Women in Leadership, Skilled Workforce, and Firm Performance in Bangladesh: A Machine Learning Analysis on Enterprise Survey Data

Chandan Kumar Roy
Bangladesh Bank, Bangladesh
chandan_hstu@yahoo.com

Tapati Basak
Jahangirnagar University, Faculty of Mathematical & Physical Sciences, Department of Statistics and Data Science, Bangladesh
tapati.basak@juniv.edu

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Abstract

This study examines the influence of women's representation in top management positions and availability of skilled human capital on firm performance in Bangladesh, a critical aspect that remains underexplored in the existing literature. We leverage a fresh and comprehensive dataset of 824 firms released by the World Bank Enterprise Survey in 2023 and employ both traditional ordinary least squares (OLS) regression and machine learning algorithms to analyze the relationship. While the presence of female leadership alone may not substantially boost firm performance, our findings underscore a notable positive influence of women in leadership roles, contingent upon the presence of a skilled workforce.

Notably, factors such as labor and electricity costs, access to financial resources, and international quality certification consistently show positive associations with firm performance. Our findings offer valuable guidance to policymakers and corporate decision-makers, highlighting the importance of supporting women in leadership roles while simultaneously investing in a skilled labor force to unlock firm productivity and success.

Keywords: women leadership, skilled workforce, firm performance, machine learning algorithms

JEL classification: J16, J24, L25, C45

1 Introduction

International development organizations have consistently emphasized the need to address gender-related cross-cutting issues to promote women's entrepreneurship and empowerment, encouraging various initiatives that facilitate women's access to credit, support women-led firms, and provide technical assistance. The United Nations Development Program's Sustainable Development Goal 5 (SDG-5) specifically focuses on promoting female rights in social, political, and economic activities to reduce gender discrimination and enhance gender equality by 2030. Policymakers and local governments have commendably taken steps to achieve SDG-5, including promoting the placement of women in board and managerial positions to empower women. This move not only fosters a healthy, high-skilled labor force but also motivates other female employees to perform better, thus contributing to overall firm performance. The inclusion of women at the top level and on boards is vital, as they play significant roles in overall governance and corporate performance. However, it is essential to consider other factors, such as firms' access to energy and finance, that can also significantly influence firm performance.

Between 2003 and 2016, Bangladesh experienced a remarkable 10 percent increase in female labor force participation, reaching 36 percent, largely driven by the readymade garments (RMG) and livestock sectors. Additionally, rural areas witnessed significant participation, with over 70 percent of women engaging in small-scale farming as small-holder farmers, owning poultry and other livestock (Tembon, 2021). Bangladesh's National Women Development Policy 2011 reflects the government's dedication to empowering women through building productive capacities, supporting women entrepreneurs, and increasing employment opportunities for skilled and non-skilled female workers. The policy also emphasizes gender-sensitive planning, equal pay in all sectors, encouraging women's leadership in politics, and increasing female representation across all administrative levels. Despite these efforts, the 2017 Global Gender Gap Report reveals concerning realities: only 15 percent of Bangladeshi firms have women as owners or co-owners, and a mere 5 percent have women in top managerial positions. Historically, top-level employees of Bangladeshi firms have been predominantly male, particularly within small, medium, and large enterprises, which can be attributed to cultural aspects within the country. Despite the sustainable goals agenda promoting gender equality, Bangladeshi culture has largely remained male-dominated, leading to limited female participation in top-level positions. In contrast, several developed economies have taken regulatory steps to promote gender diversity on corporate boards, with countries such as Iceland, Germany, Norway, France, and Belgium requiring at least 40 percent of women directors on publicly traded firms' boards (Kang, Ashton, Orujov, & Wang, 2023). Similarly, countries such as Australia, Sweden, and the UK deliberately prioritize a proper combination of female directors on corporate boards (ILO, 2019). Despite a substantial increase in the female labor force participation rate to 42.68 percent in 2022, particularly in rural areas, indicating improved access to employment opportunities and contributing to the country's economic growth, the percentage of female board directors in listed Bangladeshi firms remains at 18 percent, the highest in South Asia. This figure has not shown improvement since 2017 and is considerably lower than countries such as France (37.2 percent), Norway (41 percent), and South Africa (26.4 percent) (World Bank, 2022).

The question of whether women's presence in top management truly contributes to firms' performance remains fundamental. A systematic review conducted by Bannò, Filippi, and Trento (2021) analyzed 187 publications and highlighted the underexplored aspect of how women influence firm performance and value. Surprisingly, out of the 187 studies, only 15 specifically assessed the impact of women, particularly through sustainability, on firm-level performance. This review underscores the pressing need for further examination in order to gain a more comprehensive understanding of the connection between women holding high-ranking positions and a company's overall performance. While a substantial body of research has asserted that the presence of women in top management is linked to enhanced firm performance (Faccio, Marchica, & Mura, 2016; Moreno-Gómez & Calleja-Blanco, 2018), contrasting studies have indicated a negative correlation between women in top management and firm performance (Darmadi, 2013; Ujunwa, 2012). Furthermore, certain investigations have failed to identify any significant impact of women in top management on firm performance (Pletzer, Nikolova, Kedzior, & Voelpel, 2015; Marinova, Plantenga, & Remery, 2016). The inconclusive findings have been attributed to the utilization of inappropriate econometric methodologies and variations in the economic contexts of the studies (Moreno-Gómez & Calleja-Blanco, 2018).

Consequently, although there exist substantial empirical data regarding the correlation between women in senior leadership roles and corporate performance in developed nations, there is a conspicuous dearth of adequate empirical proof when it comes to emerging economies such as Bangladesh. This study aims to investigate how women's participation at the top-level influences Bangladeshi firms' performance and whether the effect is conditional on any other factors of production, employing advanced machine learning algorithms and traditional ordinary least squares (OLS) methods for cross-sectional data.

This study makes several contributions to the literature. Firstly, it directly explores how women's positions in top management and the availability of a skilled labor force influence the performance outcome of Bangladeshi firms, a topic that has not been adequately addressed in prior studies. Secondly, it investigates whether

the effectiveness of female positions at the management level in order to increase firm performance is conditional on any other factors, an area largely unexplored in the context of Bangladesh. Thirdly, the study separates the entire dataset into training and test datasets and employs machine learning algorithms to choose the best cross-sectional data OLS model, alongside traditional OLS models to check the stability of the findings. The use of machine learning algorithms provides greater reliability to the findings, a strategy not commonly employed in prior studies. Hence, the results of this research are notably dependable and impartial, enhancing their value for informed policy formulation.

The study is structured as follows: Section two outlines the examination of prior research. Section three delves into the study's data, sample, and methodology. Section four explains the study's outcomes, and lastly, Section five ends with the conclusion by discussing pertinent policy implications.

2 Review of Literature

The role of top management teams in an organization's success is crucial, and research indicates that enhancing gender diversity within these teams can lead to improved firm performance (Dezsö & Ross, 2012). Three theories – the agency theory, resource dependence theory, and upper echelons theory – explain the relationship between women's participation in a firm and firm performance (Gallego-Álvarez, García-Sánchez, & Rodríguez-Dominguez, 2010; Reguera-Alvarado, de Fuentes, & Laffarga, 2017; Lawal, 2012; Jamali, Safieddine, & Daouk, 2007; Croson & Gneezy, 2009; Dezsö & Ross, 2012; Becker, 1964; Kesner, 1988). The agency theory emphasizes the significance of gender diversity in corporate management, as it leads to better decision-making and improved firm performance. The resource dependence theory highlights how gender-diverse boards can help manage external dependencies and acquire necessary resources. The upper echelons theory shows that women in top management bring diverse knowledge and skills, positively influencing firm performance.

Women have traditionally been underrepresented in top management positions globally. However, a more gender-diverse workforce offers numerous advantages. Women in top management positions are known for their cooperative and inclusive leadership styles, which create a decision-making environment that considers diverse views and opinions (Dezsö & Ross, 2012). Drawing from family experiences, they possess the ability to understand both male and female perspectives, enabling them to gather timely and relevant information for effective decision-making. Additionally, female leaders are often associated with better monitoring and management qualities, prioritizing qualitative issues such as social responsibility and philanthropy, and contributing to a more ethical corporate environment (Adams & Ferreira, 2009; Hafsi & Turgut, 2013; Huang & Kisgen, 2013).

Despite the potential benefits, women's representation in top executive and board positions remains low in many countries. Some nations have implemented regulations to address this imbalance. While diverse boards may encounter more conflicts, they benefit from a wider range of perspectives and decision-making alternatives (Hambrick, Cho, & Chen, 1996). Women directors bring unique viewpoints to various fields and market segments, enhancing creativity and decision-making quality (Singh & Vinnicombe, 2004). Empirical evidence by Smith, Smith, and Verner (2006) demonstrates that women's influence in top management positively impacts firm performance, although the strength of this effect may vary based on CEO definitions and estimation methods. Women's presence on supervisory boards is associated with improved firm performance, while their representation as shareholders may have less significance. Additionally, gender-diverse boards can positively influence the career aspirations of lower-level employees (Ely, 1995; Burke & McKeen, 1996; Bell, 2005).

The existing body of empirical research on the influence of women in senior management positions on corporate performance presents divergent outcomes, with three principal lines of evidence. The first category of studies reveals a positive correlation between the presence of women in top management and a company's

performance. For instance, Reinert, Weigert, and Winnefeld (2016) identify a significant positive link between female representation in management and the performance of banks in Luxembourg. Jamali et al. (2007) suggest that inadequate female representation impedes board performance in Lebanese banking, whereas Moreno-Gómez and Calleja-Blanco (2018) establish a positive connection between female representation and subsequent business performance among publicly listed Colombian firms. Dezsö and Ross (2012) report that the inclusion of women in top management enhances corporate performance, particularly when the firm's strategy prioritizes innovation. Faccio et al. (2016) uncover a positive influence of female CEOs on corporate performance across 18 European nations, attributed to their lower leverage, more stable earnings, and improved survival rates. Perryman, Fernando, and Tripathy (2016) and Kim and Starks (2016) demonstrate that increased gender diversity in top management bolsters corporate performance and firm value. Reguera-Alvarado et al. (2017) establish a positive relationship between the number of women on boards and higher economic value for firms, while Flabbi, Macis, Moro, and Schivardi (2019) indicate that companies with female board members are more inclined to appoint female executives and exhibit superior corporate performance when female representation exceeds 30 percent. Martínez-Zarzoso (2023) sheds light on productivity disparities, emphasizing the significance of distinguishing between female management and ownership, revealing higher average labor productivity in firms with a top female manager and exclusively male ownership. Chatterjee and Nag (2023) focus on India, finding a positive impact of board gender diversity on firm performance but highlighting the nuanced influence of the mandatory appointment of one female director on boards. Chen and Kao (2022) contribute insights from Taiwanese manufacturing firms, showcasing the positive influence of female directors on accounting-based performance, although tempered by investor bias. Mastella, Vancin, Perlin, and Kirch (2021) analyze Brazilian firms, finding positive effects of female board representation on various performance measures. Saleh et al. (2021) explore the Palestinian context, revealing a positive influence of board gender diversity on firm performance, particularly in conjunction with corporate social responsibility.

Fan, Li, and Villatoro (2021) offer a US perspective, indicating lower labor costs in firms led by female CEOs. Lastly, Xing, Gonzalez, and Sila (2021) uncover nuanced dynamics in the interaction between female top managers and gender-diverse boards, with positive effects on return on assets but potential challenges associated with earnings management and negative market response.

Another strand of empirical research fails to detect a significant connection between the presence of women in top management and corporate performance. Cabrera-Fernández, Martínez-Jiménez, and Hernández-Ortiz (2016) and Ming and Eam (2016) find no apparent impact of female presence on corporate performance. D'Amato (2017) determines that women in top positions do not affect corporate performance, with this relationship being negatively moderated in family-owned firms. Pletzer et al. (2015) suggest that mere female representation on corporate boards lacks a significant impact on financial performance when other factors are not considered. Similarly, Marinova et al. (2016) detect no relationship between board diversity and corporate performance in the Netherlands and Denmark.

The third category of literature proposes that women in top management roles may have an adverse effect on corporate performance. Darmadi (2013) observes a negative association between female representation in top executive roles and corporate performance in Indonesia. Wellalage and Locke (2013) uncover a significant negative relationship between women in top management and firm value in Sri Lanka, attributing it to agency costs associated with board diversity. Ryan and Haslam (2005) also establish a negative link between female board members and share performance in the UK. Ujunwa (2012) examines Nigerian firms and concludes that gender diversity has a negative relationship with corporate performance. Soare, Detilleux, and Deschacht (2022) explore a unique Belgian context, revealing negative effects on firm performance indicators following the implementation of a gender quota policy. Ararat and Yurtoglu (2021) investigate the impact of female representation on boards in Turkey (2011–2018). Using extensive, hand-collected data on listed firms, they find that broad measures

mandated by regulators do not correlate with firm value and profitability. A list and summary of relevant and recent empirical literature is presented in Table 1.

Table 1: *List of Recent Related Literature*

Author(s)	Sample	Study period	Methodology	Findings
Martinez-Zarzoso (2023)	Six developing regions	2016	Panel data models	Firms that are managed by females but have no female owners show higher average productivity.
Chatterjee and Nag (2023)	364 firms, India	2017–2021	System GMM (generalized methods of moments)	Female leadership and presence in boards increase firm performance.
Soare et al. (2022)	4,080 companies, Belgium	2010–2017	Difference-in-difference (DID)	Increase in diversity negatively affects some company performance variables.
Chen and Kao (2022)	1,329 Taiwanese firms	1996–2017	Dynamic panel analysis	Increase in female directors linked to less downsizing and improved firm performance.
Mastella et al. (2021)	150 listed enterprises, Brazil	2010–2018	OLS, quartile and panel data	Positive correlation found between board gender diversity and firm performance.
Saleh et al. (2021)	48 listed firms, Palestine Stock Exchange	2010–2017	Fixed-effects (FE) and one-step system GMM	Positive impact of board gender diversity on firm performance, but not statistically significant.
Fan et al. (2021)	7,102 firm-year observations	1992–2018	OLS regressions	Female CEOs offer more non-monetary benefits, reducing labor costs.
Sun and Zou (2021)	Chinese listed corporations	2002–2018	Propensity score matching (PSM)	Companies led by female CEOs have better performance compared to those led by male CEOs.
Liu (2021)	1,921 US firms	2001–2014	OLS regressions	Female-led firms face fewer coercion lawsuits, reflecting better management conduct.
Xing et al. (2021)	2,325 listed firms, Shanghai and Shenzhen Stock Exchanges	2000–2014	OLS, FE, 2SLS, probit	More women in top management positively influences ROA, conditional to more gender-diverse boards.
Ararat and Yurtoglu (2021)	All listed firms, Borsa Istanbul	2011–2018	Pooled OLS, FE, RE	The correlation between women in senior management positions and firm performance lacks significance.
Akram, Abrar ul Haq, Natarajan, and Chellakan (2020)	375 listed non-financial firms, Pakistan Stock Exchange	2010–2016	FE and RE	The presence of gender diversity on boards has an adverse impact on firm performance.

Arioglu (2020)	Corporations quoted, Borsa Istanbul	2009–2017	System GMM and two stage least square (2SLS-IV)	Female directors influence firm financial performance positively.
Song, Yoon, and Kang (2020)	Publicly traded lodging companies, US	1993–2018	Panel data models	Gender diversity influences firm performance positively.
González, Guzmán, Pablo, and Trujillo (2020)	523 family companies, Colombia	1996–2006	FE and random-effects (RE) models	Women directors from outside positively influence firm's ROA, but women directors from family exert a contrary effect.
Fernández-Temprano and Tejerina-Gaite (2020)	87 non-financial companies, Spain	2005–2015	FE and RE	Gender diversity influence on firm performance is statistically insignificant.
Chijoke-Mgbame, Boateng, and Mgbame (2020)	77 listed companies, Nigerian Stock Exchange	2008–2016	FE and dynamic GMM	Boards with female representation increase firm performance.
Belaounia, Tao, and Zhao (2020)	1,986 public companies, 24 countries	2007–2016	Regressions incorporating fixed effects for both the firm and the year	Companies with higher women representation on boards show higher level of overall performance.
Ahmad, Raja Kamaruzaman, Hamdan, and Annuar (2019)	Top 200 quoted firms, Malaysia	2011–2013	Multiple regression analysis	The existence of women directors on boards exhibits an adverse correlation with return on assets.
Dang, Houanti, Reddy, and Simioni (2020)	369 firms, listed on Standard & Poor's 500	2004–2015	Pooled OLS, FE, system GMM	Women's presence on corporate boards positively influences ROA.
Shahzad, Hussain Baig, Rehman, Latif, and Sergi (2019)	5,879 corporations, USA	2008–2018	Sobel intermediary factor test method within the framework of regression analysis	Gender diversity on boards positively affects firm performance.

Sources: Simionescu, Gherghina, Tawil, and Sheikha (2021) and authors' selection.

Theoretical and empirical justifications from existing literature support the view that female representation in top management can positively influence firm performance. Women's inclusive leadership styles, information gathering abilities, and dynamic nature contribute to better decision-making and management. However, some conflicting findings in the literature warrant further exploration and research in this area. While the existing literature lacks a common consensus,

this research focuses on a specific context, Bangladesh, and identifies the importance of a skilled workforce and specific contextual factors in determining the impact of female leadership on firm performance. This study highlights the need to consider the broader organizational context when examining the relationship between women's position in top management and firm outcomes.

3 Methodology

3.1 Data Source and Sample

The initial sample for this study comprises the 998 firms that participated in the Bangladesh World Bank Enterprise Survey of 2022. The survey data are readily available online (https://www.enterprisesurveys.org/en/enterprisesurveys). After excluding firms with missing information on the relevant variables, we finally consider a total of 824 small, medium, and large enterprises for our analysis.

3.2 Empirical Specification

Drawing on the studies conducted by Liu, Wei, and Xie (2014) and Simionescu et al. (2021), we have developed an empirical specification to examine the direct influence of having women in top management positions and the presence of skilled labor on firm performance. Additionally, we explore whether the impact of women's managerial positions on enhancing firm productivity is contingent on the skill level of the workforce. The empirical specification can be expressed as follows:

$$Performance_i = \zeta_0+\zeta_1 TOP\_Women_i+\zeta_2 Labor\_Skilled_i+\zeta_3(TOP\_Women_i \times Labor\_Skilled_i)+\zeta_4 Labor\_Cost_i+\zeta_5 Electricty\_Cost_i+\zeta_6 Dummy\_Control_{j,i}+\varepsilon_i$$

where $Performance_i$ represents the performance of firm i and is measured by the natural logarithm of the firm's total annual sales in the fiscal year divided by the total number of permanent full-time workers in that year. Islam and Amin

(2023) applied a similar approach to determine firm performance or productivity. TOP_Women_i is a dummy variable indicating the presence of women in top-level positions within the firm. It takes a value of 1 if the firm has female executives in top management and 0 otherwise. The coefficient ζ_1 quantifies the change in performance when there are women in top-level positions compared to when there are no women at the top level. $Labor\_Skilled_i$ represents the logarithm of the total number of skilled laborers employed by the firm. The coefficient ζ_2 indicates how much the firm's performance changes with each unit increase in the number of skilled laborers, assuming other variables are held constant.

($TOP\_Women_i \times Labor\_Skilled_i$) captures the interaction effect between having women in top-level positions and the number of skilled laborers on the firm's performance. The coefficient of interest, ζ_3, reveals how this combined effect influences firm performance. ζ_4 and ζ_5 represent the impact of the logarithm of labor costs and electricity costs per worker, respectively, on the firm's performance. They show how changes in labor costs and electricity costs influence firm performance, assuming other variables remain constant. ζ_6 corresponds to the coefficient of dummy control variables, which take a value of 1 if the firm possesses specific characteristics, such as international quality certification, experienced power outages, and financial accounts/facilities. The coefficient ζ_6 reveals the effect of these characteristics on the firm's performance. ε_i is the error term and accounts for unexplained variations in the performance of firm *i* that are not captured by the independent variables. It encompasses all other factors and random influences affecting firm performance.

3.3 Empirical Estimation Strategies

This study adopts the estimation strategies using both traditional cross-sectional regression and machine learning algorithms. Before applying both strategies, we carefully preprocess the enterprise survey data through handling missing values and outliers as these can distort the analysis. Cross-sectional regression is

employed to test the hypotheses of the study. We also assess cross-sectional model assumptions, which include checking for linearity, normality, homoscedasticity, and multicollinearity through relevant statistical tests. We present our findings with White's robust standard errors that specifically address heteroscedasticity in the error terms in our OLS model.

However, to further validate our results and explore potential improvements in predictive accuracy, we also apply machine learning algorithms. By leveraging techniques such as cross-validation, ensemble methods, and regularization, we can assess whether these algorithms offer better predictive power and additional insights into the relationships among the variables. Integrating traditional regression and machine learning methods ensures a comprehensive and robust approach to analyzing the performance determinants of firms, empowering evidence-based decision-making across diverse business contexts.

4 Results and Discussions

4.1 Summary Statistics

Table 2 presents the descriptive statistics of the study variables. The data reflect a diverse range of variation among the sample firms. The total annual sales in the fiscal year vary significantly, with values ranging from 200,000 to 50.6 billion. The number of permanent full-time workers also shows variation, with a minimum of 1 and a maximum of 8,400. Similarly, the total annual cost of labor and electricity exhibits substantial variability. The number of highly skilled workers varies from 0 to 7,000. The log of firm performance per worker ranges from 8.923 to 20.141. The data also indicate a small percentage of top managers being female (2.8 percent). Most firms experience power outages (75.8 percent), while only 10 percent have internationally recognized quality certifications. The majority have current or savings accounts (88.5 percent), while only a few have overdraft facilities (11.3 percent) and lines of credit (39.9 percent).

Table 2: *Summary Statistics*

Variable	Count	Mean	Std.	Min.	Max.
Total annual sales in fiscal year	824	252,000,000	1,950,000,000	200,000	50,600,000,000
Permanent full-time workers	824	147.439	524.1	1	8,400
Total annual cost of labor	824	33,999,877	356,000,000	0	9,880,000,000
Total annual cost of electricity	824	3,107,580	22,797,277	5	500,000,000
Number of highly skilled workers	824	58.309	311.142	0	7,000
Log of firm performance per worker	824	13.373	1.333	8.923	20.141
Log of labor cost per worker	824	11.73	1	-3.219	17.217
Log of electricity cost per worker	824	9.305	1.425	0.182	18.084
Log of number of highly skilled workers	824	2.14	1.673	0	8.854
Top manager female (Yes=1, No=0)	824	0.028	0.165	0	1
Experienced power outages (Yes=1, No=0)	824	0.758	0.428	0	1
Has an internationally recognized quality certification (Yes=1, No=0)	824	0.1	0.3	0	1
Has current or savings account (Yes=1, No=0)	824	0.885	0.32	0	1

Source: Authors' calculations.

4.2 Correlation Matrix and Test of Multicollinearity

This study employs heteroscedasticity-robust ordinary least squares (OLS), also known as weighted least squares (WLS), for multiple regression analysis. The first step involves diagnosing the critical assumptions of each test. To examine the multivariate regression assumption of multicollinearity, the correlation matrix presented in Table 3 is utilized. The Pearson correlation coefficients are observed to be below the 0.70 threshold, as highlighted by Gujarati (2004), who noted that multicollinearity may become problematic when correlations reach or exceed 0.70. Furthermore, the study conducts VIF and tolerance tests to assess the presence of collinearity. The results, reported for each regression model in Table 4, do not indicate any signs of collinearity.

Table 3: *Correlation Matrix*

	Log of firm performance	Log of labor cost	Log of electricity cost	Log of number of highly skilled workers
Log of firm performance	1.00	0.2661	0.3571	0.1085
Log of labor cost	0.2661	1.00	0.2679	0.0049
Log of electricity cost	0.3571	0.2679	1.00	-0.0545
Log of number of highly skilled workers	0.1085	0.0049	-0.0545	1.00

Source: Authors' calculations.

4.3 Empirical Results and Discussion From Traditional OLS Regression

The study examines the impact of female representation in top management on firm performance, considering the presence of a skilled workforce and other control variables. The results from the OLS regression models with heteroscedasticity-robust standard errors, as presented in Table 4, indicate that the coefficient for the variable "top manager female" is statistically insignificant across all models ($p > 0.05$). These findings indicate that the presence of women in senior management positions does not consistently exert a significant impact on firm performance. These results align with prior research conducted by D'Amato (2017), Kyaw, Olugbode, and Petracci (2015), Marinova et al. (2016), and Ming and Eam (2016), all of which also discovered no substantial correlation between female representation at the highest organizational echelons and firm performance. In accordance with the findings of Simionescu et al. (2021), it is plausible that female executives may encounter limitations in terms of managerial authority, access to critical information, and the time necessary to influence decision-making processes, resulting in a negligible effect on firm performance. Furthermore, women in executive roles may possess close ties with shareholders, constraining their capacity to act independently (Akram et al., 2020). These findings remain consistent even after including additional control variables such as access to power, finance, and international certifications.

Table 4: *OLS Regression Findings (Dependent Variable: Firm Performance)*

Variable	(1)	(2)	(3)	(4)	(5)
Top manager female (Yes=1, No=0)	0.104	-0.0317	-0.0264	-0.0649	-0.105
	(0.281)	(0.276)	(0.280)	(0.277)	(0.278)
Log of number of highly skilled workers	0.0990***	0.0934***	0.101***	0.0596**	0.0466*
	(0.0252)	(0.0250)	(0.0252)	(0.0278)	(0.0281)
Top manager female × highly skilled workers		0.00164***	0.00147***	0.00170***	0.00172***
		(0.000236)	(0.000245)	(0.000253)	(0.000252)
Log of labor cost per worker	0.309**	0.309**	0.309**	0.293**	0.273**
	(0.134)	(0.134)	(0.132)	(0.130)	(0.132)
Log of electricity cost per worker	0.286***	0.289***	0.291***	0.304***	0.301***
	(0.0332)	(0.0332)	(0.0333)	(0.0331)	(0.0334)
Experienced power outages (Yes=1, No=0)			-0.260**	-0.265**	-0.290***
			(0.104)	(0.103)	(0.102)
Has quality certification (Yes=1, No=0)				0.607***	0.587***
				(0.144)	(0.144)
Has current or savings account (Yes=1, No=0)					0.407***
					(0.110)
Constant	6.874***	6.852***	7.016***	7.116***	7.068***
	(1.487)	(1.490)	(1.477)	(1.456)	(1.487)
Observations	824	824	824	824	824
Mean VIF	1.08	1.05	1.08	1.07	1.12
F-test	29.96	61.51	51.35	50.82	48.00
R-squared	0.185	0.189	0.196	0.211	0.220

Notes: Heteroscedasticity-robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; mean VIF values below 5 are considered acceptable and not worrisome of multicollinearity.

Source: Authors' calculations.

Our subsequent hypothesis test examines whether the availability of highly skilled workers encourages firm performance. Our empirical results reveal that the coefficient for the variable "log of number of highly skilled workers" is positive and statistically significant ($p < 0.001$) across most of the models. This indicates that an increase in the number of highly skilled workers is associated with higher firm performance. Moreover, the coefficient estimates consistently demonstrate that a one percent increase in the number of highly skilled workers is associated with an approximate 0.09 percent to 0.10 percent increase in firm performance. These findings align with the theory of human capital (Becker, 1964), which

posits that individual skills, experience, and education contribute significantly to a firm's productivity, surpassing the impact of physical capital.

The coefficient of the interaction term "top manager female and highly skilled workers" is of particular importance as it measures the combined effect of having women in top management and the number of highly skilled workers on firm performance. The positive and statistically significant coefficient ($p < 0.001$) in all models indicates that the combined effect of women in top management and highly skilled workers positively influences firm performance. Specifically, a one-unit increase in the product of the log of highly skilled workers and the presence of women at the top level is associated with an increase in firm performance. The interaction term is statistically significant ($p < 0.001$), indicating that the effect of having a female top manager on firm performance is conditional on the number of highly skilled workers. The coefficient (0.00164) is positive, suggesting that the presence of both a female top manager and highly skilled workers positively affects firm performance. This proposition that the effect of having a female top manager on firm performance is conditional on the number of highly skilled workers holds several favorable arguments that merit critical consideration. Firstly, a female top manager's leadership style, often characterized by inclusivity, collaboration, and empathy, may resonate positively with highly skilled workers. These workers, possessing specialized expertise and knowledge, may appreciate a leader who values their contributions and provides a conducive work environment, leading to enhanced motivation and productivity (Frangos, 2021). Secondly, female top managers may be more adept at recognizing and harnessing the potential of highly skilled workers, as research suggests that women leaders often excel in interpersonal skills and team building (Galsanjigmed & Sekiguchi, 2023). This ability to tap into the full potential of the skilled workforce could result in improved innovation, efficiency, and ultimately, firm performance. Additionally, a diverse leadership team that includes female representation may foster a more inclusive organizational culture, which is known to benefit highly skilled workers by reducing barriers and biases and promoting their full participation and

engagement (ILO, 2019). Female top managers may also serve as role models, inspiring highly skilled workers and encouraging them to reach their full potential. By fostering an environment of diversity and inclusion, female top managers may create a sense of belonging among highly skilled workers, leading to increased job satisfaction and loyalty, ultimately positively impacting firm performance.

The positive and statistically significant coefficient for the variable "log of labor cost per worker" in all models supports the idea that higher labor costs per worker are linked to improved firm performance. This finding underscores the importance of investing in skilled labor as a crucial factor contributing to a firm's overall success and competitiveness. The magnitude of the coefficient further indicates that even a small increase in the log of labor cost per worker can lead to a substantial improvement of approximately 0.27 to 0.31 units in the log of firm performance. This aligns with the proposition by Le and Pomfret (2011) that higher labor costs per person, encompassing wages and training expenditure, indicate the presence of highly skilled laborers in the firm. Such skilled workers are adept at assimilating new technologies and achieving higher levels of efficiency.

Our findings reveal a positive association between higher electricity costs per worker and firm performance. Although there is limited empirical evidence on this relationship, several justifications can support this finding. Firstly, higher electricity costs per worker might indicate that firms are adopting advanced and sophisticated technologies, which can significantly enhance operational efficiency and reduce production costs, ultimately leading to improved firm performance. In today's competitive business environment, firms that invest in modern technologies often experience higher productivity and competitiveness. Secondly, the electricity tariff structure and regulatory factors in Bangladesh may also impact electricity costs per worker. While higher costs could be influenced by regulatory measures or taxation, firms that comply with these regulations and demonstrate responsible behavior may be viewed more favorably by stakeholders, potentially positively influencing firm performance. However, it is essential to note that the government's provision of subsidies in the power sector may also

play a role in the overall electricity costs faced by firms. Using the experience of India, Rud (2012) found that increased electrification levels were associated with a significant 14 percent increase in manufacturing output.

The coefficient for experienced power outages is found to be negative and statistically significant in all models, indicating that firms experiencing power outages tend to have lower performance. This aligns with the argument put forth by Kessides (1993), which highlights the crucial role of power as a significant factor of production. Changes in the availability and cost of electricity can directly impact the marginal productivity and overall performance of firms. When electricity supply is disrupted, it directly affects the operation and efficiency of machinery and labor, leading to a drop in production and productivity (Abeberese, 2017; Fisher-Vanden, Mansur, & Wang, 2015).

Furthermore, the positive and statistically significant coefficient for the variable "quality certification" in all models suggests that firms with quality certification tend to have higher performance. Quality certification is associated with adherence to recognized standards and practices, indicating that certified firms have implemented robust quality management systems. This, in turn, can lead to improved product or service quality, customer satisfaction, and operational efficiency, all of which contribute to higher firm performance (Siougle, Dimelis, & Economidou, 2019; Starke, Eunni, Manoel Martins Dias Fouto, & Felisoni de Angelo, 2012).

The coefficient for the variable "firm has current or savings account" is positive and statistically significant ($p < 0.001$). This suggests that firms with current or savings accounts tend to have higher firm performance. Having a current or savings account indicates that the firm is financially stable and has access to formal financial services, which can provide various benefits. These benefits may include easier access to credit, smoother cash flow management, and the ability to invest in business expansion or improvement projects. Consequently, firms with current or savings accounts are better positioned to navigate financial challenges,

seize growth opportunities, and achieve better overall performance (Giang, Trung, Yoshida, Xuan, & Que, 2019; Han & Gu, 2021).

Overall, the *R*-squared values in each model indicate that the independent variables explain approximately 18.5 percent to 22.4 percent of the variation in firm performance. However, the *F*-test statistic is statistically significant ($p < 0.001$) in all models, indicating that the overall regression models are jointly significant.

4.4 Analysis Using Machine Learning Algorithms

4.4.1 Selection of Suitable ML Algorithm

To assess the predictive capabilities of our OLS model for elucidating the impacts of our explanatory and control variables on a firm's performance, we conducted a comprehensive evaluation utilizing various machine learning (ML) models, including linear regression (LR), random forest (RF), gradient boosting (GB), lasso regression (LAR), and ridge regression (RR). This assessment was facilitated through the utilization of performance metrics such as mean square error (MSE) and *R*-squared (R2). The evaluation procedure entailed partitioning the entire dataset into two subsets: a training dataset (comprising 78 percent of the data) and a test dataset (consisting of 18 percent of the data). Subsequently, we applied the ML models to the training dataset and assessed their performance on the test dataset. A model with lower MSE values and higher *R*-squared values on the test dataset indicates better model performance (López, López, & Crossa, 2022; Tachie, Tawiah, & Aryee, 2023).

Based on the results of the ML algorithms in Table 5, we have uncovered distinct behaviors in our model candidates. The random forest model exhibited remarkable performance during training, yielding a high *R*-squared value of 0.89, although this promising outcome was accompanied by a noticeable drop in *R*-squared (0.146) when applied to the test dataset, indicating overfitting.

Gradient boosting, while achieving a satisfactory training *R*-squared, faced similar challenges in generalization to unseen data (test *R*-squared: 0.162). Lasso regression, on the other hand, displayed a limited training *R*-squared (0.161) but slightly outperformed random forest and gradient boosting in the test *R*-squared metric (0.1829). Most notably, ridge regression emerged as a robust choice, striking a balance between training (0.2094) and test (0.1957) *R*-squared values, accompanied by consistent adjusted *R*-squared scores (0.1987 for training, 0.1436 for testing), suggesting its potential for superior generalization and suitability for further hyperparameter tuning and cross-validation efforts. These results highlight the importance of model selection and evaluation in the context of predictive analytics for firm performance, underscoring ridge regression as a compelling candidate for optimization and validation in this study.

Table 5: *Machine Learning (ML) Model Selection*

ML models	Training dataset			Test dataset		
	MSE	*R*-squared	Adj. *R*-squared	MSE	*R*-squared	Adj. *R*-squared
Linear regression	1.4059	0.2094	0.1987	1.4029	0.1955	0.1435
Random forest	0.1941	0.8908	-	1.4886	0.1464	-
Gradient boosting	0.8249	0.5361	-	1.4614	0.1620	-
Lasso regression	1.4908	0.1616	0.1502	1.4249	0.1829	0.1300
Ridge regression	1.4059	0.2094	0.1987	1.4027	0.1957	0.1436

Notes: All ML models are performed using the scikit-learn module in Python 3.7.3 with random state value 20; adjusted *R*-squared results are not applicable for RF and GB algorithm.

Source: Authors' calculations.

4.4.2 Hyperparameter Tuning, Cross-Validation, and Model Evaluation for Unseen Data

The strength of ridge regression depends on the regularization parameter, alpha. A higher alpha value will result in more regularization, which will shrink the coefficients of the model and reduce the variance of the predictions. In order to find the optimal value of alpha, we use hyperparameter tuning techniques.

Hyperparameter tuning involves searching through a range of values for alpha and selecting the value that results in the best model performance.

Table 6: *Hyperparameter Tuning of Ridge Regression*

Particulars	Before tuning	After tuning
Alpha	0.10	100
Test MSE	1.40266	1.37974
Test *R*-squared	0.19566	0.20879
Test adjusted *R*-squared	0.143577	0.15756

Source: Authors' calculations.

Table 6 represents a pivotal step in our research, where we meticulously fine-tuned the hyperparameters of the ridge regression model—a fundamental component in our investigation of predicting firm performance. Our initial alpha value of 0.10 underwent a rigorous optimization process, resulting in the selection of an optimal alpha of 1.0. This transformation led to a noteworthy reduction in the test MSE, indicating a substantial improvement in predictive accuracy. Furthermore, it showcased a significant enhancement in the test *R*-squared value, demonstrating an increased ability of the model to explain variances in firm performance. Equally significant was the improvement in the adjusted *R*-squared value after tuning, highlighting a more balanced and robust model for forecasting firm performance.

Following the systematic hyperparameter tuning process, involving a range of alpha values (0.01, 0.1, 1.0, and 100.0), we identified the most proficient ridge regression model based on MSE during a rigorous five-fold cross-validation procedure. Subsequently, the optimal ridge model, with an alpha value of 1.0, was trained on the complete training dataset. Our results unequivocally affirm the effectiveness of this fine-tuned ridge regression model, showcasing its superior performance on both validation and test sets. On the validation dataset, the model yielded an MSE of 1.4088 and an *R*-squared value of 0.1815, underscoring its ability to capture data variances effectively. Crucially, when assessed on unseen

test data, the model exhibited even greater effectiveness, displaying a diminished MSE of 1.2485 and a substantially improved *R*-squared value of 0.3221. These findings not only emphasize the efficacy of ridge regression in modeling and predicting firm performance but also underscore the promise of our tuned model in delivering robust results during out-of-sample testing.

4.5 Robustness Test Using Ridge Regression of ML Algorithm

The results obtained from ridge regression (Table 7) on the test dataset and training dataset exhibit significant consistency and robustness. Specifically, the *R*-squared values stand out as a testament to the reliability of our findings. The ridge regression model, when applied to the test data, yields an *R*-squared value of 0.306, while applied to the training data, it records an *R*-squared value of 0.209. Given that our primary concern is the model's ability to predict unseen data (test data), we place significant emphasis on the outcomes derived from the test dataset. Consequently, ridge regression demonstrates that the selected independent variables collectively explain approximately 30.6 percent of the variance in firm performance.

Moreover, a compelling aspect of our findings is the consistency observed in the coefficients of the independent variables between the ridge regression output and the OLS model output (as seen in Table 4). Both in terms of direction and statistical significance, the agreement is striking. For instance, variables such as the natural logarithm of labor cost per worker, the natural logarithm of electricity cost per worker, and a firm's access to banking services all exhibit positive and statistically significant coefficients in both the ridge regression and OLS model. Notably, the coefficient of the interaction term in the test data regression aligns with the primary OLS regression output (as seen in Table 4). This remarkable consistency in coefficient estimates suggests that the relationships between these variables and firm performance are robust and hold true across all models.

Table 7: *Ridge Regression Output Using Test Data*

Variable	Training data regression	Test data regression
Top manager female (Yes=1, No=0)	-0.2281	-2.5212
	(0.277)	(2.058)
Log of number of highly skilled workers	0.0375	0.0945
	(0.03)	(0.067)
Highly skilled workers * top manager female	0.0018**	0.5369**
	(0.001)	(0.269)
Log of labor cost per worker	0.1997***	0.3453**
	(0.046)	(0.146)
Log of electricity cost per worker	0.2993***	0.3345***
	(0.034)	(0.076)
Experienced power outages (Yes=1, No=0)	-0.3372***	-0.1314
	(0.108)	(0.225)
Has an internationally recognized quality certification (Yes=1, No=0)	0.754***	-0.0093
	(0.169)	(0.344)
Has current or savings account (Yes=1, No=0)	0.3196**	0.8916***
	(0.15)	(0.301)
Constant	8.0442***	5.3965***
	(0.553)	(1.59)
Observations	675	149
F-test statistics	22.05	7.706
R-squared	0.209	0.306
Adjusted *R*-squared	0.200	0.266

Notes: Standard errors in parentheses; ridge regression is L2 regularization, which prevents overfitting and is consistent with the multicollinearity issue.

Source: Authors' calculations.

In essence, our analysis underscores the reliability and generalizability of the findings, emphasizing the coherence of results between ridge regression and OLS modeling, particularly with respect to the key variables' influence on firm performance. These consistent outcomes reinforce our confidence in the identified relationships and their applicability in real-world scenarios.

5 Conclusion

This research represents a distinctive addition to the current body of knowledge concerning firm productivity in Bangladesh by presenting original empirical findings regarding the influence of women's presence in senior managerial roles on firm performance. Our investigation encompasses a dataset comprising 824 companies, and we employ a combination of conventional OLS regression techniques and cutting-edge machine learning algorithms. Unexpectedly, our study does not yield substantial evidence in favor of the hypothesis that female leadership exerts a direct positive impact on the performance of small, medium, and large firms. However, we do identify a significant positive effect of women's leadership, provided the firms have access to skilled workforce. Across various models, factors such as labor and electricity cost per worker, access to current and savings accounts, and international quality certification consistently show a positive influence on firm performance. Interestingly, continuous power supply emerges as a crucial determinant of firm productivity, highlighted by the OLS regression model but not the ridge regression model of the test dataset. Overall, our findings suggest that having women in top positions, combined with a skilled workforce, can substantially boost firm productivity and performance.

Given the growing emphasis on gender diversity in top management and boardrooms worldwide, policymakers and practitioners in Bangladesh face similar pressures. Our study indicates that encouraging female representation in top management can be beneficial for firms, but it hinges on the availability of a skilled and educated labor force. To fully leverage the potential benefits of female leadership, the government should complement its strategic mandate with policies and strategies aimed at developing and supplying skilled labor to the economy. The findings provide valuable empirical guidance for Bangladeshi policymakers, regulators, and corporate decision-makers in their efforts to promote gender diversity within firms.

While our study offers valuable insights, further research is warranted to enhance predictive accuracy and gain a deeper understanding. Additional firm-level data and comprehensive analyses can refine our findings and provide more robust predictions. For now, our study highlights a crucial policy implication: promoting female leadership at the top level can positively influence firm performance, but the realization of this impact depends on the simultaneous focus on recruiting and nurturing a skilled labor force. Moreover, access to finance and quality certification are identified as key determinants of positive firm performance, emphasizing their significance for policymakers and businesses in Bangladesh.

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