [8]. The implications suggest that eco-innovation is less common in female-led enterprises [9].

However, there is an assertion that women commonly experience discrimination based on their gender in their professional paths, particularly in societies with a strong patriarchal influence [10,11]. Moreover, the glass ceiling viewpoint highlights that women encounter greater obstacles in attaining senior leadership roles because of diverse social and cultural influences [5,7]. According to Becker [12], discrimination causes individuals who are discriminated against to have suboptimal demands and wages. As a result, those people must work harder to meet the limited requirements [2]. In this scenario, female chief executives are expected to engage in more green innovative activities than male CEOs to outperform their male colleagues and secure CEO positions [7,13–15].

In addition, the performance burden may escalate for women in executive positions at large companies [16]. It can be argued that gender-based discrimination is more pronounced in large corporations [17]. Gender stereotypes frequently assume that females are not assertive enough and lack the time to manage larger companies due to domestic responsibilities [18], making them unsuitable for CEO positions in larger companies [2]. Moreover, larger firms are known to attract top talents, making managerial competition more challenging [19]. Female CEOs face more managerial competition from larger firms than smaller ones [20]. Hence, female CEOs in large corporations may have a greater propensity to engage in eco-friendly innovative activities [2,11,21], which can enhance their managerial performance.

Based on prior practical studies and combining the insights of diverse theories, including upper echelon, social role, and contingency theory, this study examines how CEO gender influences the adoption of eco-friendly innovations. Specifically, this paper intends to address the following research questions:

(1) Do Asian companies with female CEOs innovate more or less in green practices than those with male CEOs? Or do female CEOs affect the adoption of GI in Asian companies?
(2) Does company size positively moderate the effect of female CEOs on GI?

Based on our research questions, the innovative performance of female CEOs is likely dependent on the size of their firms. We are motivated by the lack of generalizability and conflicting findings in the current research on the relationship between female CEOs and green innovation efforts. Moreover, there is a noticeable absence of comprehensive research on how women chief executives contribute to green initiatives in Asian companies. Moreover, based on the authors' knowledge, this study represents an inaugural attempt to examine the involvement of women chief executives in promoting eco-innovation within an Asian framework. Rising environmental concerns are forcing the industrial sector in Asia to adopt increasingly sustainable practices. Nonetheless, there is a lack of research on how female leadership promotes GI in this context [16]. Given the rise in female CEOs and the global focus on sustainability, it is crucial to comprehend this relationship.

We use data from the Refinitiv Eikon database to answer these questions regarding Asian industrial firms. These data allow us to assess the environmental practices of firms led by female CEOs. The reason for selecting Asian industrial firms for this study is their significant ecological impact. Furthermore, they face enormous pressure from stakeholders as sizable emitters of GHGs. With job creation and business support, the industrial sector has emerged as the primary force behind the global economy [22,23]. These progressions have downsides, such as depleting natural resources and disrupting ecological balance. It should be noted that the existing literature lacks comprehensive research on this association, especially on Asian industrial firms.

This study is part of the expanding body of research that explores the influence of gender diversity in leadership on the development of environmentally innovative practices

in corporations. The results of our study demonstrate a clear and positive correlation between the existence of female chief executives and the progress of eco-friendly innovation in the Asian industrial sector. Female CEOs in industrial firms are more inclined to adopt environmentally friendly practices, especially in larger companies where the effect of female leadership on eco-friendly initiatives is magnified. The influence of female CEOs in driving eco-friendly initiatives is more pronounced in giant companies, highlighting the moderating role (contingent role) of firm size. These results are essential for policymakers, corporate leaders, and industry stakeholders. The strong link between female leadership and green innovation implies that encouraging gender diversity in high-level executive roles, particularly in large corporations, could be vital to driving sustainable business practices forward. Policymakers must focus on initiatives prioritizing women's promotion into CEO positions in major corporations. Companies with female leaders have proven more successful in advancing GI. Likewise, companies should actively cultivate supportive environments that encourage and advance women in leadership roles, as this could strengthen their ability to achieve environmental sustainability objectives.

This study sheds light on valuable insights regarding governance practices, providing evidence to guide companies in enhancing their leadership diversity to drive sustainability. Additionally, it informs policymakers aiming to promote gender diversity and GI within critical industries. This research provides both theoretical and practical contributions. By integrating upper echelon and social role theories, our study explores the influence of female CEOs on GI in the Asian context, filling a gap in the literature. By examining a large sample of publicly traded Asian industrial firms, this study fills the gap left by previous research that only focused on the roles of female CEOs in GI in single countries such as China [11] and Indonesia [2]. According to our study, Asian firms led by female CEOs demonstrate a higher level of environmental consciousness compared to those headed by male CEOs, providing significant insights into both theories. This study also successfully merges two conflicting streams of financial literature. Specifically, the first stream examines how CEO gender influences firm behavior and outcomes. Alternatively, another stream delves into the factors influencing GI, but it neglects to consider the role of CEO gender in this matter [9]. Second, the nexus between Asian female chief executives and eco-innovation is contingent on the firm's size. These results could explain the conflicting findings seen in previous studies [7]. This investigation proposes that larger Asian firms are more likely to experience significant advantages when they have female CEOs than small firms. Third, this study stands out because it utilized a larger sample size and solid econometric techniques. By contrast, many studies have depended on primary data from surveys [2,9], and the lack of panel data has hindered them from conducting supplementary analysis for robustness. This study has practical implications, too. To foster more GI, stakeholders should promote the appointment of female CEOs in larger firms.

2. Theoretical Framework and Hypotheses Development

2.1. Green Innovation

The literature employs various terms to describe innovations that support the impacts of eco-friendly business activities [24], including ecological/environmental innovation, sustainable innovation, and GI [3,25]. GI has become popular among organizations, public authorities, stakeholders, and the media [7]. It encompasses various systems, techniques, and products that boost energy conservation and minimize non-eco-friendly impacts [26]. GI is typically classified in terms of design, manufacturing, processes, production, and technology [27]. GI means designing or changing products to minimize resource consumption or environmental harm [28]. Corporate GI's primary objective is to advance a sustainable future by resolving ecological challenges [29]. Adopting GI helps mitigate waste, pollution, and emissions and boosts business profitability by promoting innovative production practices and efficient resource utilization [30]. GI positively affects a company's competitive advantage [31]. Scholars assert businesses can find a profitable win–win solution by embracing GI [3,32], which addresses environmental preservation and economic growth.

The growing demand for environmentally friendly products has attracted considerable attention from academics and industry, making GI highly sought after [33]. Many studies have concentrated on understanding why corporations implement GI [28]. One reason is that companies must prioritize GI to acquire legitimacy [30]. For example, a company that develops and enacts environmentally innovative policies sends a strong message to the market of its genuine commitment to improving the environment [5]. Additionally, companies are more inclined to embrace and execute environmentally friendly innovations when confronted with an ecological legitimacy dilemma [26]. Thus, GI benefits the environment and society while promoting efficient resource utilization and enhancing profitability [3].

2.2. Female CEOs and Green Innovation

The CEO of a company makes critical strategic decisions, such as entering and exiting markets, implementing innovations, and allocating resources [34]. Based on previous studies [35,36], the CEO holds the top executive position in the company and is responsible for formulating strategies and significantly influencing decision-making. Therefore, researchers assert CEOs hold a vigorous sway over companies' strategic adoptions and implementations, permitting them to influence eco-friendly plans and practices [10]. The upper echelons theory suggests that high-level executives play a crucial role in promoting innovative eco-friendly practices [37]. Accordingly, companies' strategic choices are impacted by the traits of their senior executives, including their personality, cultural background, ethical principles, and attitude toward risk. This is because male and female executives have different viewpoints and behaviors.

Despite the frequent emphasis by market authorities on promoting female board representation [33,38–40], there is a noticeable lack of discussion regarding appointing female CEOs [7,41,42]. Furthermore, despite many businesses promising to increase female representation on their boards, the global underrepresentation of females in CEO positions continues [5,10,43]. According to analysis of the S&P for US-listed companies, there were over 19 male CEOs for each female CEO in 2018. Moreover, according to [44], women comprise only 0.8% of CEOs in Japan. According to CEO magazine, female CEOs only accounted for 5.4% of the total number of CEOs worldwide in 2023.

There has been limited research on the impact of women CEOs [5,37,45] despite substantial scholarly attention to the relationship between women on boards and corporate GI [24,25,30,45,46]. The effect on women differs depending on whether they hold CEO positions or are board members [7,14]. Board members, who are women, monitor [33]. When in CEO roles, they hold decision-making power [2,47]. The CEO has the highest position in the company and plays a crucial role in its achievements [9]. CEOs are actively involved in daily business activities and make high-level managerial decisions, including those related to GI [6,11]. Formulating strategies and exerting strong decision-making power are critical responsibilities of the CEO within the organization [48–50]. As a result, experts contend CEOs play a significant role in shaping firms' strategic preferences and execution, thus giving them considerable power to impact environmental policies and practices. Contextually, researchers, e.g., [49,51], have argued that firms with more female CEOs might have an edge in acquiring enhanced social and financial outcomes. However, academic examination of the impact of a female CEO's position on sustainable innovation strategy remains underexplored [2].

The varying biological and social attributes of females and males can debatably enlighten the divergent behaviors exhibited by gender-based CEOs, which may include their propensity to tolerate risks during the decision-making process [15]. As a result, men are more inclined to take risks to accomplish their goals [4], as these risks can lead to greater rewards [37], satisfying their assertiveness and desire for control [52]. Therefore, several investigations indicate that males are more inclined to take higher economic risks than females, possibly because of the influence of higher testosterone levels in men, which drives them to strive for more outstanding achievements [2]. In contrast, women frequently encounter discrimination based on their gender while trying to pursue their professional

goals [5,6,9]. As a result, women face more significant challenges in attaining leadership positions within different organizations. A barrier known as the glass ceiling prevents women from achieving high-level managerial roles [14]. Moreover, those who accomplish this are likely to experience a decrease in their wages compared to men in the same position.

The upper echelon theory has recognized that CEOs' traits significantly explain companies' behavior and results [7,45,53]. According to this theory [5,11], CEOs' characteristics influence how they interpret complex environments and enable them to make effective operational and strategic decisions in response [16,37]. CEOs play crucial roles that impact firms' behavior and outcomes [54]. Gender is likely to impact GI and corporate outcomes significantly. Eco-innovation heavily relies on CEOs' risk-related behaviors, which affect the risky decisions involved [48,49,54].

In addition, the social role theory suggests that women possess inherent qualities such as kindness, empathy, and a greater sense of social responsibility than men [5,14,44]. Companies have a social responsibility to engage in GI [51], so women must actively participate in decision-making processes regarding GI [11]. This will help the company meet social expectations and fulfill its social responsibilities. If a woman held the CEO position in a company, her role would significantly influence decision-making. As a result, she would gain more authority in determining the firm's annual social responsibility budget, thereby considerably impacting the company's GI. Female CEOs can enhance cognitive diversity in businesses, fostering innovation through diverse perspectives, experiences, and leadership styles [55]. Diverse leadership teams promote creative problem-solving and open-mindedness [56,57]. This can drive GI implementation, including eco-friendly practices. Female CEOs prioritize sustainability and ethics, showing empathy and moral guidance [2,58]. This supports GI principles, aiming to balance profitability with sustainability [7,59]. Female CEOs can promote eco-friendly innovations with financial benefits.

The upper echelon theory is supported by empirical studies [7,60], which show the influence of managers' idiosyncrasies on firms' performance and decision-making [34]. For example, based on French-listed companies, the authors of [7] contend that there is a connection between gender diversity among executives and an increase in GI. Similarly, the authors of [11] established conclusive evidence that female CEOs are more ecologically conscious than males. Data from Chinese listed firms between 2008 and 2016 forms the basis of this finding. The findings of [2] suggest that Indonesian firms under the leadership of female CEOs are more inclined to be innovative.

On the contrary, according to [9], female-led companies are less inclined to invest in innovation than male-led companies. Additionally, [45] argues that the gender of the chairperson does not have a substantial impact on the level of eco-friendly innovation in Chinese manufacturing companies. According to a study by [61], women who owned businesses were more likely to introduce innovations globally than women in managerial positions. Also, the research conducted by [62] does not establish a significant connection between the existence of female CEOs and innovation in all French-listed companies from 2000 to 2018. Furthermore, a study conducted from 2008 to 2017 found that having female CEOs in Chinese publicly operated companies had a negative effect on GI. It is worth mentioning that previous studies' findings have been inconsistent. According to the literature discussed above, even though women CEOs are risk-averse, they are still willing to participate in environmentally friendly innovation projects because they know the importance of corporate social responsibility. Most research on female CEOs and GI focuses on broader sectors such as non-financial companies [11].

A careful analysis of previous studies reveals the following: First, the role of feminine CEOs in indorsing sustainable innovation has not received sufficient research attention, especially in Asia. Existing studies on this topic in Asia are limited in scope.

Second, using primary data in most previous studies creates a research gap in methodology, as it limits the ability to generalize their findings and highlights the need for more reliance on secondary data, e.g., [2,9].

Third, the company's size was not considered an intervening variable that could potentially modify this relationship in previous studies. However, the industrial sector, especially in Asia, remains underexplored. As the industrial sector in Asia grapples with the dual challenge of economic growth and environmental sustainability [16], this study is both timely and necessary. Understanding the potential of female leadership in driving GI contributes to academic discourse and has significant implications for future regional business practices. This study seeks to fill these gaps.

In addition, scholars emphasize that feminine leaders tend to be more sustainable, innovative, and egalitarian in their attitude to strategy-making, and they are more likely to embrace novel initiatives [2,60]. Female leaders demonstrate a stronger inclination toward the well-being of stakeholders [7,8]. Females in high-level positions possess a critical skill set to harmonize the anxieties of several stakeholders effectively, such as eco-friendly concerns, in addition to shareholders' benefits [35]. Experimental research has shown that females in top leadership positions prioritize the environmental issues their organizations face [9,15]. These CEOs' socialization responsibilities and career paths motivate them to prioritize relationship-building and contribute to a better community by advocating for eco-friendly initiatives [63]. As a result, the gender socialization perspective suggests that female CEOs are more likely than their male counterparts to advocate for sustainable practices [11]. Exploring the link between female CEOs and a company's ecofriendly innovation is an intriguing aspect of this discussion. Taking these studies into account, we propose the following hypothesis:

Hypothesis 1 (H1): *The existence of female CEOs in Asian listed firms is strongly correlated with increased GI.*

2.3. The Moderating Role of Firms' Size

The contingency theory [64] suggests that the size of a company is a context-dependent factor [19] that can either facilitate or hinder various activities of firms, including decision-making and fostering creativity [3,17,65]. Thus, a company's size may significantly influence CEOs' involvement in making decisions for the company [66]. The importance of firm-specific factors [2], such as firm size [11], in shaping the interconnection between female CEOs and eco-friendly innovation becomes evident and needs further investigation. Furthermore, per the resource-based view theory [19], a firm's capabilities and resources determine its success and competitive advantage [21]. Even though size substantially impacts a firm's activities [18], preceding research has only considered it as a variable to control [7,32,67]. According to previous studies [3,19,20,26], the firm size can either facilitate or impede its willingness to adopt GI practices [68]. The presence of female CEOs in larger companies can have a multiplier effect on GI because of their access to abundant financial and nonfinancial resources [17].

Consequently, this study examines the influence of firm size on the connection between female CEOs and GI in Asian industrial firms for various reasons. Many compelling reasons make firm size a crucial factor [16]. For example, there is a direct association between the size of a firm and its commitment to research and development [69], which is seen as a crucial factor for GI [11]. Over time, researchers have consistently witnessed compelling empirical evidence supporting a strong correlation between the size of a firm and its investment in research and development [20], ultimately facilitating GI [2]. Increased profitability in larger corporations allows them to finance internal research and development and promote environmentally friendly innovation [19]. Financial institutions find it easier to provide funding for R&D and GI for larger firms due to their higher level of informational transparency [26]. Larger firms have the advantage of leveraging R&D investments and transforming them into eco-innovations [11]. Reference [7] argues that large companies possess greater financial flexibility than smaller ones, which drives them to pursue innovative initiatives. Additionally, [24] discovered a positive correlation between larger companies and increased eco-friendly innovation.

The influence of CEOs in firm decision-making varies depending on the firm's size [7]. Larger companies have more incredible wealth and resources [26], which can enhance the impact of female CEOs on environmentally friendly innovations [11]. Since female CEOs in larger firms have access to greater resources, they can quickly meet the demands of R&D. This, in turn, allows for the growth and success of eco-friendly innovations because of the "economies of scale and scope" that these female CEOs can effortlessly establish. Female CEOs in large corporations have a strategic advantage in accessing untapped opportunities. Also, larger companies may subject women to increased gender-based discrimination and stereotypes when vying for high-level managerial roles [2]. Take women, for instance, who are commonly believed to lack the necessary traits for high-level managerial positions and are expected to prioritize their domestic duties, even though leading larger firms requires significant time and effort. To reach top positions in larger firms, women must outperform men and engage in risky activities like GI.

Additionally, female CEOs in larger companies can effectively manage and mitigate risk by overseeing various research and development initiatives. External resources are more readily available to CEOs of larger companies [3]. With their firms holding a substantial market share, these CEOs have a competitive edge over others. This advantage allows them to attain returns easily and fosters their commitment to GI. Due to the lack of prior research or evidence, we categorize H2 as exploratory, considering the connection between female CEOs, firm size, and GI. Based on the reasons mentioned earlier, we anticipate that firm size will have a substantial moderating effect on this connection, leading us to propose the following hypothesis:

Hypothesis 2 (H2): *The size of Asian industrial firms positively moderates the connection between female CEOs and GI.*

3. Research Methodology

3.1. Sample Selection and Data Collection

To check our hypotheses, this study examined a large sample of publicly traded Asian industrial firms, specifically the most significant GHG emitters, from 2013 to 2022. The latest year for which data were accessible was 2022, thus marking the end of the sample. We collected 35,760 firm-year observations for 3576 Asian industrial firms as the initial sample (2013–2022). Data for this study were acquired using the Thomson Reuters Eikon database. Thomson Reuters Eikon, "which was previously known as ASSET4", comprises a diverse collection of business's financial information, including data from annual reports and other sources. Empirical research in the last few decades has heavily relied on this widely used database [3]. The database provided us with balanced panel data on the independent, dependent, and control variables of Asian industrial firms, which can be used for primary analysis and robustness checks. By utilizing these data, we can accomplish the study objective. The reliability and validity of these databases have been proven in prior research [4,25].

3.2. Variables Measurements

3.2.1. Dependent Variable (GI)

Prior research has relied on the number of environmental patents to show GI. Yet, this measurement is inadequate as not all innovations are patented, and not all inventions are innovative [21]. Furthermore, certain patents are crucial and tied to innovative products and advancements, while others are insignificant. By following the method of [4], this study uses the Eikon GI score pulled from the Refinitiv Eikon database as the dependent variable of interest, which measures "a firm's ability to decrease ecological burdens and expenses for its clients, generating fresh market prospects through advancements in ecological technologies, processes, or green products". The Eikon eco-innovation score measures a company's GI level on a percentile scale, with 100 being the highest commitment level. Industry specifications are considered in the Eikon eco-innovation score. The company's

score shows how much it innovates in sustainability compared to industry standards [70]. An objective assessment of the degree of GI is ensured by comparing a company's score to that of all other businesses operating in the same sector [50,71].

3.2.2. Predictor and Moderator Variables

We followed [7,11] in capturing the effect of female CEOs by using dummies of females appointed to top management. Our key independent variable is female CEOs, shown by a binary variable coded as "1" for female CEOs and "0" for non-female CEOs. In addition, previous studies have shown that firm size is crucial in determining innovation, and they have measured it by the natural logarithm of total firm assets [7,11].

3.2.3. Control Variables

This study utilized multiple control variables, including board mechanisms and firm-specific characteristics [72–75]. Incorporating control variables into the link between female CEOs and GI is crucial to establishing a trustworthy and valid correlation. By considering additional influencing factors, we can effectively isolate the influence of female CEOs on GI, address potential biases [76], and derive more precise conclusions [77]. Therefore, we include various board-specific variables, such as board expertise (B_ Expertise), board tenure (B_Tenure), and board gender diversity (BGD), to capture the quality of CG [78–82].

Our model also accounts for leverage (LEV), since [27] reports a significant negative relationship between LEV and GI because of interest and bankruptcy costs [65]. Companies with high levels of financial debt often experience increased pressures to survive, preventing them from having additional resources to invest in ecologically friendly innovation [83]. To eliminate any potential influences that could skew the findings [83,84], profitability (ROA) is assessed as a measure of accounting performance [85]. Earlier studies, e.g., [86], have employed women employees (WOMEN) as a means to consider gender equality in a country, aligning with the fifth Sustainable Development Goal [87]. The firm's age (AGE) plays a significant role in its innovation endeavors [45]. As time passes, institutional inertia grows stronger [9], posing a potential obstacle to companies adopting environmentally friendly innovations [26]. Consequently, younger firms are predicted to be more innovative than older firms [2,88]. More specific information about these variables can be found in Table 1.

Table 1. Definitions and descriptions of study variables.

Variable	Notation	Description
Dependent Variable:		
Green Innovation	GI	The GI score of Eikon Refinitiv ranges from 0 to 100, reflecting the extent of GI activities in a company.
Moderator Variables:		
Firm Size	SIZE	Measured by the natural logarithm of total firm assets.
Independent Variable:		
Female_CEOs	FCEOs	A binary variable that equals one for female CEOs and zero otherwise.
Control Variables:		
Board Expertise	B_Expertise	The ratio of board members with accounting/finance expertise to the total number of directors.
Board Tenure	B_Tenure	The average years of service for each board member.
Board Gender Diversity	BGD	Proportion of female appointed to boards.
Leverage	LEV	Total debt to total assets.
Firm Performance	ROA	Net income/total assets.

Table 1. *Cont.*

Variable	Notation	Description
Women's Employees	WOMEN	Measured by the percentage of female employees to the total company employees.
Firm Age	AGE	Measured by a natural log of the number of years since the companies were founded.

Source: Created by authors.

3.3. Statistical Model

Our study primarily aims to examine how female CEOs influence GI and whether firm size moderates this connection. Our hypotheses are tested using multivariate modeling techniques. Here are the estimations:

$$GI = \beta_0 + \beta_1 FCEO_{i,t} + \beta_2 SIZE_{i,t} + \beta_3 B_Expertise_{i,t} + \beta_4 B_Tenure_{i,t} + \beta_5 BGD_{i,t} + \beta_6 LEV_{i,t} + \beta_7 ROA_{i,t} + \beta_8 WOMEN_{i,t} + \beta_9 AGE_{i,t} + YEAR_{i,t} + INDUSTRY_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$GI = \beta_0 + \beta_1 FCEO_{i,t} + \beta_2 S\,IZE_{i,t} + \beta_3 FCEO \times SIZE_{i,t} + \beta_4 B_Expertise_{i,t} + \beta_5 B_Tenure_{i,t} + \beta_6 BGD_{i,t} + \beta_7 LEV_{i,t} + \beta_8 ROA_{i,t} + \beta_9 WOMEN_{i,t} + \beta_{10} AGE_{i,t}\, YEAR_{i,t} + INDUSTRY_{i,t} + \varepsilon_{i,t} \quad (2)$$

In these equations, i stands for Asian industrial firms (1 to 3576), t represents the study period (2013–2022), and ε represents the error term. Table 1 contains the variable definitions. Equation (1) tests the first hypothesis that female CEOs promote GI; therefore, a positive coefficient β1 is anticipated. In H2, the relationship between female CEOs and GI will be examined to assess the potential moderating effect of SIZE. To explore the second hypothesis, this study's second model incorporates an interaction term, FCEO×SIZE. This interaction showcases how female CEOs are linked to SIZE. The firm's size could be crucial in shaping our baseline outcomes. To examine the relationship between female CEOs, GI, and firm size, we estimate Equation (2) in the following manner:

Confidence in the results was enhanced through tests carried out on each operationalized model. Several tests were conducted to ensure the reliability of the data [78,89]:

First, the test results for normality [8,90,91], as shown in Table 2, involved skewness and kurtosis and were used to identify outliers. To achieve a normal distribution, the variables were winsorized at the 1% level [36,92].

Table 2. Descriptive statistics.

Variables	N	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
GI	3576	0.1434	2.667	0.0764	0.9167	−1.459	4.393
FCEOs	3576	0.0631	0.437	0	1	1.216	4.113
SIZE	3576	21.55	1.719	14.84	26.755	−0.252	3.186
B_Expertise	3576	53.682	18.511	0	100	−0.319	2.961
B_Tenure	3576	6.662	3.783	0.5	27.8333	1.509	5.86
BGD	3576	13.674	11.417	0	75	0.892	3.999
LEV	3576	0.281	0.226	0.047	0.908	1.033	3.501
ROA	3576	0.0655	0.0438	0.0089	0.147	0.605	2.202
WOMEN	3576	27.303	18.489	0.167	88.5	−1.282	5.804
AGE	3576	41.788	29.5145	1	138	−0.524	3.645

Source: Created by authors.

Second, the variance inflation factor (VIF) was calculated to check for multicollinearity among the predictors, as illustrated in Table 3.

Table 3. Correlation matrix.

Variable	GI	FCEOs	SIZE	B_Skill	B_Tenure	BGD	LEV	ROA	WOMEN	AGE
GI	1.000									
FCEOs	0.1696 * 0.0000	1.000								
SIZE	−0.235 * 0.0000	−0.271 * 0.0000	1.000							
B_Expertise	−0.1244 * 0.0000	−0.0953 * 0.0000	0.1012 * 0.0000	1.000						
B_Tenure	0.0277 0.0974	0.1000 * 0.0000	−0.1932 * 0.0000	0.0465 * 0.0054	1.000					
BGD	0.1259 * 0.0000	0.4200 * 0.0000	−0.2825 * 0.0000	−0.1336 * 0.0000	0.0456 * 0.0064	1.000				
LEV	−0.0993 * 0.0000	−0.0492 * 0.0033	0.1557 * 0.0000	−0.009 0.591	−0.0239 0.1526	−0.0119 0.4779	1.000			
ROA	0.1091 * 0.0000	0.0671 * 0.0001	−0.3031 * 0.0000	−0.0538 * 0.0013	0.0691 * 0.0000	0.1331 * 0.0000	−0.2683 * 0.0000	1.000		
WOMEN	0.1111 * 0.0000	0.3338 * 0.0000	0.0496 * 0.0030	0.0821 * 0.0000	−0.0394 * 0.0184	0.0948 * 0.0000	0.0621 * 0.0002	−0.0759 0.0000	1.000	
AGE	−0.3219 * 0.0000	−0.2933 * 0.0000	0.0938 * 0.0000	0.0858 * 0.0000	0.1507 * 0.0000	−0.1639 * 0.0000	0.0506 * 0.0000	−0.0628 * 0.0002	−0.185 * 0.0000	1.000
VIF	--	1.51	1.35	1.29	1.21	1.06	1.1	1.19	1.26	1.16

Source: Created by authors. Note: * $p < 0.05$. (2-tailed).

Third, the heteroscedasticity was measured using the Breusch–Pagan (BP)/Cook–Weisberg test [57].

Finally, the choice between fixed or random effects in the panel data was determined using the Hausman test [22,78,93,94].

The panel data method was used because the dataset comprises cross-sectional and time-series observations [95]. Panel data provide more comprehensive and varied information and reduce issues with multicollinearity among explanatory variables, leading to more reliable outcomes [96,97]. One advantage of a panel data design is that it allows for fixed-effects estimation, enabling researchers to account for unobservable firm-specific effects [98,99]. This approach also includes a feature that removes endogeneity caused by unobserved differences in model specifications.

The STATA 14 software (version 2015) was used to operationalize all the tests. To address the potential problem of omitted variable bias [100], we utilized a firm-fixed-effects regression to estimate both equations [54]. Unobservable firm-level characteristics could also influence the connection between female CEOs and GI. Characteristics that cannot be observed directly can be associated with a corporate GI and the chances of having female CEOs in top management. This issue is addressed by using the fixed-effects method. To estimate the equations, we utilize a company fixed-effects regression.

4. Results and Discussion

Here, you will find a presentation of the obtained results and corresponding reflections.

4.1. Descriptive Statistics and Correlations

Table 1 presents the descriptive data for the study variables. The GI score averages 14.34, with a minimum value of 7.64 and a standard deviation of 2.667. This variable has a maximum value of 91.67, indicating that some Asian companies invest significantly in GI. In our sample, Asian firms represented 6.31% female CEOs as the independent variable. Regarding firm size (SIZE), the average value is 21.55, the minimum value is 14.84, and the maximum is 26.755.

The literature supports the consistency of the control variables' statistics. On average, the board expertise (B_Expertise) value is 53.682 out of 100 points. The value ranges from 0 points, the lowest, to 100 points, the highest. The mean duration of board tenure is 6.662 years (B_Tenure). The average proportion of BGD is 13.674 out of 100 possible points. The lowest score is 0, whereas the highest score is 75. This suggests that certain companies in the sample excluded women from their corporate boards. The mean return on assets (ROA) among the Asian firms in our sample is 6.55%, and the average financial leverage (LEV) is 28.1%. It is worth noting that around 27.3% of Asian companies' workforce comprises women. The firms' ages vary from 1 to 138 years, averaging 41.78.

Pearson's correlations were employed to scrutinize the bivariate connections among the chosen variables before conducting the official empirical examination [101]. Table 2 presents the correlation coefficients between the independent variables in the regressions. Our regression analyses have no multicollinearity issue, as the highest correlation coefficient observed is 0.42 between SIZE and WOMEN. By conducting the VIF test, we measured the level of dependence among the model variables. The inference is supported by the VIF statistics, with the highest VIF value being 1.51. This research employed mean-centering of variables to address multicollinearity concerns before generating interaction terms [3,27], given the potential severity of multicollinearity issues in regression models [78].

4.2. Multivariate Regression Result

Our research questions depend on competing theoretical perspectives: (1) whether females CEO positively impact GI in Asian industrial firms; (2) whether the size of these firms has a moderating effect on the relationship between female CEOs and GI. Our estimated results, incorporating year and industry-fixed effects, can be found in Table 4. This paper focuses on GI as the dependent variable. Table 4 presents the outcomes of the multivariate estimations. The regression results are displayed in model (1) without incorporating the interaction term between FCEOs and SIZE (H1), where model (2) exhibits the results including the interaction term (H2). Table 4 demonstrates the significance of the F-Tests for the models, which are significant at $p < 0.01$ or better. Drawing from these findings, we can deduce the models' statistical validity. Furthermore, the R^2 values vary from 10.46% (model 1) to 17.12% (model 2).

Table 4. Results fixed-effects model (panel data estimation).

Variables	**Model I H1**		**Model II H2**	
	Coef.	**t**	**Coef.**	**t**
Constant	−0.07	−11.01	4.0228	3.03 *
FCEOs	0.107	2.11 **	0.0265	1.66 ***
SIZE	0.0947	2.28 **	0.144	2.26 **
FCEOs × SIZE	-	-	0.327	5.79 *
B_Expertise	0.114	6.11 *	0.186	5.99 *
B_Tenure	0.0666	2.36 **	0.21	4.5 *
BGD	0.1678	3.55 *	0.214	3.81 *
LEV	0.1632	3.46 *	0.186	4.07 *
ROA	−0.203	−2.67 *	−0.0637	−3.2 *
WOMEN	0.111	4.15 *	0.157	4.81 *
AGE	−0.231	−3.04 *	−0.0636	−3.31 *
Year Dummies	Inserted		Inserted	
Industry Dummies	Inserted		Inserted	

Table 4. *Cont.*

Variables	Model I H1		Model II H2	
	Coef.	t	Coef.	t
F-Test	38.65		1152.32	
Prob > F	0.0000		0.0000	
R-squared	0.1046		0.1712	
Breusch and Pagan	5302.08 *		5373.47 *	
Hausman Test	84.49 *		72.66 *	
Observations	3576		3576	

Source: Created by authors. *** $p < 0.1$, ** $p < 0.05$, and * $p < 0.01$.

In the first model, the findings from the entire sample indicate a strong and positive correlation between the presence of female CEOs and GI in Asian industrial firms. This supports H1, as the coefficient for female CEOs is positive and highly significant. Furthermore, this outcome shows that female CEOs enhance the drive for GI. While Ref. [11] supports this finding, Ref. [9] does not provide sufficient evidence to substantiate it. One interpretation of this discovery is that female CEOs within Asian companies demonstrate their effective leadership by actively participating in environmentally friendly innovation endeavors, surpassing their male counterparts to secure CEO positions [7], which aligns with a sociological perspective [2]; discrimination makes women work harder to become top managers.

Another explanation is that having females as CEOs brings fresh perspectives and experiences that positively affect top management [5]. The argument suggests that female CEOs contribute to a firm's innovation capacity because of their ability to leverage human capabilities [7,47], diverse perspectives [88], and extensive networks [15], creating opportunities for promoting environment-friendly initiatives [14]. The findings suggest that females' inherent maternal instincts compel them to be environmentally conscious and safeguard nature [49]. They confirm the social role theory that a female's upbringing influences her inclination to prioritize performing well and adopting green practices [5]. The results align with the notion that women are kind-hearted and nurturing [88]. Consequently, women in CEO positions ensure their business practices do not negatively impact stakeholders [6], including the environment [11].

Control variables reveal that firm size (SIZE) is significantly and positively associated with GI, indicating that larger firms that allocate more funds to environmental protection are more likely to prioritize GI [2,24,26,54]. Moreover, a significant and positive relationship exists between GI and the control variables for corporate governance (B_Expertise, B_Tenure, and BGD). This implies that Asian firms with a high proportion of board expertise members, longer-tenured board members, and more female board members have significantly promoted GI [24,45,63,69,82]. Both financial leverage and female employees play a positive role in driving GI [65,102]. Limited resources in Asian firms prompt them to borrow for GI and environmental preservation. Conversely, GI is significantly negatively impacted by ROA and AGE. The findings suggest that younger, less profitable Asian firms prioritize GI to boost their financial position, corporate image, and competitive advantage.

Model 2 in Table 4 presents the results for the second hypothesis. The second model, presented in Table 4, outlines the "interaction term" between female CEOs and firm size (FCEOs × SIZE). In their study, the authors of [19] asserted that the variables do not hold individual significance and do not cause interpretation. The positive coefficients for FCEOs and SIZE that were observed are shown in Table 4, alongside the statistically significant and positive interactive terms FCEOs × SIZE, which acted as determinants of the GI ($\beta = 0.327$, $t = 5.79$) at a significance level of 1% or better; this suggests that the positive connection

between female CEO and green innovation is amplified by firm size. The empirical results show that the size of a firm has marginal effects on the link between female CEOs and GIs.

Consequently, the interactive term displayed a significant and positive sign, reinforcing female CEOs' moderating impact on GI as firm size extends. The influence of women in executive positions on green innovation is more prominent in large Asian companies than in smaller ones. Therefore, it can be concluded that female CEOs exhibited a heightened positive influence on promoting environmentally sustainable innovation [103]. Hence, this result supported the view that larger firms possess greater financial flexibility than smaller ones because of having more wealth and resources [2,3,66], which drives them to pursue innovative initiatives [3,19,20,26,68].

Thus, female CEOs in larger companies can effectively manage and mitigate risk by overseeing various research and development initiatives [69]. The correlation between larger firms and increased resource availability supports female CEOs in promoting GI. Adopting environmentally friendly practices can be costly and requires significant resources and enduring dedication, which are advantages that are more accessible to larger firms [104–106]. Therefore, compared to smaller ones, female CEOs of large Asian enterprises have a more helpful position in developing and executing policies related to ecological innovation. These findings support the resource-based view theory [18], suggesting that capabilities and resources in larger companies with economies of scope and scale inspire the inclination of female CEOs toward sustainable innovation [11].

4.3. Robustness Checks—Endogeneity

Our existing Asian company fixed-effects outcomes on the link between female CEOs and sustainable innovation may be biased owing to endogeneity disputes. To address this challenge, this study uses alternative model specifications. This study applied a dynamic generalized method of moments (GMM) system estimator for accurate inference [32]. Dynamic GMM accounts for the endogeneity arising from unobservable heterogeneity and simultaneity [107]. Many studies have recommended the dynamic GMM estimator as the optimal solution for tackling endogeneity and simultaneity to overcome this problem [71]. In the GMM estimator, lagged-level variables are employed as instruments for the differenced equation, while lagged differenced variables serve as instruments for the level equation [3,33].

This study sought to obtain a valid and consistent result from the regression model by utilizing instrumental variables, including lagged values of the endogenous variable. Another benefit of using the GMM estimator is that it can tackle issues such as reverse causality and time-invariant omitted variables that may not be adequately addressed by running a fixed-effect regression [57,104]. We performed instrument validity tests following the method proposed by [108]. Table 5 confirms the significance of AR (1) with $p < 0.05$, showing the importance of lags in controlling the model's dynamics, while the insignificance of the AR (2) value suggests no serial correlation in the second difference [71]. The insignificant p-value ($p > 0.10$) of the Hansen J test of over-identifying restrictions in Table 5 confirms our instrument validity. The results in Table 5 consistently show positive and statistically significant outcomes, confirming the reliability of our main findings and reducing endogeneity concerns.

Table 5. Two-step system GMM regression/Arellano–Bond dynamic (panel data estimation).

Variables	Model I H1		Model II H2	
	Coef.	**t**	**Coef.**	**t**
Constant	0.216	7.12 *	0.0487	1.99 **
GI (t − 1)	0.483	4.43 *	0.528	3.48 *
FCEOs	0.098	2.42 **	0.133	3.58 **

Table 5. *Cont.*

Variables	Model I H1		Model II H2	
	Coef.	**t**	**Coef.**	**t**
SIZE	0.108	1.88 ***	0.045	2.15 ***
FCEOs*SIZE	-	-	0.1747	4.31 *
B_Expertise	0.203	2.69 *	0.1489	4.58 *
BTenure	0.2101	2.73 *	0.041	2.64 **
BGD	0.0689	5.43 *	0. 132	4.13 *
LEV	0.0821	1.84 ***	0.074	1.88 ***
ROA	−0.063	−2.24 **	−0.0586	−2.37 **
WOMEN	0.17	5.84 *	0.295	5.06 *
AGE	−0.097	−2.33 **	−0.054	2.72 *
Year Dummies	Inserted		Inserted	
Industry Dummies	Inserted		Inserted	
Hansen J. Test	24.163 †		35.974 †	
AR (1)	0.0000		0.0042	
AR (2)	0.1192		0.2652	
Instrument	156		148	

Source: Created by authors. *** $p < 0.1$, ** $p < 0.05$, and * $p < 0.01$. † p-insignificant. (Regression with robust standard errors.)

5. Conclusions

Ultimately, our research analyzes how female CEOs contribute to firms' endeavors to achieve environmental sustainability through implementing GI. This holds significant significance for emerging Asian markets as they undergo industrialization to capitalize on substantial economic development prospects. Despite the adverse ecological effects of industrialization, firms can mitigate these effects by adopting GI technologies. A significant and positive correlation is observed between female CEOs and GIs. The strength of the relationships is more remarkable in larger Asian companies. Conversely, ROA and AGE significantly negatively impact GI. The findings suggest that younger, less profitable Asian firms prioritize GI to boost their financial position, corporate image, and competitive advantage.

This research model improves upon previous studies on the influence of female CEOs on GI in Asian firms by considering the unique organizational structures found in emerging economies. The findings of this study have important implications for managers. This study challenges the glass ceiling effect by suggesting that women outperform men as top executives and that their Asian establishments should not hinder their advancement in top management. Thus, to sustain their GI strategy, Asian companies must actively recruit and advance females into top leadership positions.

The findings of this study have important implications for both theory and practice. For instance, this study validates upper echelon theory by demonstrating that top executives' personalities directly influence strategic decision-making within a company. This study provides empirical evidence supporting social role theory, which posits that males and females possess distinct abilities and personality traits based on gender. Our research expands our knowledge of the connection between top executives' gender and its influence on GI by exploring the specific moderating role of firm size. The contingency perception suggests that the link between a feminine CEO and eco-innovation relies on certain firm factors, as supported by these findings.

Female CEOs show a greater propensity for risk-taking through their active engagement in innovative pursuits than their male counterparts. The government and other stakeholders in Asian countries must facilitate the growth of women-led firms to promote eco-innovation. Companies headed by female CEOs have the potential to foster GI efforts nationally.

The findings also provide social insights, emphasizing the significance of hiring females in diverse managerial roles. These procedures promote a comprehensive workplace culture that delegates females and supports professional progression. It is recommended that governments enforce quotas necessitating a specific fraction of ladies in executive roles inside companies. It is imperative for regulatory bodies to enforce the enabling approach to give priority to gender equality, typically through the adherence to guidelines or the provision of justifications for non-compliance. Additionally, governance entities have the potential to offer tax incentives to organizations that prioritize gender diversity in leadership positions or provide grants to support gender inclusion initiatives led by diverse teams. This can create opportunities for women to gain access to higher-level positions. Furthermore, both customers and civil society organizations possess the ability to exert normative influence on companies, compelling them to embrace environmental innovation practices.

In addition, larger firms led by female CEOs actively participate in significantly more sustainable innovation initiatives. Therefore, it is imperative to establish policies that promote women's representation in CEO roles within large corporations. These policies are expected to potentially increase the capacity of private sectors to drive eco-innovation strategies. Asian governments and regulators must support new and less profitable companies adopting green practices.

The comprehensive metric for GI scores in this study is based on variables pulled from the Eikon Refinitiv database. The significant limitations arise from relying solely on this metric, which can limit the comprehensiveness and practicality of the findings [109,110]. Although the Eikon Refinitiv database is a reliable resource for tracking companies' environmental advancements, patent applications can serve as an esteemed alternative to gathering GI information. When considering eco-friendly innovation in this context, it is helpful to view standard certifications in eco-friendly management as a reliable benchmark. Moreover, incorporating patent applications in subsequent research endeavors may enhance the validity of the previous findings. To enhance future research, it is crucial to incorporate more qualitative and quantitative data, such as specific measurements of ecological impact reductions or the level of acceptance of green technologies. This method would enhance our comprehension of GI, enabling us to fully grasp corporate ecological strategies and expand our observation of various innovations. Incorporating this recommendation into future studies provides a framework for future researchers to improve and enhance the validity of future research findings.

Additionally, it equips stakeholders with a comprehensive set of tools to evaluate and implement effective environmental strategies. This recommendation suggests methodological enhancements for future researchers to consider encouraging a more extensive exploration of GI metrics. This will build upon the foundational work presented in this manuscript.

Limited data access and institutional weaknesses pose significant challenges for researchers studying emerging economies such as Asian countries. Our study stands out from others in this area because it utilized a larger sample size and solid econometric techniques. Despite the strengths we observed, our study was not without limitations. The primary focus of this study was exclusively on female CEOs in Asian industrial companies. Consequently, substantial work remains to be undertaken to enhance our understanding of how female CEOs' personal attributes, such as educational background and age, impact GI. To improve the generalizability of our findings, future research should be conducted in a context different from that of Asian industrial companies. Future research should also

investigate other contextual factors, such as firm age and financial capital structure, to understand how female CEOs influence eco-friendly innovation.

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