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Narrowing the eco-innovation gender divide: insights for transition economies

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ABSTRACT

This paper aims to address the gender imbalance in eco-innovation within firms, particularly focusing on the role of top managers. Drawing on Upper Echelon Theory and Social Identity Theory, the study investigates the influence of female CEOs on the promotion of eco-innovation and examines how knowledge factors influence this relationship, especially within transition countries. Using a comprehensive cross-sectional dataset from the World Bank and EBRD (BEEPS), the research analyses over 12,000 firms operating across 28 European and Central Asian transition economies. The findings show that firms led by a female CEO are less likely to engage in eco-innovation. However, the moderating effect of knowledge can complement CEO actions, though this effect varies by macro-area. The study suggests tailored strategies, emphasising the need for knowledge-sharing networks, targeted investments in human capital, and a collaborative organizational culture. These strategies represent concrete steps to enhance management capabilities and mitigating the costs and uncertainties associated with eco-innovation process in specific socio-economic contexts

KEYWORDS

Female CEO; gender identity; eco-innovation; knowledge; transition countries

JEL CLASSIFICATION

O30; O32; J16; Q50; P20

I. Introduction

The growing imperative to address environmental challenges has pushed firms to develop or adopt innovative solutions, termed ‘eco-innovations’ (Wang et al. 2021), as a means to align environmental standards and gain a competitive edge.

Despite the significant role of top managers in shaping organizational strategies, their influence on eco-innovation practices has been relatively understudied (Arena, Michelon, and Trojanowski 2018; Hambrick and Mason 1984; Nadeem et al. 2020; Wang et al. 2021).

This study aims to address this gap by examining how CEO gender, a key yet overlooked individual characteristic, affects firms’ strategies, particularly in eco-innovation (Ryan 2017). While prior research has focused on board gender diversity (Glass, Cook, and Ingersoll 2016), we emphasize the unique impact of a female CEO, who holds significant authority within the organization (Bannò, Filippi, and Trento 2023).

It is essential to differentiate between the representation of females on boards and the presence of a female CEO, as the former may not always

translate into significant decision-making power. Sometimes, such representation might be a response to gender quota requirements rather than a genuine effort towards balanced representation (Kogut, Colomer, and Belinky 2014). Moreover, comparing studies on the impact of female board members on eco-innovation with those involving female CEOs is challenging due to complexities in equating the influence of the number of females on the board with that of single female CEO (He and Jiang 2019; Javed et al. 2023).

Transition countries face distinct challenges in advancing environmental practices, such as restricted access to green technologies and evolving socio-political environments (Khan et al. 2023; UNECE 2012, 2022; United Nations 2013). Within these contexts, female CEOs may deal with gender-specific constraints that hinder their ability to leverage innovation potential (Richter et al. 2016). In such scenarios, collaboration can enhance female CEOs’ perspective on environmental issues, fostering a deeper understanding of the

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opportunities presented by green innovation and increasing their awareness of the importance of environmental considerations.

Our research contributes to the literature in several ways.

Firstly, we address a gap by exploring the impact of CEO gender on eco-innovation strategies within transition economies, focusing on the influence of CEO gender distinct from board composition and ownership structures (Javed et al. 2023). While previous studies have examined various CEO attributes, such as age (Barba Navaretti, Castellani, and Pieri 2022), tenure (Darouichi et al. 2021), education (Zhou, Chen, and Chen 2021), and experience (Li and Patel 2019), the role of gender still remains underexplored.

Secondly, our study examines the intersection of gender identity and leadership roles through Social Identity Theory, emphasizing the direct influence of a female CEO on eco-innovation strategies within transition economies, how their leadership shapes organizational responses to environmental issues, and the social identity conflicts that female CEOs may face (Hässler et al. 2020).

Thirdly, we highlight the role of knowledge in bridging the environmental-gender gap in firms led by female CEOs (Carrasco 2014; Expósito, Sanchis-Llopis, and Sanchis-Llopis 2021). While previous studies focused on the direct link between knowledge collaboration and eco-innovation, we emphasize how knowledge cooperation enhances female CEOs' confidence and validates their strategic decisions. It's not that females lack the capability for eco-innovation decision-making; rather, knowledge acts as a powerful accelerator by enhancing their awareness and confidence, and serves as a validation mechanism that amplifies their capabilities.

Our findings suggest that firms led by female CEOs are less inclined to engage in eco-innovation. However, the impact of knowledge cooperation with other firms positively moderates this relationship, indicating that collaboration and external knowledge sources can play a role in enhancing eco-innovation efforts within these companies.

To our knowledge, this study is the first to investigate how having a female CEO influences a company's likelihood of adopting eco-

innovation in transition countries. By exploring the complementary and concurrent effects of internal and external factors, our research sheds light on the multifaced dynamics influencing eco-innovation in firms led by female CEOs.

The role of CEOs in firms' eco-innovation decision-making process

Despite the similarities between general innovation and eco-innovation, the latter is constrained by environmental regulations and standards that vary across regions and evolve over time (Shao et al. 2020). These requirements add uncertainty into the innovation process, since many eco-innovations involve advanced technologies or the integration of multiple technologies to address environmental challenges, requiring adjustments in supply chains, the sourcing of sustainable materials, and the adoption of environmentally friendly production methods (Konadu et al. 2022).

Dealing with these changes can be more complex, often demanding alterations in consumer behaviour (Albitar et al. 2023). While eco-innovations can provide substantial long-term benefits, they often require higher initial investments due to research, development, and the incorporation of new technologies, presenting significant financial challenges (Keshminder and Del Río 2019).

In this context, the Upper Echelons Theory (Hambrick and Mason 1984) highlights the central role of CEOs in decision-making processes, explaining why organizations exhibit specific behaviours and achieve particular performance levels. Managers rely on accumulated knowledge and subjective judgements to make strategic decisions, which are significantly influenced by their perceptions of reality (Bekos and Chari 2023). Scholars such as Chung and Low (2022) emphasize the impact of managers' perspectives on organizational performance and team dynamics, while Chatterjee and Hambrick (2007) note that CEOs with narcissistic tendencies may pursue audacious approaches despite uncertain outcomes. Decision-making biases, shaped by assumptions about future events and the values of decision-makers, also influence strategic priorities, as highlighted by Hambrick and Mason (1984) and March (1993).

The acceptance of Upper Echelon Theory underscores CEO's responsibility to identify opportunities and allocate resources effectively, integrating eco-innovations for a balanced approach between exploration and exploitation strategies (Arena, Michelon, and Trojanowski 2018). As decision complexity increases, the personal characteristics of decision-makers becomes more crucial in determining outcomes, necessitating that leaders possess the knowledge, abilities, and conduct required to drive innovative initiatives (Berger et al. 2016; Nielsen 2010). CEOs who align their personal values with eco-innovation efforts are more likely to build meaningful partnerships with stakeholders who share similar values, ensuring that their involvement extends beyond technical progress to include sustainable business models and long-lasting environmental impact (Zheng and Iatridis 2022).

However, the diversity of eco-innovation strategies among firms reflects the multifaceted perceptions of top managers, particularly when they hold significant influence over organizational performance (Hambrick and Mason 1984).

Female leadership and eco-innovation dynamics

The social identity theory and gender conflict

CEOs are not in the same way aware of the need to foster environmental issues or how to manage them, as this depends on several factors, including their gender, which influences personal expectations, risk-taking tendencies (Vo et al. 2023), sensitiveness, and a firm's innovative behaviour (Alsos et al. 2013).

The Social Identity Theory (Tajfel and Turner 1986) underlines the function of identity in connecting social structures to individual behaviour, showing that people's self-perception is influenced by their social groups and how their traits align with the socially constructed self (Hogg 1996).

As females rise to leadership positions, they often adopt transformational leadership styles (Foss et al. 2022), which can drive various forms of corporate innovation. They may also encourage collaborative and inclusive work-environments, promote gender equality (Dezso and Ross 2012), and build trust that facilitates the sharing of knowledge and approaches towards eco-innovation (Lyngsie and Foss 2017).

Despite progress in narrowing the gender gap in professional spheres, females still face economic and social barriers in business management, wage-equality and representation in higher organizational positions (AAUW 2016).

Societal narrative often identifies males as competent, ambitious, and assertive, while females are seen as supportive, caring, and emotional, creating additional obstacle for them to exhibit effective leadership roles (Hässler et al. 2020). Due to societal norms and biases, females may downplay their gender, adopt male-oriented norms, and adhere to established standards associated to gain recognition (Becker and Tausch 2014).

Increased social identity conflicts can lead females to perceive a lower status, and engage in lower-risk activities, such as avoiding environmental innovation (P. Guo et al. 2024; Keltner, Gruenfeld, and Anderson 2003).

Contextual factors, including political, social, and legal attributes, further shape gender dynamics within organizations (Giddens 1984). In transition countries, female CEOs face with complex barriers related to organizational structures and historical gender biases (Garcés-Galdeano and García-Olaverri 2019).

Most studies have focused on industrialized countries and female representation in top management rather than on the relationship between female CEOs and innovation investments (Dohse, Goel, and Nelson 2019). Among studies on developing or transition countries, Becic and Vojinic (2018) found that firms led by female managers in Central and Eastern European countries are less likely to innovate compared to those led by males. Dohse, Goel, and Nelson (2019) examined 100 developing and emerging economies and found that female owners are more likely to introduce innovations than female managers. Na and Shin (2019), by focusing on 30 emerging countries, showed a significant impact of the top manager's gender on the likelihood of realizing innovation.

For eco-innovation, the relationship is more complex as many studies on emerging countries focus on female representation rather than the specific impact of female CEOs. Rehman, Oriji, and Khan (2020) found that gender diversity on boards in 14 Asian and Middle Eastern countries from 2006 to 2018 is associated with more

environmentally friendly firms, though CEO gender correlates with better performance only in firms with lower female board diversity. Javed et al. (2023) observed that female CEOs in developed regions of China lead greener firms than those in less developed areas. However, Alazzani, Wan-Hussin, and Jones (2019) did not find evidence of a correlation between environmental performance and female directors in 133 firms listed in Malaysia. Garcia Sanchez et al. (2020) studied 321 agri-food firms across 44 countries and found that gender diversity does not significantly sustain eco-innovation projects.

Based on these propositions, we propose the following research hypothesis:

Hp1: In transition countries, there is a negative relation between firms led by a female CEO and the likelihood of adopting eco-innovation.

II. The supporting role of knowledge

Knowledge plays a key role in shaping eco-innovation strategies as firms leverage both internal resources and external collaborations with stakeholders, including competitors, suppliers, and academia (De Marchi 2012; Dimakopoulou et al. 2022). This dynamic knowledge exchange enhances a firm's absorptive capacity, facilitating the identification and assimilation of diverse knowledge sources -both codified and tacit- thus creating a robust foundation for eco-innovation (Horbach 2008).

In the context of eco-innovations, the decision to engage in collaborative ventures is often driven by the necessity to address technologically advanced tasks, especially when firms have limited internal resources and knowledge reserves, making external partnership meaningful for progress (Belderbos et al. 2015; Horbach 2008). Recent research highlights that knowledge collaborations, including R&D, are critical factor compared to conventional innovation (Cainelli, De Marchi, and Grandinetti 2015; De Marchi 2012; Lee and Min 2015). Collaborations with specialized partners and institutions, external R&D, and the pursuit of know-how are avenues for firms to access advances scientific and

technical expertise, which are crucial for advancing eco-innovative initiatives (Krishnan and Park 2005).

In developed countries, governments actively promote environmental initiatives, encouraging organizations to adopt green practices (Berrone et al. 2013). However, in emerging and transition economies, institutional constraints and limited gender inclusivity may hinder female CEOs' ability to develop cognitive proximity and expand their knowledge base for eco-innovation, thus limiting their access to external knowledge and impeding transformative eco-innovations (Araújo and Franco 2021).

Female managers, known for their networking skills, can strategically leverage diverse connections to overcome bureaucratic obstacles and drive innovation (Foss et al. 2022; Ibarra 1993). This capability allows them to validate their eco-innovation choices, gain technical support, and build confidence in their decisions (Carrasco 2014; Expósito, Sanchis-Llopis, and Sanchis-Llopis 2021).

Horbach (2008), using German panel datasets, found that enhancing knowledge capital through R&D positively influences eco-innovations. Similarly, De Marchi (2012), drawing from the Spanish Technological Innovation Panel (PITEC), showed the importance of knowledge sharing, particularly through R&D cooperation, in fostering green innovation. This finding is supported by Ghisetti, Marzucchi, and Montresor (2015) across 11 European countries, who observed that internal eco-innovative efforts, such as R&D, and their interactions with external knowledge sources and actors are significant.

In emerging and less developed economies, Hájek and Stejskal (2018) noted that increased knowledge from internal sources correlates with higher ecological performance. This suggests that female-led firms may have a competitive advantage compared over their male counterparts in accessing external knowledge sources, due to their proficiency in people management and stronger investments in networking and cooperation activities (Amoroso and Audretsch 2022; Galindo and Ribeiro 2011).

Our conceptual model is summarized in Figure 1.

While some researchers have explored the interplay between knowledge cooperation and CEO

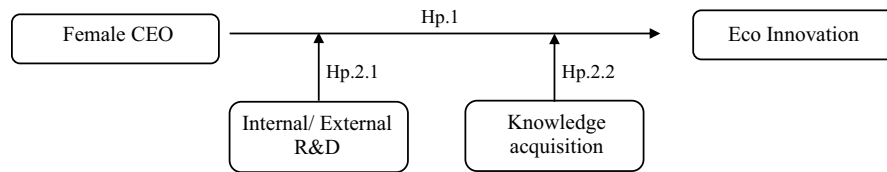


Figure 1. Conceptual model.

gender for general innovation (Dohse, Goel, and Nelson 2019; Expósito, Sanchis-Llopis, and Sanchis-Llopis 2021) and others have investigated the direct impact of female CEO characteristics on green innovation (Javed et al. 2023), prior studies have not examined how various forms of knowledge moderate the relationship between female CEOs and eco-innovation in transition countries.

Accordingly, we posit:

Hp.2.1: In-house and collaborative R&D activities positively moderate the relationship between firms led by a female CEO and eco-innovation.

Hp.2.2: The acquisition of external know-how positively moderates the relationship between firms led by a female CEO and eco-innovation.

III. Data and methods

The dataset

Our data is sourced from the Business Environment and Enterprise Performance Survey (BEEPS), a collaborative project involving the European Bank for Reconstruction and Development (EBRD), the European Investment Bank (EIB), and the World Bank Group (WBG). Spanning from 1999 to 2020, the survey employed a standardized questionnaire to collect firm-level data, covering various aspects of the business environment and performance, such as business-government interactions, financial matters, input costs, workforce demographics, infrastructure, and relevant subjects like competition, training, technology, R&D and innovation (Madison et al. 2022). Over time, the survey has expanded and updated its questions to align with the World Bank's Enterprise Surveys.

The data are collected through face-to-face interviews with top managers and company-owners. The survey process follows a two-stage approach. First, a screener questionnaire is administered by phone to assess eligibility and schedule an in-person interview. Interviews are conducted using Computer-Assisted Personal Interviewing (CAPI) in all countries except Belarus. The survey uses a stratified sampling approach to ensure representative samples across different firm sizes and industries, providing a balanced view of various categories. Post-2006 BEEPS surveys incorporate weights derived from stratified sampling, while earlier surveys used quota sampling techniques and thus lack weight-related information.

Our study uses the latest wave (2018–2020), known as the sixth round. This wave includes data from 41 economies and nearly 28,000 enterprises, introducing a specialized Green Economy module that explores sustainable management practices and investments.¹ The survey encompasses all manufacturing sectors based on the classification of ISIC Revision 3.1 (group D), construction (group F), services (groups G and H), and transport, storage and communications (group I).

For our analysis, we generally consider transition countries, specifically those belonging to Eastern European and Eurasian countries (see footnote).

After removing missing observations, final sample includes over 12,000 establishments from 28 countries.²

Empirical strategy

The dependent variable in our study is 'Eco-innovation', representing the count of green practices adopted by the firm. This variable is computed by summing the firms' responses to 10 questions related to green practices, with each positive response adding one unit to the count. Since

¹https://www.beeeps-ebd.com/wp-content/uploads/2020/04/beeeps_vi_es_r_oct20.pdf.

²Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herz, Bulgaria, Croatia, Cyprus, Czech Rep., Estonia, Georgia, Hungary, Kazakhstan, Kyrgyz Rep., Latvia, Lithuania, Moldova, Montenegro, North Macedonia, Poland, Romania, Russia, Serbia, Slovak Rep., Slovenia, Tajikistan, Ukraine, Uzbekistan.

Eco-innovation exhibits count-data characteristics, taking only the non-negative integer values, we adopt count models to analyse it.

The Poisson model is a commonly employed approach for count data, as it assumes the data-generating process follows a Poisson distribution (C. Cameron and Trivedi 2009). However, a limitation of Poisson regression arises from its assumption that the conditional expected value equals its variance. This assumption is frequently violated, resulting in over-dispersion.

To test for potential over-dispersion, we conducted post-estimation statistics and evaluated the goodness of fit. The large chi-square and deviance values indicated that the Poisson distribution was not a suitable choice (C. Cameron and Trivedi 2009). In our case, we opted for negative binomial regression, an extension of the Poisson regression model, which is more appropriate for addressing over-dispersion.

Our theoretical hypotheses were tested using the following models. The first equation tests the first hypothesis, showing the nexus between firms led by a female CEO and the adoption of eco-innovations, controlling for various factors including the three identified types of knowledge support (Internal R&D, External R&D and Knowledge acquisition).

Equation (2) introduces interaction terms to investigate whether various types of knowledge support act as moderators in the relationship between a female CEO and eco-innovation.

- $$\begin{aligned} (1) \quad & Eco-innovation = \alpha + \beta_1 FemaleCEO + \beta_2 \\ & Knowledge\ acquisition + \beta_3 Internal \\ & R\&D + \beta_4 External\ R\&D + \gamma controls + \epsilon_i \\ (2) \quad & Eco-innovation = \alpha + \beta_1 FemaleCEO + \beta_2 \\ & Knowledge\ acquisition + \beta_3 Internal \\ & R\&D + \beta_4 External\ R\&D + \beta_5 \\ & FemaleCEO * Knowledge\ acquisition + \beta_6 \\ & FemaleCEO * Internal\ R\&D + \beta_7 \\ & FemaleCEO * External\ R\&D + \gamma controls + \epsilon_i \end{aligned}$$

IV. Variables

The variables used are shown in Table 1.

Dependent variable

As the dependent variable, we use *Eco-innovation*, which is constructed by counting the number of

green measures adopted by firms over the past three years. This variable captures a diverse set of specific actions undertaken by firms to promote environmental sustainability, classified into 10 distinct types of green measures, each representing a unique aspect of eco-friendly practices within the business context. Following Ghisetti, Marzucchi, and Montresor (2015), *Eco-Innovation* is considered a count variable encompassing 10 different types of eco-innovations covered in the BEEPS 2018–2020 wave. In the robustness check section, following De Marchi (2012) and Dimakopoulou et al. (2022), we include *Eco-innovation Dummy* taking a value of one if the firm has introduced eco-innovations.

Independent variables and control variables

The main independent variable is *Female CEO*. Following the methodology of Javed et al. (2023), who explored the impact of a female CEO on eco-innovation, we include a dummy variable that takes a value of 1 if the top manager is female.

Among other independent variables, we employ proxies for internal and external knowledge sources. Consistent with Y. Guo (2023), we introduce a dummy variable (*Knowledge acquisition*), taking a value of 1 if the firm has allocated resources to external knowledge, such as licencing, patents and know-how from other businesses or organization over the past three years. Then, following the approach of De Marchi (2012) and Araújo and Franco (2021), we include other two dichotomous variables. *Internal R&D* takes a value of 1 if the firm has undertaken in-house expenditure activities over the past three years, while *External R&D* takes a value of 1 if the firm has invested in R&D in collaboration with other firms during the same period. Control variables are included in the analysis to account for the influence of other factors on the likelihood of adopting eco-innovations.

V. Results

Table 2 reports the summary statistics. The dataset includes a set of variables reflecting various aspects of firms' characteristics and practices. *Eco-innovation* ranges from 0 to 10, with an average of approximately 3.10. The presence of a female CEO is observed in around 20% of cases, indicating

Table 1. Variables description.

Variable	Description	Reference studies
Eco-innovation	Number of green measures adopted by firms over the last three years (Heating and cooling improvements, more climate-friendly energy generation on site, machinery and equipment upgrades, energy management, waste minimization/recycling and waste management, air pollution control measures, water management, upgrades of vehicles, improvements to lighting systems, other pollution control measures)	Ghisetti, Marzucchi, and Montresor (2015); Biscione, Caruso, and de Felice (2020); Javed et al. (2023)
Eco-innovation Dummy	Dummy 1: if the firm has adopted at least one green measure	De Marchi (2012); Dimakopoulou et al. (2022)
Independent variables		
Female CEO	Dummy 1: if the top manager is a female	Javed et al. (2023)
Knowledge acquisition	Dummy 1: if over the last three years the firm has spent on the acquisition of external knowledge such as the purchase or licencing of patents and non-patented inventions, know-how, and other types of knowledge from other businesses or organizations	Y. Guo (2023)
Internal R&D	Dummy 1: if over the last three years the firm has spent on research and development activities within the establishment	De Marchi (2012); Araújo and Franco (2021)
External R&D	Dummy 1: if over the last three years the firm has spent on research and development activities contracted with other companies	De Marchi (2012); Araújo and Franco (2021)
Control variables		
Group participation	Dummy 1: if the firm is part of a business membership organization, trade association, guild, chamber of commerce, or other business support group	Dimakopoulou et al. (2022)
International market	If in the fiscal year the establishment sold its main product in international markets (International Market = 1, otherwise = 0)	Marco-Lajara et al. (2023)
Board	Dummy 1: if the firm has a board of directors or a supervisory board	Gallego-Álvarez and Rodríguez-Domínguez (2023)
Ln firm age	Natural logarithm of the number of years since the firm began operations	Leyva-de la Hiz and Bolívar-Ramos (2022)
Firm Size	Categorical: 1 for micro firms (1-9 employees), 2 for small firms (10-49 employees), 3 for medium firms (50-249), 4 for large firms (250+ employees)	Dimakopoulou et al. (2022); Javed et al. (2023)
Certification	Dummy 1: if the firm has an internationally-recognized quality certification	Hernandez-Vivanco and Bernardo (2022)
Grants	Dummy 1: if the firm has received grants from Government	Horbach (2008); Biscione et al. (2022)
Sector Dummies	Sector dummies (Manufacturing sectors according to the classification of ISIC Revision 3.1 (group D), construction (group F), services (groups G and H), and transport, storage and communications (group I)).	Nadeem et al. (2020)
Macro-area	Denotes the geographical region of the firm's location	Ghisetti, Marzucchi, and Montresor (2015)

Table 2. Summary statistics.

Variable	Obs.	Mean	St. dev.	Min	Max
Eco-innovation	12,936	3.10	2.76	0	10
Eco-innovation Dummy	12,936	0.76	0.42	0	1
Female CEO	12,936	0.20	0.40	0	1
Know. Acquisition	12,936	0.13	0.34	0	1
Internal R&D	12,936	0.20	0.40	0	1
External R&D	12,936	0.09	0.29	0	1
Group participation	12,936	0.33	0.47	0	1
International market	12,936	0.13	0.34	0	1
Board	12,936	0.26	0.44	0	1
Firm age	12,936	20.32	13.78	2	207
Size	12,936	2.12	0.87	1	4
Certification	12,936	0.24	0.43	0	1
Grants	12,936	0.02	0.14	0	1

a moderate representation of females in management roles. Knowledge Acquisition is reported with a mean of approximately 0.13. Internal R&D efforts exhibit a mean of roughly 0.20, while External R&D collaboration is observed with a mean of about 0.09. Additionally, group participation shows a mean of approximately 0.33, suggesting a notable degree of involvement in collaborative business networks. International market engagement is recorded at a mean of roughly 0.13, and the presence of Board, on average, is 0.26.

Firms' average age stands at approximately 20.32 years, indicating a diverse range of maturity levels. The variable 'size' ranges from 1 to 4, where 1 denotes micro firms, 2 denotes small firms, 3 denotes medium-sized firms, and 4 denotes large firms. With a mean of 2.12, the most common category is that of small firms.

Certification is observed with a mean of about 0.24, and Grants are reported at a mean of roughly 0.02, indicating a relatively minor role for such grants in supporting firms' activities.

Table 3 provides an overview of the distribution of firms across various countries included in the study. The number of firms in each country ranges from 123 firms in Montenegro to more substantial economies like Kazakhstan, with 1,161 firms.

Table 4 presents the correlation matrix. A moderate positive correlation is observed between micro and small firms ($r = -0.52$), and a negative correlation is found between Eco-innovation and Female CEO ($r = -0.07$). Similarly, small negative

correlations emerge between Female CEO and other independent variables.

To assess multicollinearity, we run the Variance Inflation Factor (VIF). A high VIF indicates potential collinearity issues. However, our results show VIF values below the critical threshold of 10, with the highest recorded at 1.86, suggesting no significant concerns regarding multicollinearity (Chatterjee and Hadi 2012).

The results of the negative binomial regressions are reported in Table 5. The regression includes the parameter α , which estimates the degree of over-dispersion. When the over-dispersion parameter is zero, the negative binomial distribution approximates a Poisson distribution. A larger α indicates greater over-dispersion in the data. In our study, $\ln \alpha$ is significantly different from zero, suggesting some level of over-dispersion. The likelihood ratio (LR) test assesses whether the restriction assumed by the Poisson model holds true. The LR values range from 4,399.77 to 4,410.66, depending on the model specification, and show that the probability of observing these data under $\alpha = 0$ is zero, confirming that the data are not Poisson-distributed.³

The first column (Model 1) of Table 5 shows the baseline results, including all independent variables, firm characteristic, and controls, such as macro-area and sector (Biscione, Caruso, and de Felice 2020; Gogokhia and Berulava 2021; Morris 2018).⁴ We test the 'Female CEO effect', finding an inverse relationship, which indicates that firms led by a female

Table 3. Firms' distribution by country.

Country	N
Albania	279
Armenia	336
Azerbaijan	173
Belarus	554
Bosnia and Herzegovina	268
Bulgaria	542
Croatia	331
Cyprus	316
Czech Rep.	370
Estonia	236
Georgia	349
Hungary	725
Kazakhstan	1,161
Kyrgyz Rep.	276
Latvia	219
Lithuania	314
Moldova	224
Montenegro	123
North Macedonia	306
Poland	872
Romania	512
Russia	1,053
Serbia	293
Slovak Rep.	344
Slovenia	347
Tajikistan	224
Ukraine	1,107
Uzbekistan	1,082
Total	12,936

Table 4. Correlation matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Eco-inn.	1															
2. Eco-inn. Dum.	0.63	1														
3. Female CEO	-0.07	-0.05	1													
4. Know. Ac.	0.21	0.14	-0.07	1												
5. Internal R&D	0.28	0.16	-0.04	0.33	1											
6. External R&D	0.21	0.11	-0.03	0.30	0.47	1										
7. Group part.	0.22	0.18	-0.03	0.12	0.15	0.14	1									
8. Intern. Market	0.17	0.10	-0.01	0.09	0.14	0.12	0.15	1								
9. Board	0.22	0.14	-0.05	0.13	0.16	0.13	0.17	0.09	1							
10. Age	0.11	0.07	-0.02	0.04	0.07	0.05	0.17	0.10	0.20	1						
11. Micro	-0.20	-0.11	0.08	-0.09	-0.14	-0.11	-0.16	-0.14	-0.21	-0.14	1					
12. Small	-0.07	-0.01	0.01	-0.03	-0.03	-0.04	-0.05	-0.09	-0.12	-0.08	-0.52	1				
13. Medium	0.18	0.08	-0.07	0.08	0.12	0.10	0.15	0.17	0.21	0.12	-0.32	-0.49	1			
14. Large	0.17	0.08	-0.04	0.09	0.10	0.10	0.11	0.14	0.25	0.19	-0.16	-0.24	-0.15	1		
15. Certification	0.25	0.14	-0.06	0.12	0.22	0.17	0.28	0.22	0.20	0.19	-0.21	-0.10	0.21	0.20	1	
16. Grants	0.04	0.03	-0.01	0.03	0.05	0.03	0.06	0.02	0.03	0.03	-0.04	-0.01	0.04	0.04	0.05	1

³LR test is available upon request. Results from Poisson regressions are available upon request. Nevertheless, findings do not significantly alter the estimates.

⁴We also run estimates using a dummy variable for each country. The results do not change significantly.

Table 5. Results from negative binomial regressions.

Dependent variable				
Eco-innovation	Model 1 (Baseline)		Model 2 (Interaction effects)	
Independent variables				
Female CEO	−0.078***	(0.020)	−0.102***	(0.025)
Knowledge Acquisition	0.234***	(0.019)	0.230***	(0.020)
Internal R&D	0.255***	(0.018)	0.249***	(0.020)
External R&D	0.079***	(0.023)	0.057**	(0.025)
Interaction effects				
Female CEO*Know.Acq.			0.013	(0.050)
Female CEO*Internal R&D			0.039	(0.048)
Female CEO*External R&D			0.135**	(0.062)
Control variables				
Group	0.210***	(0.016)	0.210***	(0.016)
International market	0.124***	(0.021)	0.126***	(0.021)
Board	0.186***	(0.016)	0.187***	(0.016)
Certification	0.152***	(0.018)	0.151***	(0.018)
Grants	0.080*	(0.047)	0.079*	(0.047)
Ln firm age	0.009	(0.013)	0.009	(0.013)
<i>Size</i>				
<i>(Micro)</i>				
Small	0.152***	(0.022)	0.150***	(0.022)
Medium	0.290***	(0.025)	0.289***	(0.025)
Large	0.355***	(0.032)	0.356***	(0.032)
Sector Dummies	YES		YES	
Macro-area	YES		YES	
Constant	0.167**	(0.072)	0.173**	(0.072)
Ln alpha	−0.775***	(0.028)	−0.776***	(0.028)
N	12,936		12,936	

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Micro is the reference category.

CEO in transition countries exhibit a reduced propensity to adopt eco-innovation. This supports *Hypothesis 1*, suggesting a *negative* association potentially due to a lack of experiential familiarity with environmental practices among female top executives in these transitional contexts. These findings are in line with Tang and Li (2023), who reported that female CEOs negatively influence green innovation in China.

In Model 2, we explore how knowledge support proxies, such as Knowledge Acquisition, Internal R&D, and External R&D, interact with the gender of the CEO and influence the likelihood of adopting eco-innovation. The results reveal a positive and statistically significant moderating effect between a female CEO and External R&D. This finding aligns with Expósito, Sanchis-Llopis, and Sanchis-Llopis (2021), who emphasize that collaborative R&D with other businesses positively impacts the relationship between female leadership and innovation, particularly in process innovation. Collaborating on R&D helps mitigating budget constraints related to internal R&D funding, and enhances the firm's capacity for sustained eco-innovation initiatives.

In contrast, the interaction between a female CEO and the other two knowledge proxies (Knowledge

Acquisition and Internal R&D) do not show statistically significant effects. This provide partial support for *Hypothesis 2.1*, suggesting that *in-house and collaborative R&D activities positively moderate the relationship between firms led by a female CEO and eco-innovation*. However, *Hypothesis 2.2*, which posits that *the acquisition of external know-how positively moderates the relationship between firms led by a female CEO and eco-innovation*, is not supported. This outcome may be explained by the complexities involved in establishing collaborations for acquiring specific types of knowledge, such as know-how, patents, and licencing agreements, as opposed to collaborative R&D. Belderbos, Carree, and Lokshin (2004) indicate that managers often adopt a cautious approach when entering collaborations involving highly specialized knowledge or legally matters, such as patent procurement, due to potential legal complexities.

Despite these complexities, Knowledge Acquisition exerts a positive and statistically significant effect on eco-innovation (Y. Guo 2023). Similarly, both Internal and External R&D exhibit positive and significant effects on eco-innovation, in line with De Marchi (2012) and Araújo and Franco (2021).

Control variables, including *Group participation*, *International market*, *Board*, *Firm age*,

Size, Certification, and Grants display the expected signs in both Model 1 and Model 2. The analysis uses robust standard errors and accounts for potential correlations of residuals between countries by including clustered errors. Results remain consistent without significant changes.^{5,6}

To better account for potential heterogeneity and understand how socio-political contexts may influence firms' investments in green innovation differently, Table 6 presents a comparative analysis between European and Eurasian countries.⁷ This choice is driven by the ongoing structural macro-economic transitions in Eurasian countries, moving from a state-led to a more market-oriented economic system. In contrast, most European countries are EU members, aligning with European Union environmental standards and social inclusion goals, except Albania, Montenegro, Serbia, North Macedonia and Bosnia and Herzegovina, which are EU membership candidates.⁸

In general, the results are consistent with the main estimates, confirming the presence of an environmental gender gap. However, collaborations for R&D with other firms exhibit a positive moderating effect only in Eurasia. This may suggest a greater need for external support in these countries, crucial for dealing with the green paradigm, where companies led by females may lack sufficient encouragement and support for adopting eco-innovations.

VI. Robustness check

To validate the robustness of our main results, we conduct various robustness checks. We control for the year in which the questionnaires were administered and the results remain stable.

Also, we control for the legal status of firms and explore alternative model specifications, including censored Poisson regressions and logarithmic transformations of the dependent variable. These alternatives do not lead to significant alterations in our results.⁹

We further examine the likelihood of adopting eco-innovations under the leadership of a female CEO using a logit model (Column 1 of Table 7). The results confirm the negative correlation between having a female CEO and engaging in eco-innovation, consistent with the baseline findings. To address potential endogeneity and self-selection bias, we conduct supplementary analyses.

Instrumental variables analysis

We acknowledge the potential endogeneity issues in our regression model due to omitted factors affecting both the CEO and the outcome variable, which could lead to a spurious correlation between CEO gender and eco-innovation (He and Jiang 2019). Additionally, the appointment of a female as CEO may be perceived as a strategy to enhance firm legitimacy, and weaker environmental performance could influence such appointments, introducing potential reverse causality between a female CEO and eco-innovation.

To address this concern, we employ instrumental variables techniques. A frequently used model for count and non-negative outcome variables relies on the assumption of exponential conditional mean in which some of the regressors are endogenous.^{10,11} This approach allows us to instrument endogenous variables using excluded exogenous variables (instruments) (Atif et al. 2021; A. C. Cameron and Windmeijer 1997). Valid instruments are those that are significantly correlated with the independent variable while remaining uncorrelated with the error term. In our context, we use 'Sole proprietorship' and 'Female ownership' as instrumental variables.

⁵Estimates are available upon request.

⁶Measures of fit such as Log-Likelihood indicates that the full model is significantly better than the null model. Log ratio test is also good and provides support for the robustness of our model. The value of the Log ratio test together with a very low probability (0.000) suggests that the full model with all independent variables provides a much better explanation of the data than the reduced model. Cragg-Uhler (also sometimes called Nagelkerke's R²) is an adjusted version of the Cox and Snell's R². The Cragg & Uhler's R² value of 0.159 indicates that the model has a quite good ability to explain the variability in the data. Given the context of nonlinear models, this can still represent a useful and informative fit, especially if supported by other goodness-of-fit and significance tests, such as the likelihood ratio (LR) test, which in your case is significant (Maddala 1983; Cameron and Windmeijer, 1999).

⁷European countries: Estonia, Latvia, Lithuania, Hungary, Poland, Croatia, Bulgaria, Czech, Romania, Slovakia, Slovenia, Cyprus, Albania, Bosnia, Montenegro, North Macedonia, Serbia; Eurasian countries: Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyz., Tajikistan, Uzbekistan, Russia, Ukraine, Moldova.

⁸As additional robustness check, we drop out Albania, Montenegro, Serbia, North Macedonia and Bosnia and Herzegovina from the European group since they are still candidate members and could be considered as potential outliers. However, the results remain consistent with previous estimates.

⁹Estimates are available upon request.

¹⁰<https://www.stata.com/manuals13/rivpoisson.pdf>.

¹¹Specifically, we use a Generalized Method of Moments (GMM) estimator for Poisson regression, following Stata manual.

Table 6. Results from negative binomial regressions for eurasian and European countries.

Dep. variable: Eco Innovation	Model 1 Eurasia		Model 2 Europe	
Independent variables				
Female CEO	−0.069*	(0.037)	−0.054*	(0.033)
Knowledge Acquisition	0.221***	(0.030)	0.258***	(0.029)
Internal R&D	0.248***	(0.028)	0.272***	(0.029)
External R&D	0.054	(0.037)	0.049	(0.036)
Interaction effects				
Female CEO*Know.Acq.	0.070	(0.074)	−0.050	(0.069)
Female CEO*Int. R&D	0.049	(0.066)	0.047	(0.070)
Female CEO*Ext. R&D	0.192**	(0.098)	0.058	(0.084)
Control variables				
Group	0.215***	(0.024)	0.186***	(0.025)
International market	0.047	(0.035)	0.150***	(0.028)
Board	0.185***	(0.024)	0.092***	(0.025)
Ln firm age	0.032*	(0.019)	0.016	(0.019)
Size				
(Micro)				
Small	0.164***	(0.031)	0.202***	(0.029)
Medium	0.353***	(0.036)	0.335***	(0.035)
Large	0.453***	(0.045)	0.407***	(0.046)
Regulation	0.151***	(0.027)	0.149***	(0.024)
Governmental Grants	0.134	(0.082)	0.135**	(0.059)
Sector Dummies	YES		YES	
Macro-area	YES		YES	
Constant	0.200*	(0.111)	0.432***	(0.107)
LnAlpha	−0.822***	(0.041)	−1.051***	(0.045)
Log-Lik Intecept only	−14877.286		−14396.706	
Log-Lik Full Model	−14086.325		−13695.661	
Log-ratio test	1581.922		1474.090	
Prob>Log ratio test	0.000		0.000	
Gragg & Uhlker's pseudo R ²	0.217		0.208	
N	6,539		6,397	

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Micro is the reference category.

Sole proprietorship is a dummy variable indicating whether the firm is structured as a sole proprietorship, where a single individual has complete control over operations and strategy. Females often hold leadership positions in such structures, particularly in small-scale ventures. The variable Female ownership is a binary indicator reflecting all owners of the firm are females. Charpin, Szafarz, and Tojerow (2023) show that this is strongly correlated with the presence of a female CEO, especially in less developed countries. In such contexts, traditionally male-dominated ownership structures, known as ‘old boys’ club’, can present obstacles to the empowerment of female professionals. The ‘female cascade’ phenomenon suggests that female ownership influences the appointment of female executive within the firm. Thus, we anticipate a positive correlation between these instrumental variables and having a female CEO. However, there is limited evidence suggesting that these variables inherently influence a firm’s propensity to adopt eco-innovations.

Hansen’s (1982) over-identification test supports the validity of our instruments ($p = 0.67$). The outcomes align with the baseline findings. When examining the impact on the number of eco-innovations, a substantial proportion of cases exhibit statistically significant coefficients, closely with those observed in the previous analysis (Column 3 in Table 7).

Sample selection bias

Addressing potential selection bias is important for understanding the impact of female CEOs, who may choose to lead environmentally conscious firms due to perceived high ethical standards (Javed et al. 2023). This self-selection process suggests that female CEOs may opt for specific firms (supply-side arguments). To address this issue, we use a model with endogenous sample selection to correct for any sample-selection bias.¹²

Our model consists of two equations: one for the count outcome, *Eco-innovation*, and

¹²We employ the Heckman model to address sample selection in count data using the Stata 16 commands (A. C. Cameron and Trivedi 2013; Greene 2018; Windmeijer and Santos Silva 1998).

Table 7. Robustness check. Logit, IV Poisson and model with sample selection.

	Endogenous sample selection							
	Logit		IV Poisson		Selection model		Outcome Model	
	Dep. variable: Eco-innov. Dummy		Dep. variable: Eco Innovation		Dep. variable: Eco-innov. Dummy		Dep. variable: Eco Innovation	
Female CEO	−0.155***	(0.054)	−0.100**	(0.041)	−0.103***	(0.032)	−0.037**	(0.015)
Subnational HDI	—		—		1.475***	(0.299)	—	
Knowledge Acquisition	0.913***	(0.095)	0.219***	(0.018)	0.478***	(0.050)	0.123***	(0.015)
Internal R&D	0.690***	(0.078)	0.241***	(0.019)	0.369***	(0.043)	0.152***	(0.015)
External R&D	0.260**	(0.118)	0.070***	(0.022)	0.106*	(0.063)	0.070***	(0.018)
Control variables								
Group	0.763***	(0.057)	0.199***	(0.016)	0.431***	(0.032)	0.083***	(0.013)
International market	0.440***	(0.088)	0.122***	(0.020)	0.248***	(0.048)	0.072***	(0.016)
Board	0.482***	(0.061)	0.167***	(0.016)	0.269***	(0.034)	0.102***	(0.013)
Ln firm age	0.114***	(0.038)	0.006	(0.012)	0.065***	(0.022)	−0.007	(0.010)
Size								
(Micro)								
Small	0.114**	(0.051)	0.153***	(0.022)	0.078**	(0.031)	0.110***	(0.017)
Medium	0.147**	(0.070)	0.289***	(0.025)	0.097**	(0.041)	0.242***	(0.019)
Large	0.366***	(0.126)	0.350***	(0.032)	0.225***	(0.068)	0.297***	(0.025)
Certification	0.306***	(0.066)	0.161***	(0.017)	0.183***	(0.037)	0.113***	(0.014)
Grants	0.245	(0.194)	0.033	(0.046)	0.104	(0.107)	0.038	(0.037)
Sector Dummies	YES		YES		YES		YES	YES
Macro-area	YES		YES		YES		YES	
Constant	−0.419*	(0.198)	0.208***	(0.072)	−1.491***	(0.283)	0.692***	(0.057)
Hansen's J chi2(1)			0.186	p = 0.67				
/athrho					0.303***	(0.103)		
/Insigma					−1.426***	(0.035)		
rho					0.294	(0.094)		
sigma					0.240	(0.008)		
Wald test of indep. eqns.(rho = 0):						chi2 (1) = 8.72 Prob>chi2 = 0.003		
Log-Lik Intercept Only	−7078.693							
Log-Lik Full Model	−6430.012							
Log-ratio test	1297.362							
Prob > Log ratio test	0.000							
Cragg & Uhler's/Nagerkerke pseudo R ²	0.143							
N	12,936		12,586		12,936		9,874	

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Micro is the reference category.

IV Poisson: Instrumented: Female CEO. Instruments: Sole Proprietorship, Female Ownership.

another for a binary selection indicator, *Eco-innovation Dummy*. The *Eco-innovation Dummy* takes a value of one if the firm has adopted at least one green measure and zero otherwise. The *Eco-innovation Dummy* is influenced not only by the variables in the baseline model but also by the Subnational Human Development Index (SHDI).¹³ The SHDI, which is excluded from the outcome model, measures achievements in critical human development dimensions within the firm's region, including education, health, and standard of living.

Column 5 in Table 7 presents the selection equation, assessing the determinants of adopting at least

one green measure. Column 6 in Table 7 displays the outcome equation, evaluating factors influencing the intensity of green practices adopted by the firm. The negative coefficient of Female CEO in the outcome equation confirms the negative relationship with the number of green measures adopted by the firm. This suggests that our main results remain robust even when correcting for self-selection bias.

The estimated correlation between the selection errors and outcome errors is 0.29. The Wald test indicates that we can reject the null hypothesis of zero correlation. This positive and significant correlation indicates that unobservable factors leading to an increase in green practices are likely to

¹³Data retrieved from the Subnational HDI Database of the Global Data Lab, <https://globaldatalab.org/shdi/>, version v5.0. The Subnational Human Development Index (SHDI) is a translation of the UNDP's official HDI and GDI (hdr.undp.org) to the subnational level (geographic regions within countries). At the national level, it is measured with the following indicators: (i) Education: 'Mean years of schooling of adults aged 25+' and 'Expected years of schooling of children aged 6'; (ii) Health: 'Life expectancy at birth'; (iii) Standard of living: 'Gross National Income per capita (PPP, 2011 US\$)'.

coincide with unobservable factors that also make a firm more inclined to invest in eco-innovations.

VII. Discussion and conclusions

While prevailing studies often suggest that female CEOs are more likely to drive eco-innovation, this research reveals a counterintuitive negative relationship, highlighting the complexities of gender dynamics in environmentally sustainable activities. These findings call for deeper analysis to understand the underlying factors.

Drawing on Social Identity Theory, this study highlights the challenges faced by female CEOs in transition economies, where perceived disparities between gender roles and leadership positions contribute to a fragmented self-concept. These circumstances carry significant implications for individual satisfaction in leadership roles and the engagement of female leaders in eco-innovation initiatives.

To address these challenges, implementing support mechanisms becomes crucial to mitigate biases and facilitate the empowerment of female leaders. Such support structures serve as tool for dealing with social identity dynamics, enabling female CEOs to lead sustainable practices within their organizations, particularly in context where such efforts face substantial obstacles. The interplay of societal norms, historical gender roles, and cultural influences underscores the complex relationship between gender dynamics and sustainability initiatives. This emphasizes the need for targeted support to validate and mentor female leaders as they face male-dominated environments.

Moving forward, policy interventions should prioritize capacity-building initiatives, ensuring equal access to critical resources. This includes supporting flexible business models conducive to leveraging the potential of female leaders. Increasing the awareness and participation of females in eco-innovation through specialized training equips them with the knowledge and skills needed. This encompasses understanding environmental regulations, sustainable supply chains, and responding to growing consumer demands for green products and services.

Access to external knowledge networks complements existing expertise, validating eco-innovation efforts. Establishing channels for collaboration and knowledge exchange with external partners – such as

industry-academia partnerships, innovation clusters, and knowledge-sharing platforms- can bridge internal capabilities gaps and confer competitive advantages.

Nevertheless, several limitations to our study suggest room for further research. Firstly, the empirical analysis is limited by the cross-sectional nature of the data. Another limitation pertains the range of external partners and the intensity of these relationships, which may provide higher consistency to the heterogeneous effects of cooperation, such as those with academia and civil society.

Despite these limitations, our study attempted to advancing the understanding on the relationship between females in leadership positions and eco-innovation dynamics in transition economies. Future research will further explore these dimensions, providing deeper insights.

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