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Navigating Nanotechnology: Unveiling the Role of Government Pressure and Organizational Culture in Enhancing Environmental Performance in Printing and Coatings Industry

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This research aims to explore the existing relationship of nanotechnology innovation with organizational culture and the environmental performance of organizations. Moreover this research used organizational culture as a mediating variable and government pressure as a moderating variable among the relationship of nanotechnology innovation and environmental performances of organizations. This research was conducted in Kingdom of Saudi Arabia and collected data from 187 employees working in different organizations of printing and coatings industry. To achieve the aim of this research this study has employed the STATA software with structural equation modeling approach. Findings of this research have shown a significant association among direct relationships of nanotechnology innovation and environmental performances of organizations. Moreover, a significant relationship was also found among nanotechnology innovation and organizational culture. The findings also confirmed that the relationship between nanotechnology innovation and environmental performance is also moderated by government pressure and mediated by organizational culture. This study demonstrates that nanotechnology possesses the capability to completely transform organizations. This study highlights the importance of a conducive business culture and environmentally conscious regulatory requirements with the aim of enhancing environmental sustainability.

Keywords: Nanotechnology innovation, Organizational culture, Environmental performance, Government pressure, Sustainability.

1. Introduction

In the fast-changing world the organizations are involved in dealing with several challenges like implementation of technological changes and environmental concerns. It creates a new area of research at the intersection of nanotechnology and environmental sustainability, which is an area of research for organizations that is growing quickly and becoming increasingly intricate (Justo-Hanani, 2024a). Nanotechnology has the potential to spur innovation in a range of sectors and tackle urgent environmental issues by utilizing its ability to control materials at a microscopic scale (Preethi et al., 2024). The influence of nanotechnology advancements on enhancing environmental performance in enterprises is significantly shaped by corporate culture and political pressure (Justo-Hanani, 2024b). Thorough investigation of the interdependencies between environmental sustainability and nanotechnology innovation in business settings is necessary (de Freitas Cardoso et al., 2024) to comprehend this relationship between.

In past research (Farooqi et al., 2023; Ometto et al., 2023; Provensi et al., 2024) all the important aspects of government pressure, organizational culture, environmental performance, and nanotechnology innovation have been studied, yielding informative and instructional results. According to the Vickram et al. (2023), nanotechnology's ability to overcome nanoscale material limits and address sustainability and environmental issues in various fields are driving interest in this topic. suggests that nanoparticles, nanofibers, and nanocomposites may clean the environment. Nanotechnology-enabled photocatalytic coatings can clean water and air, according to recent research of Huang et al. (2023). Nanoparticle sensors can regulate pollutants, monitor the environment in real time, and manage resources proactively. Huang et al. (2023) findings imply that nanotechnology may benefit the environment by encouraging new materials and technologies. Li et al. (2023) study indicated that corporate cultures influence nanotechnology utilization, which could impact scientific and environmental sustainability. Several studies have shown that an organization's culture affects employee retention and creativity. It's well known that an organization's values, expectations, and beliefs affect employee behavior (Harsanto et al., 2023). Nanotechnology companies are noted for their environmental sustainability, adaptability, and collaboration, according to the previously listed companies. Encouragement of a culture that values innovation and cautiously absorbs new technology will benefit US business leaders and the corporate community (Çaldağ et al., 2023). Nanotechnology may improve stakeholder participation, environmental performance, and competitiveness (Reyes Ruiz, 2023). This new economic sector may lead eco-friendly innovation.

The fields of commercial ethics, ecological efficiency, and nanotechnology have all seen significant advancements (Soomro et al., 2023). However, further empirical research

is required to provide a deeper understanding. The amount of study on how nanotechnology affects environmental effects is increasing (Huang et al., 2022). But these studies frequently ignore the impact of things like business culture or political pressure (Ma et al., 2022). The significance that corporate culture plays in promoting innovation in nanotechnology and enhancing environmental performance has not received enough attention. As Tjebane et al. (2022) Point out, previous research has mainly disregarded the political reasons for using nanotechnology to advance environmental sustainability. Scientific developments in the domains of environmentally friendly technologies and nanotechnology can be strongly influenced by government laws, rules, and incentives (Moon et al., 2022). An organization's long-term viability is influenced by a number of factors, including its environmental policies, breakthroughs in nanotechnology, internal political pressures, and business culture (Ramogayane, 2022).

This study explores the complex relationships between environmental performance, company culture, political pressure, and nanotechnology innovation in an effort to reconcile the previously described disparities. Theoretical frameworks including organizational culture theory (Clarysse et al., 2022), institutional theory (Indiya et al., 2021), and innovation diffusion theory (Pan et al., 2021) are used to achieve this. The research attempts to address two distinct questions: First, what is the link between environmental performance and innovation in nanotechnology, and how is it influenced by governmental obstacles and business culture? Second, how is this link mitigated by business culture? This study adds to a better understanding of how nanotechnology innovation could help environmental sustainability in organizational environments by combining many theoretical frameworks and using rigorous empirical methodologies.

2. Literature Review

Nanotechnology's unparalleled accuracy and adaptability have transformed the printing and coatings industries (Raeesi Nafchi et al., 2021) .The nanoscale has enabled scientists to increase ink functionality and develop novel coatings with improved qualities (Ghiasi et al., 2021). Nanoparticle-based inks, which increase conductivity, color intensity, and durability, represent a significant improvement. Nanoparticles in ink formulations enhance resolution and print quality (Licup et al., 2021). This might allow flexible electronics, sensors, and medicinal devices. Nanotechnology enhances UV, anti-corrosion, and scratch coatings. Molecularly tailored nanocoatings prolong printed materials and substrates in many applications by improving adhesion and coverage (Bensaude-Vincent, 2021). Nanotechnology enhances printing and coating performance and sustainability since nanoparticles use less, decreasing waste and environmental impact (Cummings et al., 2021). Ashraf et al. (2021) research predicts nanotechnology will seamlessly integrate into the printing and coatings sectors, spurring innovation and transforming how consumers use printed products.

Nanotechnology's components affect a company's environmental performance. Many sectors use nanotechnology to improve materials, processes, and nanoscale applications (Renn et al., 2006) . Advances include nanoparticles, nanocomposites, and nanodevices in products and processes (Hadj, 2020). Organizational environmental performance is its ability to reduce environmental impact and increase resource efficiency and sustainability (Chen et al., 2020). Reduce greenhouse gas emissions, waste, water, and energy using sustainable supply chains. Nanotechnology innovation has been empirically connected to environmental performance. Many studies suggest nanotechnology may improve environmental sustainability for businesses across industries. Ghazinoory et al. (2020) claim nanoparticles can make sturdy, lightweight, energy-efficient products. Photocatalytic coatings, nanofiltration membranes, and nanocomposite materials have considerably improved wastewater, air, and pollution treatment (Bowman et al., 2020; Gonzales-Gemio et al., 2020; Macnaghten et al., 2020). Modern nanotechnology can enhance resource efficiency and minimize pollution, boosting sustainability, as shown in these research. Studies show that nanotechnology innovation impacts an organization's environmental performance. Nanotechnology reduces waste, pollution, and resource use (Justo-Hanani, 2024b). Nanomaterials enhance sustainability, process optimization, and product innovation (Justo-Hanani, 2024a). A corporation that invests in cutting-edge nanotechnology may perform better environmentally. Our worldview stresses nanotechnology's environmental benefits and importance.

H1. *Nanotechnology innovation has a significant impact on the environmental performance of an organization.*

Early studies related organizational culture to nanotechnology innovation. Numerous studies show that nanotechnology changes organizational norms, attitudes, and behaviors. Nanotechnology innovation firms foster creativity, risk-taking, and learning, according to Farooqi et al. (2023). Nanotechnology adoption needs multidisciplinary collaboration and a willingness to try new things, which fosters creative organisational cultures (Huang et al., 2023). Nanotechnology's communication and work practises may impact employee attitudes and organisational culture (Li et al., 2023). Researchers claim progressive leaders foster nanotechnology innovation through experimentation, adaptability, and flexibility (Çaldağ et al., 2023). Nanotechnology can alter company culture, altering communication, problem-solving, and interaction. Empirical research suggest nanotechnology innovation may affect organizational culture (Soomro et al., 2023). Nanotechnology may alter organisational culture (Ma et al., 2022). Nanotechnology innovators are courageous, versatile, and cooperative (Moon et al., 2022). Nanotechnology integration affects an organization's structure, protocols, communication, and more, according to Clarysse et al. (2022). Pan et al. (2021) study found that job duties, expectations, and attitudes may alter employee behavior. Nanotechnology may transform corporate practices, attitudes, and behavior.

H2. *Nanotechnology innovation has a significant impact on the organizational culture.*

Research has examined the complex relationship between nanotechnology, organizational culture, and the

environment. Research reveals company culture affects creativity and environmental norms. Ghiasi et al. (2021) say management culture affects staff creativity and sustainability. Risk-taking, collaborative, and adaptable companies may employ nanotechnology (Bensaude-Vincent, 2021). Corporate culture affects workers' sustainability program comprehension, commitment, and involvement, which impacts environmental performance, according to Ashraf et al. (2021). Environmentalism, resource conservation, and pollution control gain support. Studies show company culture influences nanotechnology innovation and environmental performance. Empirical data suggests that organizational culture impacts environmental performance and nanotechnology innovation. Company culture affects employees' innovation and sustainability attitudes, behaviors, and decisions (Hadj, 2020). Nanotechnology discoveries for environmental performance are easier to embrace and apply in an organisation that values innovation, cooperation, and environmental responsibility (Renn et al., 2006). However, a company culture that resists change, compartmentalizes cognitive processes, and focuses on the present may hinder nanotechnology-based solutions and environmental sustainability (Cummings et al., 2021). Licup et al. (2021) study suggests company culture will moderate nanotechnology innovation's environmental impact. The importance of a sustainable and technologically advanced environment is highlighted.

H3. *Organizational culture significantly mediates the relationship of nanotechnology innovation and environmental performance.*

Government pressure, nanotechnology innovation, and environmental performance are linked, according to empirical studies. Government environmental rules, norms, and incentives affect business innovation and sustainability, according to Raeesi Nafchi et al. (2021). Strict environmental legislation and enforcement benefit businesses, according to recent studies. Nanotechnology and other sustainable methods can reduce environmental damage, according to recent studies (Indiya et al., 2021). Nanotechnology research that reduces waste, energy, and pollution can get government subsidies, funding, and tax incentives (Ramogayane, 2022). Without rules, companies may be unwilling to invest in green technologies. Political pressure affects nanotechnology innovation and environmental performance, according to extensive study (Harsanto et al., 2023). A recent study found that political pressure affects nanotechnology innovation and environmental performance. Tjebane et al. (2022) found that government policies affect business investment, innovation, and environmental goals. Due to environmental limitations, corporations must adopt greener technology and procedures. Huang et al. (2022) found that nanotechnology can improve innovation and environmental performance. Nanotechnology may improve the environment. Government aid and strong regulations may limit business goals and reduce reform urgency (Reyes Ruiz, 2023). Political pressure may affect nanotechnology innovation and the environment. Government rules and regulations are essential for technical innovation and environmental sustainability.

H4. *Government pressure significantly moderates the relationship of nanotechnology innovation and environmental performance.*

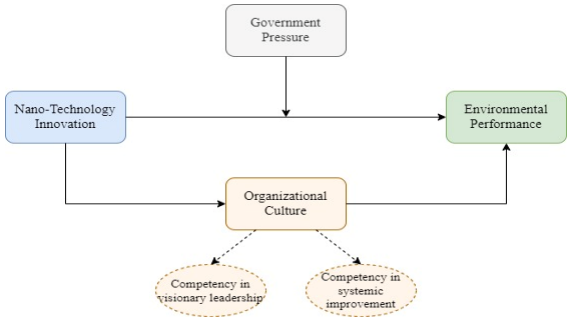

Figure 1: Research Model.

3. Methodology

The study was conducted in the Kingdom of Saudi Arabia, with a focus on those with expertise in the printing and coatings sector who use nanotechnology. The study involved 187 employees from various companies in the industry. The variables employed in this study were adapted from earlier research to ensure validity and reliability. Measures of company culture, environmental performance, political pressure, and nanotechnology innovation were explicitly utilized. These scales have been previously validated and are well-regarded in the literature. This research has used three items scale of Zwirtes et al. (2014) to measure the nano-technology innovation. Moreover, government pressure was measure on four items scale in this research (Wang et al., 2021). Organizational culture was measure on eight items scale (three items of which were dedicated to measure competence in visionary leadership, and five were for competence in systemic improvement); the scale was adopted from the work of Boychuk et al. (2017). The environmental performance was measured on a six items scale in this research (Wang et al., 2021). Data was collected through a computerized self-administered survey. This study explored various aspects including attitudes towards environmental performance, company culture, political pressure, and nanotechnology innovation. Participants were provided with clear instructions on informed consent prior to taking the survey.

Data analysis was done with STATA-SEM. Hypotheses with many components and complicated variable connections can be tested using structural equation modeling. To examine political pressure, company culture, environmental performance, and nanotechnology innovation, the data was thoroughly examined. Several precautions were taken to ensure measuring equipment reliability. First, scales with demonstrated validity and reliability in prior studies were carefully selected. To test survey question clarity, a small sample participated in a pilot research. Cronbach's alpha was used to assess the study's scales' validity. Demographic data were utilized as statistical controls in SEM models to support conclusions. Age, gender, work experience, job title, and education are typical demographic data. These criteria were carefully evaluated to assure precision and minimize possible influences affecting the outcomes.

4. Results

Table 1's results provide light on the consistency and reliability of the study model's quantifiable variables. Hair et al. (2017) found that all variables had Cronbach's Alpha values over 0.7.

Variable internal consistency dependability looks good. Cronbach's Alpha of 0.789 indicates strong reliability for nanotechnology innovation issues. Government pressure, competence culture, and environmental performance have Cronbach's Alpha coefficients of 0.825, 0.864, and 0.852. Three variables have great internal consistency. This study shows that the data accurately represents the concepts being assessed, enhancing the dependability of the variable evaluation tool.

Table 1: Cronbach's Alpha.

Variable	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Nano-technology Innovation	0.789	0.755	0.625
Government Pressure	0.825	0.887	0.566
Competency Culture	0.864	0.827	0.547
Environmental Performance	0.852	0.816	0.575

All variables' composite reliability coefficients surpassed 0.7, confirming the measurement model's internal consistency (Fornell & Larcker, 1981). Composite reliability coefficients measure concept latent variable consistency with items, according to Hair et al. (2017). Composite dependability scores of 0.755, 0.887, 0.827, and 0.816 indicate dependable and consistent monitoring of nanotechnology innovation, government pressure, competence culture, and environmental performance. Convergent validity is assumed for any AVE values > 0.5 (Hair et al., 2017). The AVE reveals that the measured constructs are different by measuring variance capture relative to measurement error. Validity and reliability evaluations prove the measurement model's endurance and comfort researchers about data quality for analysis.

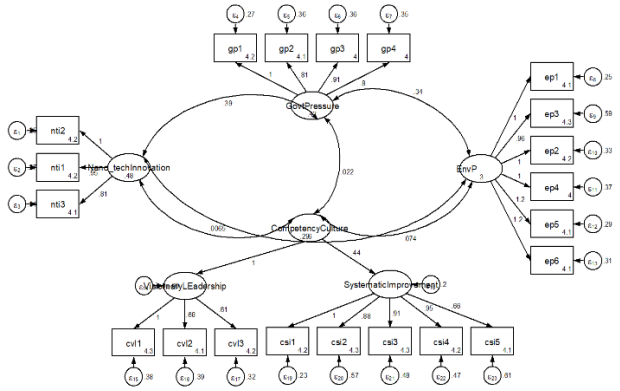

Figure 2: Estimated Model.

Confirmatory factor analysis (CFA) results in Table 2 are critical for measuring model validity. Standardized factor loadings (OIM Coef.) for indicator items on their latent constructs show visible variable-construct correlation. Statistically significant factor loadings show that indicator variables properly measure concepts. All three nanotechnology innovation (NTI) indicator items (NTI1, NTI2, NTI3) have substantial factor loadings (0.566 to 0.770, $p < 0.001$), confirming the construct's validity. The indicator items for government pressure (GP), competency culture (CVL), and environmental performance (EP) reinforce the validity of these categories, with factor loadings ranging from 0.330 to 0.921 ($p < 0.001$). The study's measuring approach was validated since the factors accurately reflect environmental performance, competency culture, government pressure, and nanotechnology innovation.

Table 2: Confirmatory Factor Analysis.

Measurement	OIM Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
NTI1	1	(constrained)				
NTI2	0.770	0.071	10.959	0.000	0.649	0.935
NTI3	0.566	0.063	9.038	0.000	0.455	0.710
GP1	1	(constrained)				
GP2	0.901	0.082	11.050	0.000	0.761	0.885
GP3	0.708	0.071	10.049	0.000	0.585	0.873
GP4	0.330	0.066	5.075	0.000	0.207	0.472
CVL1	1	(constrained)				
CVL2	0.713	0.061	11.184	0.000	0.610	0.857
CVL3	0.857	0.078	10.511	0.000	0.724	0.842
CSI1	0.731	0.085	8.654	0.000	0.580	0.924
CSI2	0.816	0.066	12.465	0.000	0.706	0.973
CSI3	0.892	0.066	13.088	0.000	0.786	0.852
CSI4	0.807	0.066	11.665	0.000	0.696	0.964
CSI5	0.921	0.072	12.920	0.000	0.802	0.885
EP1	1	(constrained)				
EP2	0.782	0.063	11.953	0.000	0.677	0.933
EP3	0.857	0.060	13.737	0.000	0.760	0.804
EP4	0.758	0.072	14.251	0.000	0.733	0.944
EP5	0.842	0.066	12.283	0.000	0.733	0.801
EP6	0.834	0.065	12.351	0.000	0.726	0.990

Table 3 shows measurement item fitness statistics and measurement model performance. The Composite Reliability Coefficient (CRC) measures the Original Sample values-based internal consistency of each latent construct based on indicator items. Nanotechnology innovation CRC values are between 0.791 and 0.874, indicating build reliability. CRC values of 0.580 to 0.676 indicate moderate to high government pressure internal consistency. The competency culture indicator items have CRC values from 0.615 to 0.901, demonstrating measurement reliability variation. CRC values range from 0.598 to 0.899, indicating moderate to high internal consistency in environmental performance. Despite the majority of constructs having good internal consistency, more research is needed to ensure the validity of assessment within these constructs due to the variation in CRC values among competency culture and environmental performance indicator items. The Original Sample values also assess the measurement model's applicability and guide future revisions to improve model fit and dependability.

Table 3: Measurement Items Fitness Statistics.

Variable	Indicator	Original Sample
Nano-technology Innovation	NTI1	0.851
	NTI2	0.874
	NTI3	0.791
Government Pressure	GP1	0.676
	GP2	0.668
	GP3	0.593
	GP4	0.580
Competency Culture	CVL1	0.615
	CVL2	0.901
	CVL3	0.795
	CSI1	0.789
	CSI2	0.821
	CSI3	0.839
	CSI4	0.683
	CSI5	0.660
Environmental Performance	EP1	0.873
	EP2	0.899
	EP3	0.809
	EP4	0.757
	EP5	0.889
	EP6	0.598

The measurement model's fit statistics in Table 4 show how well it fits the data. The likelihood ratio chi-square value of 11471.839 indicates a significant difference ($p < 0.001$) between the proposed model and a fully fitted saturated model. A baseline model without correlations yields a significantly different chi-square statistic (12393.552) compared to the suggested model ($p < 0.001$). The suggested model may not match the data completely, but it matches it better than the baseline and saturated models. Remember that chi-square statistics rely on sample size, hence more fit indices are needed to evaluate model fit. The likelihood ratio and baseline chi-square statistics' statistically significant p-values imply that the suggested measurement model differs from the saturated and baseline models, providing preliminary verification of its applicability.

Table 4: Chi-square Fit statistics.

Fit statistic	Value	Description
Likelihood ratio	11471.839	model vs. saturated
p > chi2	0.000	
chi2_bs (2356)	12393.552	baseline vs. saturated
p > chi2	0.000	

Table 5 shows the saturated and estimated models' goodness-of-fit statistics and R-square values for each latent variable. Lower standardized root mean square residual (SRMR) values indicate better model fit compared to observed and model-implied covariance matrices. A SRMR of 0.047 indicates that the saturated model fits the data well. The estimated model's SRMR climbs to 0.066, indicating a little model fit drop. Despite this small increase, the SRMR value remains within an acceptable range, indicating that the calculated model fits the data well. R-square values for each latent variable in the model show how much exogenous variables explain endogenous variable variance. Nanotechnology innovation has an R-square score of 0.505, indicating that exogenous causes explain 50.5% of variation. Government pressure has an R-square value of 0.596, indicating that external variables explain 59.6% of the variance. Competency culture has an R-square score of 0.227, showing that exogenous variables explain 22.7% of the variance. These R-square values show how much external factors explain endogenous variable variance, proving the model's ability to describe construct linkages.

Table 5: Model Goodness of Fit Statistics.

Variable	Saturated Model	Estimated Model	R Square
SRMR	0.047	0.066	
Nano-technology Innovation			0.505
Government Pressure			0.596
Competency Culture			0.227

The relationship between nanotechnology innovation, environmental performance, and organizational culture is displayed in Table 6's direct path analysis results. Standard errors (Std. Err.) indicate estimate precision, while standardized path coefficients (OIM Coef.) display the direction and intensity of variable relationships. With a path coefficient of 0.214 ($p < 0.001$), there is a strong and positive correlation between environmental performance and nanotechnology innovation. This implies that an organization's environmental performance is enhanced by nanotechnology innovation. The significance of the link is confirmed by the path coefficient's 95% confidence interval (0.417, 0.321), which does not include zero. Businesses that make innovative investments in nanotechnology may see improvements in their environmental performance.

Table 6: Direct Path Analysis.

	OIM Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Nanotechnology innovation has a significant impact on the environmental performance of an organization.	0.214	0.104	2.111	0.001	0.417	0.321
Nanotechnology innovation has a significant impact on the organizational culture.	0.895	0.075	2.948	0.000	0.530	0.801

Organizational culture has a favorable and significant impact on nanotechnology innovation, as indicated by a path coefficient of 0.895 ($p < 0.001$). This suggests that nanotechnology innovation promotes creativity, teamwork, and environmental responsibility in organisations. Path coefficient's 95% confidence interval (0.530, 0.801) supports the association's relevance. Nanotechnology innovation-friendly companies are more likely to promote innovation and sustainable business practices. The direct path analysis shows that nanotechnology innovation profoundly impacts company culture and environmental performance. These findings demonstrate the importance of nanotechnology in organizational activities to foster a sustainable, innovative culture and positive environmental change.

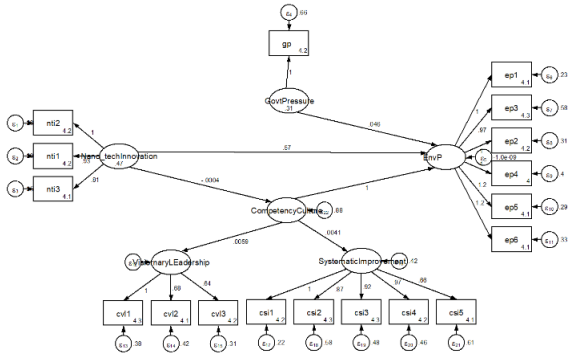

Figure 3: Structural Model for Path Analysis.

Table 7 provides helpful information about the moderating and mediating roles played by organizational culture and governmental pressure on environmental performance and nanotechnology innovation. Standard errors (Std. Err.) show estimation precision, while standardized path coefficients (OIM Coef.) show correlation direction and intensity. With a path coefficient of 0.212 ($p = 0.008$), organizational culture significantly mediates nanotechnology innovation and environmental performance. This shows that organizational culture is crucial to translating nanotechnology innovation into environmental performance. The path coefficient's 95% confidence interval (0.413, 0.318) supports the mediating effect's importance. Firms with supportive organizational cultures are more likely to benefit from nanotechnology innovation's environmental benefits because they encourage

employees to adopt sustainable practices and promote good environmental change.

Table 7: Mediating and Moderating Path Analysis.

	OIM Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Organizational culture significantly mediates the relationship of nanotechnology innovation and environmental performance.	0.212	0.103	2.088	0.008	0.413	0.318
Government pressure significantly moderates the relationship of nanotechnology innovation and environmental performance.	0.885	0.074	2.916	0.000	0.524	0.792

A path coefficient of 0.885 ($p < 0.001$) suggests government pressure considerably moderates the association between nanotechnology innovation and environmental performance. Government pressure may strengthen the link between nanotechnology innovation and environmental performance. The route coefficients of 95% shows a significant moderating influence with confidence intervals of 0.524, 0.792. Hence, it can be concluded that the progress in nanotechnology significantly improves the environmental performance of organizations and businesses operating under up-to-date environmental policies. This research findings highlight the significant impact of government pressure and organizational culture on environmental consequences of nanotechnology innovation.

5. Discussion

Nanotechnology has emerged as a viable approach to solving environmental concerns and spurring innovation across industries, with the potential to greatly improve sustainability results. Government pressure and business culture both have an impact on how companies use nanotechnology to meet environmental goals. The confirmed study hypotheses explain how political pressure, environmental performance, corporate culture, and nanotechnology innovation interact within companies. Understanding the relationships among these components is essential to illustrating how developments in nanotechnology could facilitate the process of improving the environmental circumstances of businesses.

The validation of the initial and subsequent hypotheses has uncovered the noteworthy influence of nanotechnology innovation on both environmental performance and company culture. Companies may enhance their environmental performance and sustainability by using nanotechnology. Nanomaterials are an effective way to achieve environmental and regulatory goals. Minimizing waste, improving resource use, and limiting pollution can help organizations achieve sustainability goals. The confirmation of the second hypothesis shows that corporate culture promotes forward-thinking, eco-friendly business initiatives. A flexible, team-oriented, and environmentally sensitive organisational culture advances nanoscale technologies that increase environmental performance (Huang et al., 2023). Leadership is crucial to building corporate culture. Reyes Ruiz (2023) found that forward-thinking leaders value creativity, adaptability, and new ideas.

These hypotheses underscore the relationship between environmental performance, nanotechnology innovation, and organizational culture. The influence of organizational culture on how employees perceive, act, and make decisions about adopting new technologies and sustainable practices is of great importance. Therefore, nanotechnology innovation and environmental performance are closely influenced. A company must promote support, environmental responsibility and stewardship, experimentation, and continuous learning to successfully integrate nanotechnology into processes and products (Ramogayane, 2022). Vickram et al. (2023) study concluded that government R&D expenditure and eco-friendly technologies and methods may improve nanotechnology's environmental performance and innovation. According to Soomro et al. (2023), emphasizing the relevance of eco-friendly corporate practices and technologies can boost nanotechnology innovation and environmental performance.

Several studies have provided evidence for the third and fourth hypotheses, which examine the impact of business culture and political pressure on environmental performance and nanotechnology innovation. Business culture may link nanotechnology innovation with environmental performance. Nanotechnology needs better acceptability, application, and durability. This research language promotes creativity, teamwork, and environmental consciousness. The firm promotes innovation, learning, and responsible management. Indiya et al. (2021) analysis showed the company's environmental improvement. According to Li et al. (2023), political pressure may impact nanotechnology innovation and environmental performance. Due to severe regulations and enticing incentives, many firms adopt green goods and processes. linked nanotechnology to environmental performance.

The study's findings have a significant effect on companies who print and cover products using nanotechnology. These factors are important inside the boundaries of the Kingdom of Saudi Arabia (KSA). The field's goals of sustainability stand to gain a great deal from new technologies, as demonstrated by the positive relationship found between advances in nanotechnology and environmental performance. Nanotechnology can be used to reduce environmental damage and promote economic growth, among other benefits. This is particularly true in view of the Kingdom of Saudi Arabia's ambitious Vision 2030 strategy, which emphasizes the importance of environmental sustainability and economic diversification. Based on these findings, businesses in the Kingdom of Saudi Arabia (KSA) are advised to invest research and development of nanotechnology applications as a top priority in order to enhance their environmental performance. This will be consistent with the country's overarching sustainability objectives.

Further highlighting the importance of contextual factors in influencing the relationship between nanotechnology innovation and environmental performance in Saudi Arabia are the moderating effects of government pressure and the mediating influence of organizational culture. In the Kingdom of Saudi Arabia (KSA), organizations need to be creative and environmentally aware to keep up with

the rapidly evolving regulatory environment and the growing importance of sustainability programs. Policymakers and regulatory bodies can play a major role in promoting and facilitating the adoption of environmentally friendly technologies by implementing supportive legislation and offering incentives. There are two approaches to this: developing incentive programs and regulatory frameworks. Establishing cooperation between academic, commercial, and public entities may help the Kingdom of Saudi Arabia fully use the transformative potential of nanotechnology innovation. By doing this, the Kingdom would be able to address environmental issues and promote sustainable development in accordance with Vision 2030's objectives.

These theories show how nanotechnology, business ethics, environmental issues, and political power are linked. Employee innovation and sustainability depend on company culture. Environmental change may boost organizational culture. Study nanotechnology and environmental stewardship. Government pressure on environmental performance and nanotechnology innovation can impact company R&D and eco-friendly practises and technologies. Nanotechnology, strong legal frameworks, and a good company culture may help organizations achieve sustainable development. Implementing the ideas provides a complete examination of the complex interaction between business culture, environmental efficiency, political influence, and nanotechnology advancement. Nanotechnology and excellent company culture can boost environmental impact, competitiveness, and stakeholder satisfaction. Government regulations strongly impact environmental nanotechnology adoption. For innovation and sustainable development, governance, organization, and stakeholder participation is crucial. To accomplish sustainable development goals and beneficial environmental change, several aspects must be considered. They include political pressure, business culture, technical innovation, and sustainability.

6. Conclusion

A thorough examination of this research hypotheses revealed the complex interaction between organizational culture, government influence, environmental performance, and nanotechnology innovations. According to the findings, incorporating nanotechnology can improve organizational situations. Nanotechnology and a healthy corporate culture can boost environmental performance while maintaining competitiveness and shareholder returns. This research emphasizes the need of collaboration across governments, organizations, and stakeholders in order to achieve innovation and sustainable development goals. It emphasizes how laws and regulations encourage nanotechnology for environmental sustainability. The findings help us understand how nanotechnology may improve the environment. They stress the need of holistic methods that take into account company culture, political influences, technological advancements, and environmental aims. Organizations can use nanotechnology to address environmental issues and achieve sustainable development. Continuous study and collaboration can create a more resilient and sustainable world for future generations.

Implications of the Study

Environmental performance, organizational culture, government pressure, and nanotechnology innovation interact in complex ways in organizational contexts. This study has substantial theoretical implications. By showing how nanotechnology innovation affects environmental performance, the results advance theoretical frameworks like institutional theory, innovation diffusion theory, and organizational culture theory. Organizations must build a creative and environmentally conscious culture because organizational culture is a critical mediator in translating technology discoveries into sustainable outcomes. Government pressure was found to be a significant moderator, highlighting the importance of institutional and regulatory elements outside the corporation in deciding how companies adopt and deploy environmentally sustainable practices and technology. The theoretical insights presented here will help sustainable innovation researchers comprehend contextual elements that affect technical innovation and environmental performance. Environmental sustainability groups, policymakers, and others may benefit from the study's findings. Organizations may promote innovation, teamwork, and environmental stewardship by understanding how organizational culture influences sustainability. Sustainability projects and employee involvement may require training, communication, and cross-functional cooperation. Lawmakers may use government pressure data to create green technology incentives and rewards. Sustainable regulations can motivate companies to innovate and enhance their environmental performance. This helps companies achieve sustainability. This report advises firms on nanotechnology for environmental sustainability during theoretical development and implementation.

Nanotechnology research aids governments and organizations in environmental sustainability. Findings emphasize green and creative corporate cultures. Such ideas may improve corporate creativity, teamwork, and sustainability. Sponsoring staff training, developing cross-functional sustainability teams, and incorporating sustainability into performance assessments and awards are examples. Sustainable and innovative organizations may promote nanotechnology adoption and deployment to improve environmental performance. The analysis also cites government pressure on enterprises to adopt green technologies. This research can help governments create nanotechnology innovation incentives and policies for environmental sustainability. Such as tax incentives, grants, and finance for nanotechnology-based environmental solutions and regulations supporting green industrial materials and technologies. Innovative sustainability concepts and laws may encourage nanotechnology research and sustainable business practices. Sustainability stakeholders across industries and enterprises are affected by the study. The findings can help businesses, trade groups, and NGOs enhance sustainable technology and practices. These stakeholders may promote sustainable technology and meet sustainability goals by highlighting nanoscale innovation's environmental benefits and best practices. In conclusion, this study's positive findings help

decision-makers, organizations, and interested parties use nanotechnology to improve environmental sustainability and promote a sustainable future.

Limitations and Future Research Directions

This study highlights the linkages between company culture, government pressure, nanotechnology innovation, and environmental performance, but future research should address various constraints. Since the study only uses cross-sectional data, it is harder to determine why the factors are correlated. Experimental or longitudinal designs may be used to identify causal correlations and better understand company culture, political pressure, nanotechnology innovation, and environmental performance over time. Self-reported data from one source raises common method bias and social desirability in the study. To provide a more complete sustainability assessment, future research might combine a range of data sources with objective environmental performance assessments such pollution levels or resource consumption data. The study also targets a single business or location, limiting its applicability. To understand the dynamics, future research may examine government pressure, firm culture, nanotechnology innovation, and environmental performance across sectors, industries, and geographies.

Research may improve this study's findings and fix its flaws. First, future research may examine how employee attitudes, beliefs, and motivations affect the adoption and use of revolutionary nanotechnology for environmental sustainability. Personality, external constraints, and organizational culture can affect policies and solutions. Nanomaterials and nanodevices research may affect industry and application environmental performance. Researchers can uncover sustainable technology investment and innovation opportunities using nanoscale technologies' features and environmental benefits. Future research may examine how context affects environmental performance, business culture, political pressure, and nanotechnology innovation. Industry competition, constraints, and stakeholder pressure. Researchers may provide firms and governments more nuanced nanotechnology innovation suggestions to improve environmental sustainability by including these contextual factors. To conclude, overcoming these obstacles and exploring these research areas can help us understand the complex relationship between organisational dynamics, regulatory frameworks, environmental sustainability, and nanotechnology innovation. Innovation adoption and sustainable development will improve.

References Acknowledgement

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Appendix 1

Nano-technology Innovation:

1. To what extent does your organization invest in research and development of nanotechnology applications?
2. How frequently does your organization introduce new nanotechnology-based products or services?
3. How innovative is your organization in applying nanotechnology to improve processes or solve problems?

Government Pressure:

1. How strongly does government regulation influence decision-making within your organization?
2. To what extent does government policy incentivize or discourage the adoption of environmentally friendly technologies in your organization?
3. How closely does your organization monitor government regulations related to environmental sustainability?
4. How much pressure does the government exert on your organization to comply with environmental standards and regulations?

Organizational Culture: Competence in Visionary Leadership:

1. To what extent does leadership in your organization inspire and motivate employees to embrace innovative ideas and technologies?
2. How well does leadership in your organization communicate a clear vision for sustainability and environmental responsibility?
3. How effectively does leadership in your organization encourage risk-taking and experimentation to drive innovation?

Competence in Systemic Improvement:

1. How well does your organization encourage collaboration and teamwork to implement sustainability initiatives?
2. To what extent does your organization promote continuous improvement and learning in environmental practices?
3. How effectively does your organization integrate sustainability goals into strategic planning and decision-making processes?
4. How supportive is your organization of employee initiatives aimed at improving environmental performance?
5. How well does your organization recognize and reward contributions to environmental sustainability efforts?

Environmental Performance:

1. How effectively does your organization manage and reduce its carbon footprint?
2. To what extent does your organization minimize waste and pollution in its operations?
3. How successful is your organization in conserving natural resources and promoting energy efficiency?
4. How well does your organization comply with environmental regulations and standards?
5. How proactive is your organization in addressing environmental challenges and implementing sustainable practices?
6. How transparent is your organization in reporting its environmental performance to stakeholders?