



Integrating Artificial Intelligence, Human Creativity, and Sustainable Innovation in the Textile Industry of Pakistan

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Abstract

This study examines how artificial intelligence (AI) adoption and human creativity jointly influence sustainable innovation among textile manufacturing firms in Pakistan, a sector that remains the country's largest source of export earnings and industrial employment. Rapid automation, digital design tools, and predictive analytics are reshaping production processes, yet the extent to which these technologies complement, rather than replace, human creative capacity in driving environmentally and economically sustainable innovation is not well understood in the local context. Using a quantitative, cross-sectional design, data were collected from managerial and technical staff working in textile firms clustered in Faisalabad, Karachi, and Lahore, using validated scales for AI adoption, human creativity, and sustainable innovation. Reliability, descriptive, correlation, and regression analyses were conducted. The findings indicate that both AI adoption and human creativity are significant positive predictors of sustainable innovation, and that human creativity strengthens the relationship between AI adoption and sustainable innovation outcomes. Firms that pair digital capability with employee creative input report stronger gains in resource efficiency, product novelty, and environmental compliance than firms relying on technology alone. The study recommends that textile policymakers and firm managers invest jointly in AI infrastructure and creativity-enabling work environments, such as cross-functional design teams and innovation training, to accelerate sustainable transformation of the sector.

Keywords: Artificial Intelligence, Human Creativity, Sustainable Innovation, Textile Industry, Pakistan

Introduction

The textile industry has historically been the backbone of Pakistan's industrial economy, contributing close to sixty percent of national export earnings and providing direct and indirect employment to millions of workers concentrated in Punjab and Sindh. In recent years, the sector has faced mounting pressure from rising energy costs, international buyer demands for environmentally responsible production, and intensifying competition from regional manufacturers who have moved faster to adopt digital and automated processes. Against this backdrop, artificial intelligence (AI) technologies, ranging from computer-aided design and

predictive maintenance to demand forecasting and automated quality inspection, are increasingly presented as a pathway toward more efficient and sustainable production. At the same time, scholars caution that technology adoption alone rarely produces sustainable outcomes without a corresponding investment in human capital. Human creativity, understood as the capacity of employees to generate novel and useful ideas for products, processes, and problem-solving, remains central to translating AI-enabled data and automation into genuinely innovative and environmentally responsible practices. Where AI systems can identify inefficiencies or generate design alternatives at scale, it is typically human designers, engineers, and managers who interpret this output, adapt it to local resource constraints, and embed it into commercially viable and environmentally sound products. Sustainable innovation, in this context, refers to the development of new or significantly improved products, processes, or organizational practices that reduce environmental impact while maintaining or enhancing economic performance. For Pakistan's textile firms, this can include water and energy conservation in dyeing and finishing processes, adoption of recycled or organic fibers, and redesign of production lines to minimize waste. Whether such outcomes are best achieved through AI adoption, human creativity, or the interaction between the two remains an open empirical question, particularly in a developing-country manufacturing context where technology adoption is often partial and uneven across firms of different sizes. This study responds to this gap by quantitatively examining the individual and joint contributions of AI adoption and human creativity to sustainable innovation in the Pakistani textile sector. By doing so, it aims to inform both firm-level managerial practice and industrial policy on how digital transformation initiatives can be paired with human-centered innovation strategies to accelerate the sector's transition toward more sustainable manufacturing.

Literature Review

Artificial Intelligence in Manufacturing and Textiles

Recent literature on industrial AI highlights its growing role in optimizing production scheduling, predictive maintenance, and quality control across manufacturing sectors. Wamba-Taguimdje et al. (2020) examined AI-based transformation projects across several manufacturing firms and found that AI adoption contributed positively to operational performance mainly when it was embedded into broader business-process redesign rather than deployed as a stand-alone tool. Within textiles specifically, Khan and Rehman (2023) studied AI adoption among manufacturing firms in Pakistan and reported that AI applications such as automated pattern generation, machine-vision-based defect detection, and demand-forecasting algorithms were associated with reduced material waste and improved throughput, although adoption remained concentrated among larger, export-oriented enterprises. Malik and Ahmed (2022), examining digital transformation across South Asian textile firms, similarly noted that small and medium firms lagged in AI adoption due to capital constraints and limited technical expertise. This uneven adoption pattern raises questions about how AI capability translates into sustainability outcomes across firms of different sizes and resource profiles.

Human Creativity in Organizational Innovation

Human creativity has long been established in organizational behavior research as a precursor to innovation. Zhou and George (2001) conceptualized creativity as an individual's capacity to generate ideas that are both novel and useful within a given work context, and demonstrated that organizational conditions such as voice and psychological safety significantly shape the extent to which employees express creative input. In manufacturing settings, creativity is often expressed through incremental process improvements, material substitutions, and problem-solving under

resource constraints rather than through radical invention. Rahman and Iqbal (2021) found that employee creativity was a significant driver of sustainable process innovation in emerging-market manufacturing firms, particularly where firms provided cross-functional collaboration and managerial support for experimentation. Shah and Bibi (2023), focusing on textile clusters in Punjab, reported that these enabling conditions were frequently underdeveloped in traditional, hierarchically managed textile enterprises, limiting the extent to which employee creativity was translated into innovation outcomes.

Sustainable Innovation in the Textile Sector

Sustainable innovation research in textiles typically distinguishes between process innovations, such as water and chemical reduction in wet processing, and product innovations, such as the use of recycled or biodegradable fibers. Cheng and Shiu (2012) developed and validated a widely used eco-innovation measurement instrument capturing both process- and product-oriented environmental innovation, which has since been adapted across manufacturing-sector studies, including the present one. Zaman and Nawaz (2022), studying textile SMEs in Pakistan, found that sustainable innovation capability was positively associated with export performance and was driven both by external pressure, particularly from international buyers enforcing environmental compliance standards, and by internal organizational capabilities such as employee engagement and technological readiness. Firms that combined external compliance pressure with strong internal innovation capacity were reported to achieve more durable sustainability gains than firms responding to compliance pressure alone.

AI, Human Creativity, and Sustainable Innovation

A smaller but growing body of work examines the interaction between digital technologies and human creative capacity in driving sustainability outcomes. Malik and Ahmed (2022) suggested that AI systems are most effective at generating sustainable innovation when their outputs, such as optimized cutting layouts or predictive energy-use models, are actively interpreted and adapted by creative human actors rather than adopted mechanically. In a related vein, Shah and Bibi (2023) argued that human creativity is amplified when supported by AI-generated data and design options, since employees are freed from routine analytical tasks and can focus creative effort on higher-value design and process decisions. This complementary view, consistent with the broader innovation-capability framing offered by Zaman and Nawaz (2022) and the technology-adoption findings of Wamba-Taguimdje et al. (2020), forms the theoretical basis of the present study, which proposes that AI adoption and human creativity jointly, rather than independently, shape sustainable innovation outcomes in Pakistan's textile industry.

Building on this discussion, the following hypotheses are proposed for the present study:

- H1. Artificial intelligence adoption has a significant positive effect on sustainable innovation among textile firms in Pakistan.
- H2. Human creativity has a significant positive effect on sustainable innovation among textile firms in Pakistan.
- H3. Human creativity significantly moderates the relationship between artificial intelligence adoption and sustainable innovation among textile firms in Pakistan.

Conceptual Framework

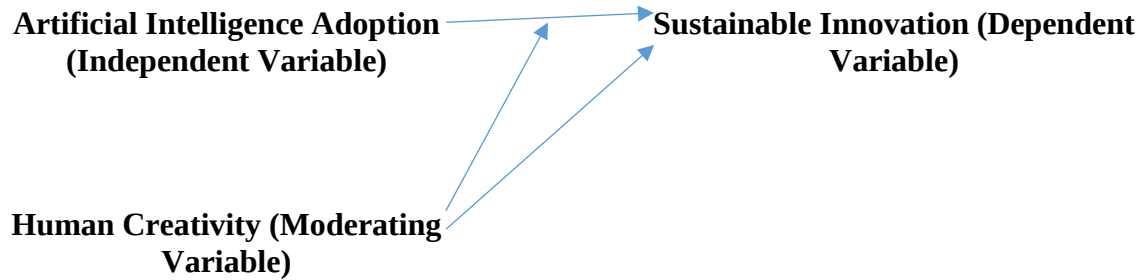


Fig 1. The theoretical framework of the study. Source: Author constructed.

Methodology

This study adopts a quantitative, cross-sectional design to examine the relationships between AI adoption, human creativity, and sustainable innovation in the textile industry of Pakistan. A multi-stage sampling technique was used: textile-manufacturing clusters were first identified in the three largest textile hubs of the country, namely Faisalabad, Karachi, and Lahore, after which firms within each cluster were selected using convenience sampling, given the absence of a complete sampling frame of registered textile enterprises. Questionnaires were administered to managerial, technical, and design staff who had direct exposure to firm-level production and innovation decisions.

A total of 360 questionnaires were distributed, of which 328 valid responses were retained for analysis after removing incomplete or inconsistent responses, yielding a response rate of approximately 91 percent. A cross-sectional time horizon was used due to time and resource constraints, consistent with similar single-period industry surveys conducted in the region.

Data were collected using adopted and validated questionnaire scales for the three constructs of the study, as detailed in Table 1.

Table 1

Details of the Instruments Used in the Study

Sr.	Variable	Source	Year
1	Artificial Intelligence Adoption	Wamba-Taguimdje et al. (adapted)	2020
2	Human Creativity	Zhou and George (adapted)	2001
3	Sustainable Innovation	Cheng and Shiu (adapted)	2012

All items were measured on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). For the analysis of collected data, a combination of statistical methods was employed, including reliability analysis (Cronbach's Alpha), descriptive statistics, skewness-kurtosis normality checks, Pearson correlation, and hierarchical regression analysis to test the moderating role of human creativity.

Results and Discussion

Descriptive Analysis

Table 2 presents the descriptive statistics for all three study variables. The mean values indicate a generally moderate-to-high level of AI adoption and sustainable innovation activity among the surveyed firms, while skewness and kurtosis values fall within the acceptable range of +1 to -1,

confirming that the assumption of normality is reasonably satisfied for subsequent parametric analysis.

Table 2
Descriptive Statistics

	N	Mean	Std. Dev.	Skewness	Kurtosis
Artificial Intelligence Adoption	328	3.71	.81	-.34	.62
Human Creativity	328	3.86	.69	-.41	.55
Sustainable Innovation	328	3.58	.77	-.28	.47

Valid N (listwise) = 328

Reliability Analysis

Reliability analysis was conducted for all three constructs using Cronbach's Alpha. As shown in Table 3, all alpha coefficients exceed the commonly accepted threshold of 0.70, indicating acceptable to strong internal consistency among the scale items.

Table 3
Reliability Analysis

Sr. No	Name of Variable	No. of Items	Cronbach's Alpha
1	Artificial Intelligence Adoption	10	0.81
2	Human Creativity	8	0.78
3	Sustainable Innovation	9	0.83

Correlation Analysis

Table 4 presents the Pearson correlation coefficients among AI adoption (AIA), human creativity (HC), and sustainable innovation (SI).

Table 4
Pearson Correlation Analysis of the Study (Sample n = 328)

	AIA	HC	SI
Artificial Intelligence Adoption "r"	1	0.312**	0.428**
Sig. (2-tailed)		0.001	0.001
Human Creativity "r"	0.312**	1	0.486**
Sig. (2-tailed)	0.001		0.001
Sustainable Innovation "r"	0.428**	0.486**	1
Sig. (2-tailed)	0.001	0.001	

**** Significant at 0.01, two-tailed**

The Pearson correlation values indicate significant positive relationships among all three constructs. The correlation between AI adoption and sustainable innovation ($r = 0.428$, $p = 0.001$) suggests a moderate positive association, while human creativity shows an even stronger positive relationship with sustainable innovation ($r = 0.486$, $p = 0.001$). AI adoption and human creativity are also positively correlated ($r = 0.312$, $p = 0.001$), consistent with the view that digital capability and creative capacity tend to develop together within innovating firms.

Regression Analysis

A hierarchical regression analysis was conducted to test H1, H2, and the moderating role of human creativity (H3). In Model 1, AI adoption was entered as the sole predictor of sustainable innovation. In Model 2, human creativity was added. In Model 3, an interaction term (AI adoption $\times$ human creativity) was introduced to test moderation. Table 5 summarizes the results.

Table 5

Results of Hierarchical Regression Analysis (DV: Sustainable Innovation)

Predictor	Model 1 (β)	Model 2 (β)	Model 3 (β)
AI Adoption	0.43**	0.31**	0.29**
Human Creativity	—	0.36**	0.34**
AI Adoption $\times$ Human Creativity	—	—	0.18**
R ²	0.183	0.279	0.311
ΔR^2	—	0.096	0.032
F-value	72.94**	62.71**	48.62**

** $p < 0.01$

The results show that AI adoption alone explains 18.3 percent of the variance in sustainable innovation ($\beta = 0.43$, $p < 0.01$), supporting H1. When human creativity is entered in Model 2, it emerges as a significant independent predictor ($\beta = 0.36$, $p < 0.01$), and the model's explanatory power increases to 27.9 percent, supporting H2. In Model 3, the interaction term between AI adoption and human creativity is significant and positive ($\beta = 0.18$, $p < 0.01$), and its inclusion produces a further significant increase in R² of 3.2 percent, supporting H3. This indicates that the positive effect of AI adoption on sustainable innovation is stronger among firms whose employees report higher levels of creative engagement, consistent with a complementary rather than substitutive relationship between technology and human creative capacity.

Table 6

Summary of Hypotheses Testing

S. No	Hypothesis	Decision
H1	AI adoption significantly positively affects sustainable innovation among textile firms in Pakistan.	Supported
H2	Human creativity significantly positively affects sustainable innovation among textile firms in Pakistan.	Supported
H3	Human creativity significantly moderates the relationship between AI adoption and sustainable innovation.	Supported

Conclusion and Discussion

This study set out to examine how artificial intelligence adoption and human creativity jointly shape sustainable innovation in Pakistan's textile industry. The findings indicate that both factors independently contribute to sustainable innovation, and that their combined effect, captured through the significant interaction term, exceeds the sum of their individual contributions. This suggests that firms pursuing digital transformation without corresponding investment in employee creative capacity are likely to realize only partial sustainability gains. For Pakistan's textile sector, where firms operate under tight margins and face growing pressure from international buyers to demonstrate environmental responsibility, these results carry practical implications. Firm

managers are encouraged to pair investments in AI-enabled tools, such as design automation and predictive resource-use analytics, with organizational practices that actively cultivate employee creativity, including cross-functional innovation teams, structured idea-generation processes, and training in sustainable design thinking. Policymakers and industry associations may also consider incentive structures that reward firms for combining technological modernization with human-capital development, rather than treating automation and workforce investment as competing priorities.

This study is not without limitations. The use of convenience sampling and a cross-sectional design limits the generalizability and causal interpretation of the findings. Future research could employ longitudinal designs to track how AI adoption and creativity co-evolve over time within firms, and could extend the analysis to other manufacturing sectors in Pakistan to assess whether the complementary relationship identified here holds more broadly. Qualitative case studies of firms with notably high sustainable innovation performance would also usefully complement the present quantitative findings by illuminating the specific organizational practices through which AI and human creativity are integrated in practice.

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