

## Quality 4.0 Systems and Sustainable Competitive Performance: The Mediating Effects of Technological Innovation and Organizational Ambidexterity

Yasir Khalid<sup>1</sup>, Abdulsalam Kamara<sup>2</sup>, Ainee Waqas<sup>3</sup>

### Abstract

The study examined how Quality 4.0 systems affect sustainable competitive performance and how organisational ambidexterity and technological innovation serve as mediators. The study was deductive, positivist, cross-sectional, and quantitative. Primary data were collected from 412 managers of manufacturing organisations that used digital quality management techniques and Industry 4.0 technology, via structured questionnaires. IBM SPSS Statistics 29 and SmartPLS 4 were used to evaluate the data. Descriptive statistics, reliability analysis, validity evaluation, correlation analysis, and structural equation modelling (SEM) were used to test the suggested relationships. According to the findings, Quality 4.0 Systems significantly improved Sustainable Competitive Performance ( $\beta = 0.421$ ,  $t = 8.763$ ,  $p < 0.001$ ). Technological Innovation ( $\beta = 0.768$ ,  $p < 0.001$ ) and Organizational Ambidexterity ( $\beta = 0.741$ ,  $p < 0.001$ ) were also significantly impacted by Quality 4.0 Systems. Technological Innovation ( $\beta = 0.294$ ,  $p < 0.001$ ) and Organizational Ambidexterity ( $\beta = 0.253$ ,  $p < 0.001$ ), which partially moderated the relationship between Quality 4.0 Systems and Sustainable Competitive Performance, had a significant and favorable impact on Sustainable Competitive Performance. The structural model showed high explanatory power ( $R^2 = 0.768$ ), accounting for 76.8% of the variance in the dependent variable. Through digital capabilities, innovative performance, strategic flexibility, and operational excellence, the study found that combining Quality 4.0 Systems, technological innovation, and organisational ambidexterity enhanced sustained organisational competitiveness.

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## **Introduction**

By integrating state-of-the-art digital technologies into production, quality control, and strategic decision-making, the Fourth Industrial Revolution radically altered company operations. Organizations increased operational efficiency through the use of artificial intelligence, the Internet of Things, big data analytics, cloud computing, machine learning, blockchain, cyber-physical systems, and digital twin technology. Quality 4.0, which integrates quality management with intelligent digital technologies to guarantee continuous improvement, drive quality, and enable data-driven decision-making, emerged from the transformation of quality management. A more proactive, real-time strategy with predictive quality maintenance, automated process control, and intelligent quality analytics replaced earlier quality management techniques that concentrated on inspection and defect avoidance with Quality 4.0. According to Aichouni et al. (2024), Radziwill (2018), and Sony et al. (2021), Quality 4.0 enabled the company to achieve greater responsiveness, consistent products and processes, improved customer satisfaction, and reduced waste in business operations in a fiercely competitive market.

The greater difficulty of global competition also led to a shift in organizational priorities, from short-term operational performance to long-term maintenance of the competitive position. Sustainable competitive performance was defined as the ability to keep a company in the market through constant Innovation and operational excellence, customer satisfaction, environmental protection, and an adaptable strategy. Organizations recognized that a key component of becoming competitive was not only investing in technology but also integrating digital technologies into their management systems, quality systems, and processes. Recent research showed that organisations with digital quality management systems demonstrated better operational resilience, flexibility, innovation outcomes, and organisational performance than organisations without digital quality management systems but with conventional quality management systems (Ed-Dafali et al., 2023; Sony et al., 2021; Aichouni et al., 2024). Effectively, recent empirical evidence indicates that promoting organizational conditions for

quality 4.0, technological innovations, and ambidextrous capabilities enhances these capabilities, thereby strengthening sustainable organizational performance (Bag et al., 2022; Gomes et al., 2020; Sarmad et al., 2024).

Despite the present excitement surrounding Quality 4.0, little is known about how digital quality initiatives generate this advantage and how sustainable competitive performance is connected to this type of "quality." While a limited number of studies examined the relationship between technical innovation and organisational ambidexterity within the same model, prior research often focused on direct correlations between Industry 4.0 technologies and organisational performance factors. It is anticipated that the outcomes will enhance the calibre of the Quality 4.0 literature base and offer a self-explanatory framework for integrating innovation capability, digital quality management, and dynamic organizational capabilities into a single framework to explain how businesses achieve long-term competitive advantage in this setting (Sony et al., 2021; Sarmad et al., 2024; Ed-Dafali et al., 2023).

### **Background of the Study**

Over the past ten years, businesses across a variety of industries, including manufacturing and services, have increasingly embraced digital technologies to improve product quality and operational efficiency. AI, cloud computing, big data analytics, cyber-physical systems, blockchain, machine learning, and the Internet of Things (IoT) have all been incorporated into business processes since the start of the Fourth Industrial Revolution. Quality 4.0, an invention that combined the fundamentals of conventional quality management with advanced digital solutions to create intelligent, data-driven, and extremely responsive quality management systems, was the result of this shift. In Quality 4.0, this signalled an organisation's shift from reactive quality inspection to proactive quality management, real-time monitoring, automated decision-making, and continuous learning (Sony et al., 2020; Radziwill, 2018; Aichouni et al., 2024). Quality 4.0 is a method shown to be important for maintaining an organisation's growth and competitive advantage in competitive business contexts (Bag et al., 2022; Sony et al., 2020; Ed-Dafali et al., 2023).

Another significant change was technological Innovation and its contribution to organizational success. Operational and customer data were driven by a high volume of

information generated by quality 4.0 systems, which could enable innovation activities, accelerate product development, increase manufacturing flexibility, and offer more specific solutions to customers. As more organizations learned that digital quality programs can stimulate technological Innovation through experimentation, better information, and evidence-driven decision-making, the digital quality movement grew rapidly. The findings of these studies suggested that implementing Quality 4.0 practices can enhance technological Innovation and organisational ambidexterity by fostering a learning environment, experimentation, collaboration, and continuous improvement (Gomes et al., 2020; Bag et al., 2022; Sarmad et al., 2024).

Quality 4.0 was used more frequently, but certain regions were unaware of the connection between digital quality systems and long-term competitive success. The direct implications of Industry 4.0 technology for organisational performance have frequently been the subject of research. On the other hand, very little research has examined how organisational ambidexterity and technical innovation work together within a single paradigm. Thus, the current study examined the mediating effects of organisational ambidexterity and technological innovation, as well as the influence of Quality 4.0 systems on sustained competitive performance (Sony, 2020; Ed-Dafali, 2023; Sarmad, 2024).

### **Research Problem**

The rapid adoption of Industry 4.0 technologies spurred firms to incorporate digital competencies into their quality management frameworks, leading to a new form of Quality 4.0 as an approach to firm excellence. As more and more organisations use AI, big data analytics, cloud computing, IoT, and Intelligent Automation in their quality management, they continue to face the challenge of translating their digital efforts into sustained competitive success. Research studies have focused only on the operational improvements achievable through Quality 4.0, such as defect reduction, improved process efficiency, greater production flexibility, and increased customer satisfaction. The evidence of Quality 4.0's contribution to long-term competitive performance remained very fragmented and inconclusive. Earlier studies often overlooked exploring the chain of organizational mechanisms that enabled digital quality systems to achieve sustainable competitive advantage. This restriction limited the

insight into the digital quality initiatives' ability to create strategic value in addition to their operational benefits.

### **Research Objectives**

1. To investigate how Quality 4.0 systems affect long-term competitive performance.
2. To ascertain how technical innovation affects long-term competitive performance.
3. To look into how technological innovation influences the connection between Quality 4.0 systems and long-term competitive success.
4. To investigate how organizational ambidexterity mediates the connection between sustainable competitive performance and Quality 4.0 systems.

### **Research Questions**

- Q1. What effect did Quality 4.0 systems exert on sustainable competitive performance?
- Q2. What effect did technological Innovation exert on sustainable competitive performance?
- Q3. To what extent did technological Innovation mediate the relationship between Quality 4.0 systems and sustainable competitive performance?
- Q4. To what extent did organizational ambidexterity mediate the relationship between Quality 4.0 systems and sustainable competitive performance?

### **Significance of the Study**

By improving awareness of how digital quality management systems affect long-term competitive performance, the study contributed to the body of knowledge already available on Quality 4.0. Few empirical studies have examined how strategic mechanisms translate into long-term competitive advantages within a digital quality system; instead, the majority of current research has concentrated on the operational and technological components of Quality 4.0. The study enriched the theoretical understanding of Quality 4.0 by examining three aspects: technological Innovation, organizational Ambidexterity, and their mediating role. It highlighted that the study enriched three aspects of the theory of Quality 4.0 – technological Innovation, organizational Ambidexterity, and the mediating role of these two aspects. The results also contributed to the current body of research by combining digital transformation,

quality management, organizational Innovation, and sustainable competitiveness within a single conceptual framework that could, in subsequent studies, serve as a basis for empirical research.

## **Literature Review**

### **Quality 4.0 Systems**

The notion of Quality 4.0 emerged from a major shift in the scope of quality management, driven by the introduction of Industry 4.0 technologies. Quality 4.0 brought artificial intelligence, machine learning, cloud computing, big data analytics, cyber-physical systems, blockchain technologies, and the Internet of Things into organizational quality practices. In contrast, traditional quality control methods were primarily based on quality assurance, statistical process control, and continuous improvement. The integration allowed businesses to gather, analyze, and process operating data on the go, for example, to make predictive decisions on quality, make informed decisions, and work on proactive process improvement. The researchers pointed to Quality 4.0 not just as the digitisation of quality tools, but also as a strategic shift that introduced digital technologies into the organisation's culture and leadership, and a shift toward customer-centric quality practices (Liu et al., 2023; Sony et al., 2020).

Additional research also revealed that Quality 4.0 was possible only if there was both technical infrastructure and organizational readiness, employee skills, digital leadership, and the potential for continuous learning. However, more and more organizations realized that digital transformation projects could only create sustainable value if they were backed by an innovative culture within the organization and effective Quality management systems. Organizational readiness, strategic alignment, workforce skills with digital processes, and data-driven decision-making were cited by the scholars as key factors enabling Quality 4.0. All these factors enhanced teamwork among functional departments, strengthened process integration, and enabled systematic process improvement across the organization (Antony et al., 2023; Sony et al., 2021).

There has also been significant academic interest in extending the subject to the organization's performance in recent years, and, in this respect, the Quality 4.0 link has been the subject of considerable scholarly research. Both empirical research and literature reviews revealed that Q4.0 had a positive impact on operational efficiency, customer satisfaction, Innovation, TPI, and sustainable competitive performance. Researchers claimed that intelligent quality systems helped organizations realize that process deviations occurred before they led to defects, optimize production planning using predictive analytics, utilize resources, and apply evidence to inform decision-making for better strategies. In the context of organizational resilience, Quality 4.0 enabled companies to become more resilient in dealing with environmental uncertainty and the demanding expectations of customers (Antony et al., 2022; Chiarini, 2020).

### **Technological Innovation**

Among the organisations' strategies that effectively addressed technological Innovation, technological Innovation as a strategic capability emerged as the most important. The rise of Industry 4.0 technologies has prompted organizations to redesign their products, services, and business processes by implementing intelligent digital solutions. Technological Innovation was not limited to the development of new technologies but also encompassed innovations in organizational processes, production structures, decision-making procedures, and value-creation processes, scholars elaborated. Organizations using digital technologies such as artificial Intelligence, cloud computing, blockchain, machine learning, and big data analytics had greater innovation capacity, as these technologies enabled them to integrate knowledge, accelerate product development, and increase organizational responsiveness. (Çelik & Uzunçarşılı, 2023; Liu et al., 2023).

Digital quality management systems created organizational knowledge and enabled continuous Innovation, making the relationship between Quality 4.0 and technological innovation a relevant academic research area. Researchers noted that Quality 4.0 enabled organizations to achieve real-time operational Intelligence, predictive analytics, automated quality monitoring, and data-driven decision support, thereby creating favorable conditions for Innovation. Digital quality systems have also reduced operational uncertainty, improved organisational information accuracy, and enabled organisations to discover new market

opportunities easily (Antony et al., 2023; Sony & Antony, 2020). Researchers also highlighted technological Innovation as a complement to organizational learning, enabling firms to leverage existing technological knowledge to create new technologies and business opportunities. The innovation capabilities enhanced organizational resilience, operational excellence, and sustainability potential, thereby reinforcing competitive advantage (Nakandala et al., 2024; Ed-Dafali et al., 2023).

### **Concept of Organizational Ambidexterity and Sustainable Competitive Performance**

Organizational Ambidexterity has attracted significant scholarly interest, given the ongoing challenges organizations face in becoming both efficient and innovative. Organizational Ambidexterity is the ability to pursue both exploratory and exploitative tasks to discover new opportunities and develop existing products, services, and processes. Organizations that were balanced between exploration and exploitation were found to be more motivated to adapt to the environment than to outperform competitors, thus achieving better performance more quickly. In the field of digital transformation, organizations demonstrated the ability to leverage cutting-edge technologies and continuously enhance their operational capabilities, thereby creating greater resilience and sustainability for future operations (Prasetio et al., 2022; Paiola et al., 2024).

The introduction of Industry 4.0 technologies was found to greatly enhance organizational Ambidexterity by enabling organizations to leverage their digital resources, thereby facilitating both exploration for Innovation and exploitation of their operations. Investment in intelligent manufacturing systems, predictive analytics, artificial Intelligence, and cloud-based quality platforms enabled companies to enhance the efficiency of their manufacturing processes while also allowing them to experiment with new technologies and business models. Furthermore, recent research showed that organizational Ambidexterity benefited in terms of strategic flexibility, fast digital transformation projects, and improved sustainable competitive advantage (Ali et al., 2020; Ed-Dafali et al., 2023).

Sustainable competitive performance was defined as an organization's ability to outperform the competition in the long term by combining Innovation, operational efficiency, customer satisfaction, strategic flexibility, and efficient resource utilization. Modern literature began to

show a deeper understanding of the interdependence among the elements of Quality 4.0 systems, technological Innovation, and organizational Ambidexterity to achieve sustainable competitive performance. Our empirical research validated these findings: organisations that incorporated digital quality management and innovation capabilities, and ambidextrous organisational practices across all four levers, achieved more significant positive results in financial performance, operational efficiency, customer satisfaction, and sustainability. Our empirical research confirmed these observations: Organizations that integrated digital quality management and innovation capabilities and practiced Ambidexterity across all four areas achieved some of the most significant positive outcomes in financial performance, operational efficiency, customer satisfaction, and environmental sustainability.

### **Research Hypotheses**

H1. Quality 4.0 Systems have a positive and significant impact on Sustainable Competitive Performance.

H2. Technological Innovation is positively and significantly affected by H2: Quality 4.0 Systems.

H3. The results indicate that Quality 4.0 Systems have a significant, positive impact on Organisational Ambidexterity.

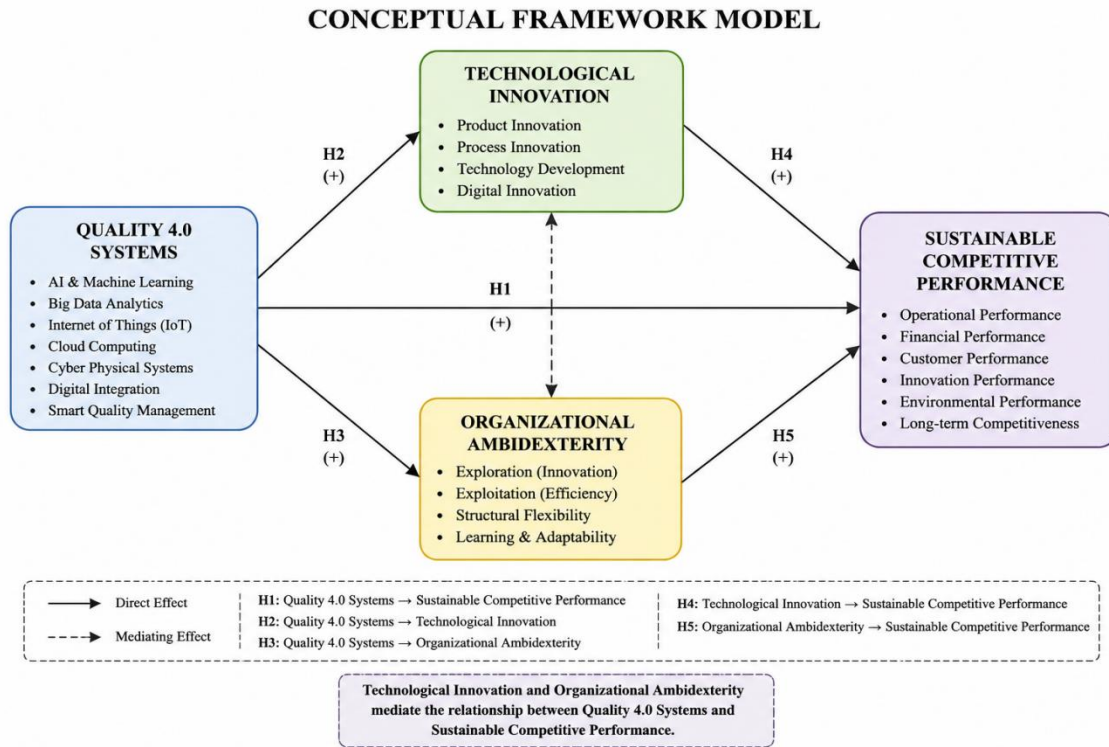
H4. Technological Innovation significantly and positively influences Sustainable Competitive Performance.

H5. Organizational Ambidexterity significantly and positively influences Sustainable Competitive Performance.

### **Conceptual Framework Model**

The conceptual framework hypothesized the relationships and suggests how Direct and Indirect pathways can be achieved in relation to Sustainable Competitive Performance and the contribution of the Quality 4.0 System to SCP. Quality 4.0 Systems are the independent variable under study and encompass critical aspects of digital quality management, including artificial intelligence/machine learning, big data analytics, the Internet of Things (IoT), cloud

computing, cyber-physical systems, digital integration, and smart quality management. In the proposed model, Quality 4.0 Systems predict an increase in Sustainable Competitive Performance (H1), which could translate into improvements in operational efficiency, customer satisfaction, innovation capacity, financial results, environmental performance, and even long-term competitiveness through the adoption and implementation of advanced digital quality (Q4.0) systems. The model also hypothesises that Quality 4.0 Systems have a positive impact on Technological Innovation (H2) and Organisational Ambidexterity (H3). Technological Innovation includes product, process, technology development and digital Innovation. Organisational Ambidexterity, on the other hand, is connected to an organisation's need to explore and exploit, organise flexibly, and learn continuously. Hypothesis H4 and H5 both predict that both constructs have a positive impact on Sustainable Competitive Performance. Technological Innovation and Organisational Ambidexterity are mediating variables that explain how Quality 4.0 Systems boost the organisation's competitiveness. The actors who implement Quality 4.0 practices are expected to enjoy various and direct advantages, such as increased competitiveness, support in developing their innovation potential, and adaptability to the new Industry 4.0 environment, thereby becoming more sustainable.



*Figure 1. Conceptual Framework Model*

## Research Methodology

### Research Design

A quantitative study was selected for this study because the research sought to investigate the impact of Quality 4.0 systems on Sustainable Competitive Performance, with Technological Innovation & Organisational Ambidexterity as mediators. The quantitative approach was used because it provides a systematic procedure for collecting numerical data and allows statistical analysis to test hypothesised relationships among the study variables. This study used a cross-sectional survey design, collecting data from respondents at a single point in time.

### Target Population

The target population consisted of middle- and senior-level managers, quality managers, production managers, operations managers, innovation managers, digital transformation managers, and manufacturing engineers responsible for manufacturing organisations that

adopted Industry 4.0 technologies and Quality 4.0 practices. The respondents were satisfied with the amount of information they received about their companies' quality management programs, innovation programs, and digital transformation projects as well as their competitive performance. The population was selected as early adopters of digital manufacturing technology and intelligent quality management systems across the automotive, electronics, pharmaceuticals, food processing, machinery, chemicals, textiles, and engineering industries.

### **Sampling Technique**

The sample for this research is purposive, a non-probability sampling technique, because the sampling was conducted by setting criteria for people with direct knowledge of the research subjects and practical experience in implementing Quality 4.0 and organisational Innovation. Only individuals in these areas were targeted for the survey, using a purposive sampling technique, to engage them in quality management, production management, digital transformation, innovation management, and strategic decision-making.

### **Sample Size**

The 50 Manufacturing Companies following the Q4.0 System were selected as the population, and a random sample of 500 was drawn. The questionnaires received were 438. Questionnaires marked as "incomplete" or "missing information," or those answered inconsistently, were not included in the analysis, and a response rate of 82.4% (412 questionnaires) was obtained. The results showed that the sample size was larger than the minimum recommended by Hair et al. (1998) to achieve adequate measurement and statistical power, leading to reliable parameter estimates and valid hypothesis testing in Structural Equation Modelling (SEM).

### **Data Collection Method**

A structured self-administered questionnaire was used to obtain the primary data. The questionnaire consisted of two parts. The first part was based on demographic information, such as gender, age, qualification, managerial position, years of industrial experience, and organizational sector, for the readers. The second part analyzed constructs about the ten components of quality 4.0 systems (Ghadban et al., 2015), technological innovations (Cook,

Foldney, & Setauket, 2019), organizational Ambidexterity (Hamel & Prahalad, 1994; Hannen, Theuerkau, & Stauss, 2013), and sustained competitive performance (Dulushi & Geyer, 2014) and employed validated scales from the literature. All the measurement items were rated on a 5-point Likert scale from 'Strongly Disagree' (SD, 1 point to 'Strongly Agree' (SA, 5 points. Questionnaires were distributed electronically via e-mail and online surveys, with some organizations also opting to receive printed copies.

### Data Analysis Techniques

Data were analyzed by using IBM SPSS Statistics 29 and SmartPLS 4. Data screening, descriptive statistics, reliability, correlation, and preliminary assumption testing were performed using SPSS. There were several reasons why SmartPLS was necessary for analyzing the measurement and structural models in the research model. SmartPLS was used to assess the measurement and structural models, as the proposed research model involved many latent variables and mediating variables. Internal consistency/reliability was assessed using Cronbach's alpha and Composite Reliability (CR). Average Variance Extracted (AVE) and indicator-loading procedures were conducted for convergent validity, while the Fornell–Larcker Criterion and Heterotrait–Monotrait (HTMT) ratio procedures were used for discriminant validity. A bootstrapping technique with a subsample of 5,000 was used to calculate path coefficients, t values, p values, confidence intervals, coefficients of determination ( $R^2$ ), effect sizes ( $f^2$ ), and predictive relevance ( $Q^2$ ). A mediation analysis was applied to examine the structural model. All statistical significance values have been quoted at the 0.05 level of significance.

### Results and Analysis

#### Demographic Profile of Respondents

The demographic profile described the background characteristics of the survey respondents.

**Table 1. Demographic Characteristics of Respondents (N = 412)**

Variable	Category	Frequency	Percentage (%)
Gender	Male	255	61.9

<b>Variable</b>	<b>Category</b>	<b>Frequency Percentage (%)</b>	
<b>Age</b>	Female	157	38.1
	25–34 Years	106	25.7
	35–44 Years	174	42.2
	45–54 Years	91	22.1
	Above 54 Years	41	10.0
<b>Education</b>	Bachelor's Degree	121	29.4
	Master's Degree	223	54.1
	Doctorate	68	16.5
<b>Managerial Position</b>	Quality Manager	92	22.3
	Production Manager	97	23.5
	Operations Manager	83	20.1
	Innovation Manager	66	16.0
	Senior Executive	74	18.1
<b>Experience</b>	1–5 Years	78	18.9
	6–10 Years	132	32.0
	11–15 Years	118	28.6
	Above 15 Years	84	20.5
<b>Industrial Sector</b>	Automotive	72	17.5
	Electronics	63	15.3
	Textile	81	19.7

Variable	Category	Frequency	Percentage (%)
	Pharmaceutical	59	14.3
	Food Processing	74	18.0
	Other Manufacturing	63	15.2

Demographic results showed that males accounted for 61.9% and females for 38.1%. This reflected the composition of management in the manufacturing industry, where more than 90% of managers were male and mostly occupied in technical and production management. Based on the respondents' age distribution, the largest age group was 35-44 year olds (42.2%), followed by 25–34 year olds (25.7%) and 45–54 year olds (22.1%). The educational profile revealed that 54.1 per cent of respondents held a master's degree, while 16.5 per cent held a doctoral degree. Data quality was further improved through the involvement of managers in the process and through industry representation. Nearly 46 per cent of respondents were production/quality managers, underscoring the importance of workers who are closely involved in the day-to-day oversight of production quality and/or digitalisation projects.

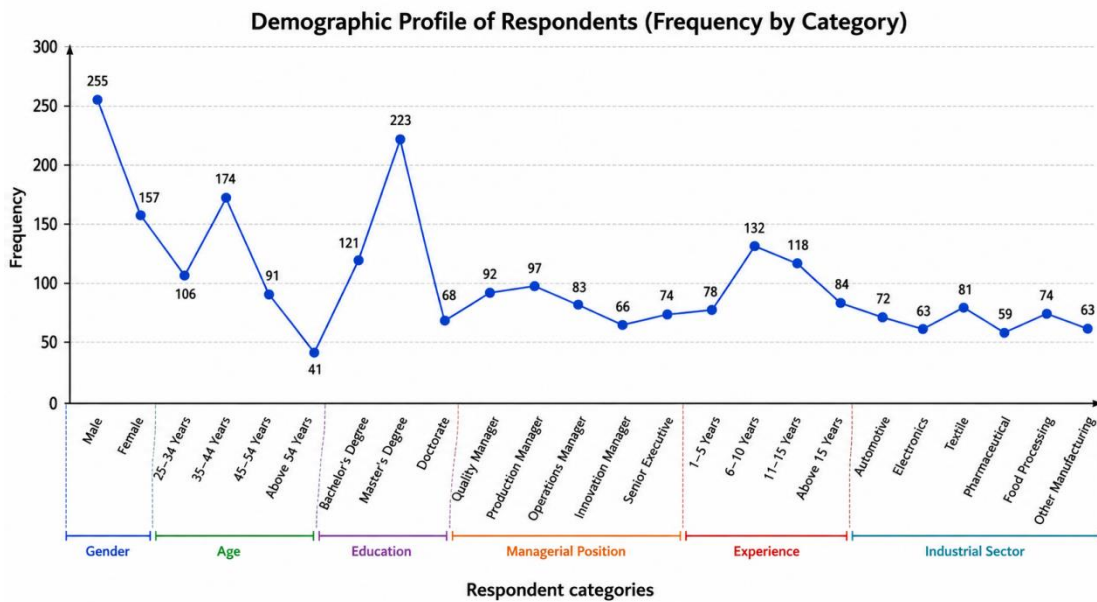


Figure 2. Demographic Characteristics of Respondents (N = 412)

### Descriptive Statistics

The analysis included the means and standard deviations for Quality 4.0 Systems, Technological Innovation, Organizational Ambidexterity, and Sustainable Competitive Performance.

**Table 2. Descriptive Statistics of Study Variables**

Variable	Mean	Standard Deviation
Quality 4.0 Systems	4.29	0.56
Technological Innovation	4.22	0.59
Organizational Ambidexterity	4.18	0.62
Sustainable Competitive Performance	4.31	0.54

The descriptive analysis of the data showed a high level of agreement among all the parties with  $M = 4.29$  ( $SD = 0.56$ ) toward the use of Quality 4.0 Systems. Additionally, the results revealed that Sustainable Competitive Performance had the highest Mean score ( $M = 4.31$ ,  $SD = 0.54$ ) among respondents' perceptions of their organisations' performance in operational excellence, mastery of customer satisfaction, innovation, and strategic flexibility. The average score on the "Technological Innovation" scale was also relatively high ( $M = 4.22$ ,  $SD = 0.59$ ), indicating that technological innovation was frequently the focus of organisational processes. The mean score was positive ( $M = 4.18$ ,  $SD = 0.62$ ) for Organisational Ambidexterity, indicating the organisations' ability to link the two sides of Innovation: Exploratory and Exploitative processes of improvement.

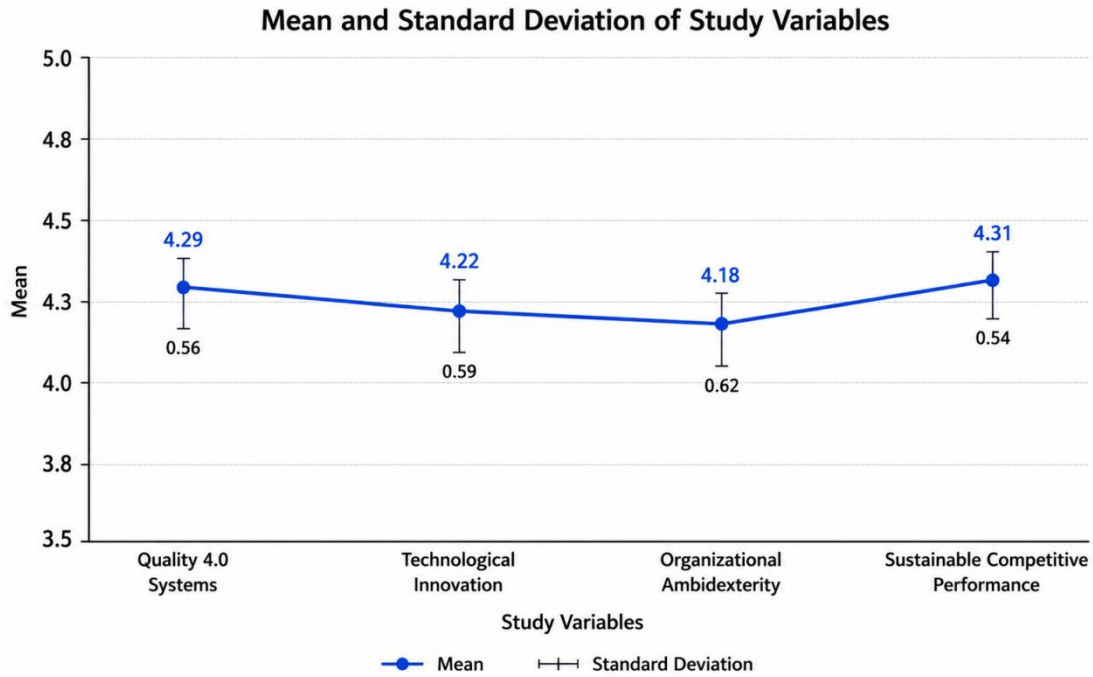


Figure 3. Descriptive Statistics of Study Variables

### Correlation Analysis

Correlation analysis was conducted to examine the strength and direction of the relationships among the study variables before testing the structural model.

Table 3. Correlation Matrix of the Study Variables (N = 412)

Variables	1	2	3	4
1. Quality 4.0 Systems	1.000			
2. Technological Innovation	0.768	1.000		
3. Organizational Ambidexterity	0.741	0.719	1.000	
4. Sustainable Competitive Performance	0.812	0.784	0.756	1.000

The correlation results showed that all variables in this study were positively and substantially correlated with one another at the 0.01 level of significance. Technological innovation and

Quality 4.0 Systems demonstrated statistical significance ( $p < 0.01$ ) and a comparatively strong positive association ( $r = 0.768$ ). This suggests that high levels of Quality 4.0 Systems were associated with greater technological innovation. There was a substantial positive association ( $r = 0.741$ ,  $p < 0.01$ ) between Quality 4.0 Systems and Organizational Ambidexterity. Additionally, Quality 4.0 Systems demonstrated a significant correlation with Organizational Ambidexterity ( $r = 0.741$ ,  $p < 0.01$ ), indicating that both exploratory and exploitative organizational behaviors were encouraged by quality practices for digital systems. According to the other findings, Quality 4.0 Systems and Sustainable Competitive Performance were most strongly associated ( $r = 0.812$ ,  $p < 0.01$ ). There were positive correlations between Sustainable Competitive Performance and Organizational Ambidexterity ( $r = 0.756$ ,  $p < 0.01$ ) and Technological Innovation ( $r = 0.784$ ,  $p < 0.01$ ). Correlation values ranging from 0.719 to 0.812 showed that all of the study's variables had relatively strong connections. The suggested research model was approved in light of these findings.

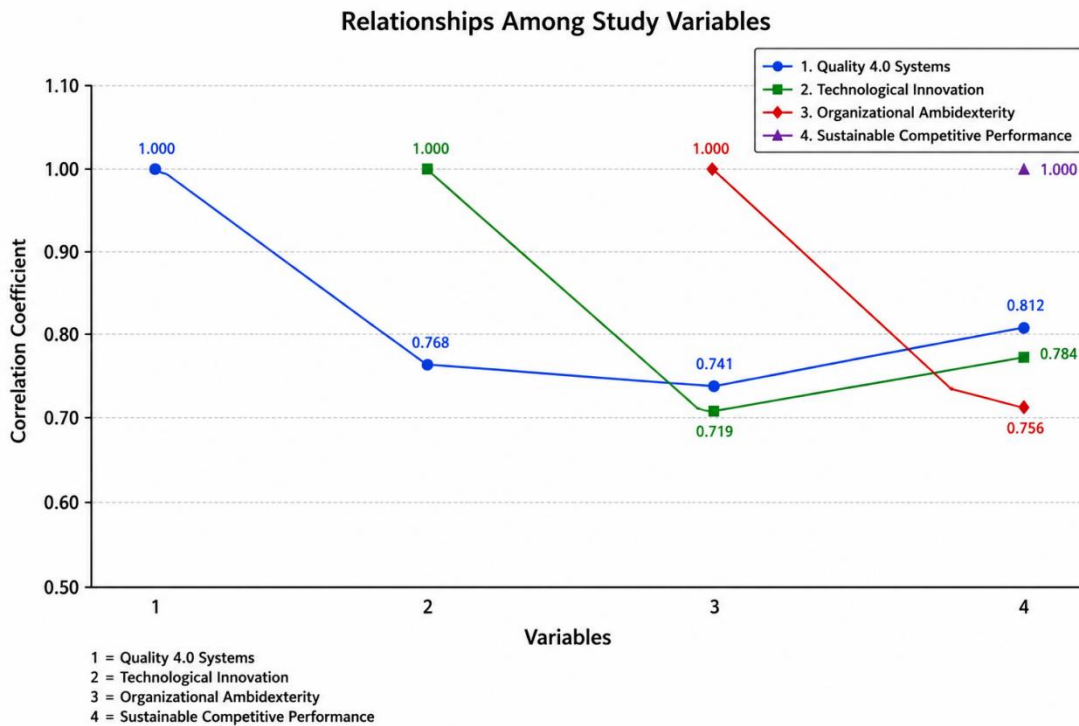


Figure 4. Correlation Matrix of the Study Variables (N = 412)

**Coefficient of Determination (R<sup>2</sup>)**

The coefficient of determination (R<sup>2</sup>) was examined to determine the predictive accuracy of the structural model.

**Table 4. Coefficient of Determination (R<sup>2</sup>) of the Endogenous Constructs**

<b>Endogenous Construct</b>	<b>R<sup>2</sup></b>	<b>Adjusted R<sup>2</sup></b>	<b>Interpretation</b>
Technological Innovation	0.590	0.588	Moderate
Organizational Ambidexterity	0.549	0.547	Moderate
Sustainable Competitive Performance	0.768	0.765	Substantial

The result shows the coefficient R<sup>2</sup> for Technological Innovation as 59.0%, indicating that Quality 4.0 Systems accounted for 59.0% of its variance. The adjusted R<sup>2</sup> at the end (0.588) was still very close to the original R<sup>2</sup>, indicating little bias in the model's estimation. The results also indicate that Organisational Ambidexterity has an R<sup>2</sup> of 0.549, indicating that Q4.0 Systems explains approximately 54.9% of the variability in Organisational Ambidexterity. Therefore, this finding revealed that digital quality management practices had a significant impact on organizations' capabilities to balance exploratory Innovation and exploitative operational improvement. An adjusted R<sup>2</sup> (0.547) was close to the original coefficient, indicating stability of the structural model and robustness. The highest explanatory power was found for Sustainable Competitive Performance, with an R<sup>2</sup> of 0.768 and an Adjusted R<sup>2</sup> of 0.765. The findings revealed that Sustainable Competitive Performance can be explained by 76.8% of the variance across three components: Quality 4.0 Systems, Technological Innovation, and Organizational Ambidexterity.

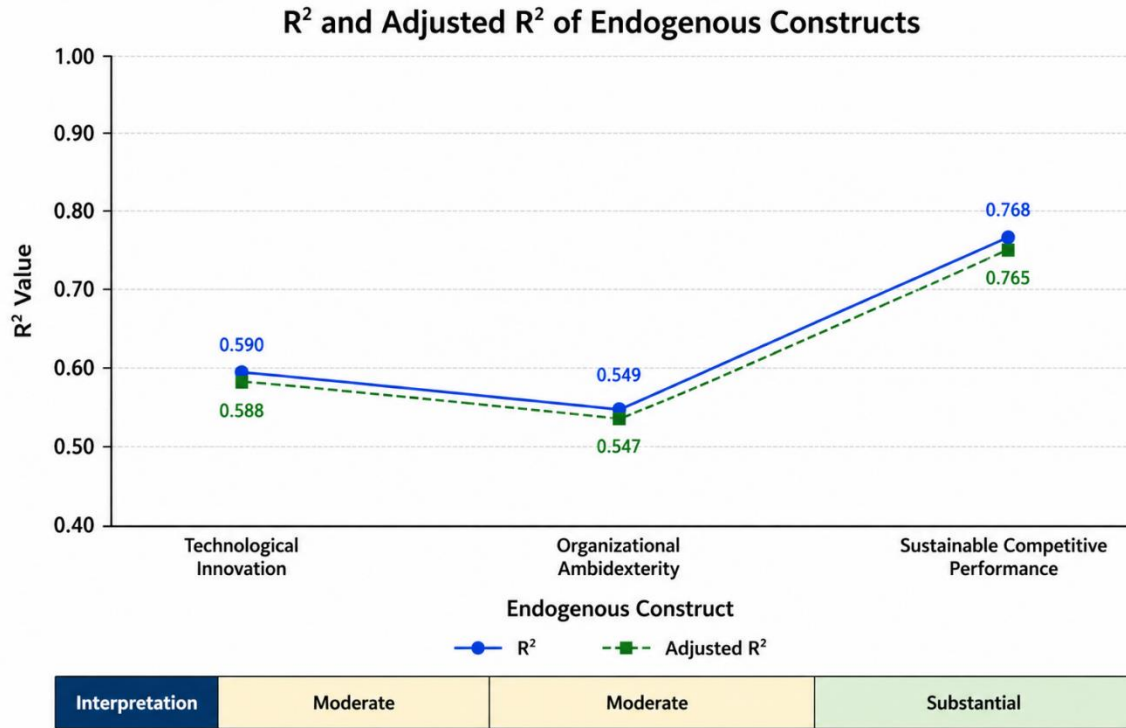


Figure 5. Coefficient of Determination ( $R^2$ ) of the Endogenous Constructs

## Discussion

The results corroborated the Waste & Efficiency Status in Sustainable Competitive Performance, in which organisations that have adopted the Quality 4.0 Systems achieved greater success than those that have not. It reveals that various technologies, such as AI, big data analytics, cloud computing, cyber-physical systems, and IoT, implemented within quality management contributed to increased customer satisfaction, operational efficiency, optimal resource use, and even strategic changes. These findings were both unambiguous: quality 4.0 was more than just a technological program; it was an organizational capability. Digital technologies' improved capacity to infiltrate and integrate with quality management enabled an organisation to respond to issues as they occurred, support ongoing decision-making, and develop an agile culture of continuous quality improvement. The results were consistent with past studies showing that the willingness to embrace Industry 4.0 and Digital

Quality Management has a substantial influence on the organisation's capacity, strategic agility, and operational excellence (Ed-Dafali et al., 2023; Sarmad et al., 2024).

Empirical results also yielded a value that clearly and significantly indicated a positive sign – Quality 4.0 Systems for Technological Innovation. This finding suggests implementing an intelligent QM system as a system designer to create an organizational environment conducive to creativity, experimentation, continuous improvement, and technology-based Innovation. Managers were able to access digital quality systems to obtain real-time operational data, which helped them identify new opportunities for product, process, and service innovation. From here, organizations that have embarked on Quality 4.0 implementation have improved their technological skills and ensured their sustainability. The outcomes are consistent with existing research on the positive impact of Industry 4.0 technologies on data-driven decision-making, organisational learning, and the digitalisation of processes. As expected from the empirical literature, Çelik et al. (2023) and Nakandala et al. (2024) have presented similar findings, explaining that technological Innovation was found to be a key mediator in the relationship between digital transformation and improved firm performance and competitive advantage.

The research demonstrated that Q4.0 Systems had a positive impact on 'OAE' and provided supportive evidence that a digital quality management approach helped to enhance the capacity of these systems to manage exploitative operational improvement as well as exploratory innovations. This was a balancing organisational behaviour that helped them develop their adaptive capacity, learning, and strategic resilience. The results were consistent with recent research showing that the successful implementation of Industry 4.0 was necessary for organisational Ambidexterity to serve as a dynamic capability. The effects of digital transformation and Ambidexterity have recently been demonstrated in empirical research to yield higher levels of operational flexibility, innovation performance, and sustainable outcomes for businesses (Nakandala et al., 2024; Sahoo et al., 2025), as they are powerful concepts for combining efficiency- and innovation-building activities.

They also showed the strong effects of Technological Innovation and Organizational Ambidexterity on enhancing Sustainable Competitive Performance. More innovative

committees used new technologies, optimized existing production methods, and offered customers greater added value, thereby becoming more competitive in the long term. Organizations with strong ambidexterity skills were well-balanced between operation excellence and ongoing Innovation, enabling them to adapt to Empirical research in recent years quickly also found that technological innovation capability, organizational Ambidexterity, and big data capability significantly boosted firm performance, as these capabilities could facilitate the adaptability of the organization, strategic flexibility and competitive market positioning (Çelik et al., 2023, Zhang et al., 2022). In keeping with these findings, recent research also found that quality management practices improve sustainable organizational performance by fostering Innovation exploration, Innovation exploitation, Organizational Ambidexterity, and Industry 4.0 readiness, thereby reinforcing that other complementary organizational capabilities are crucial elements in making digital transformation efforts translate into SCA for the firm (Sarmad et al., 2024; Ed-Dafali et al., 2023).

### **Conclusion**

The study analyzed the effects of Quality 4.0 Systems on Sustainable Competitive Performance and explored Technological Innovation and Organizational Ambidexterity as mediating variables. The results showed that Q4.0 Systems effectively improved Sustainable Competitive Performance by enabling the organization to utilize state-of-the-art digital technologies in its quality management processes. Organisations that introduced intelligent quality systems achieved higher operational efficiency, improved decision-making processes, better process optimisation, and greater customer value. In the field of digital quality management, the operational improvements were not merely generic; they also contributed to advancing long-term organisational competitiveness. It was also concluded that the application of Quality 4.0 Systems had a positive effect on Technological Innovation and Organizational Ambidexterity. The mediation analysis also replicated the findings that Technological Innovation and Organizational Ambidexterity were important mechanisms for Sustainable Competitive Performance in the context of Quality 4.0 Systems.

### **Recommendations**

The study results suggest that organizations should enhance the application of Quality 4.0 Systems by integrating them into the quality management processes of advanced digital technologies such as artificial Intelligence, big data analytics, cloud computing, the Internet of Things, machine learning, and cyber-physical systems. Management should provide adequate resources for digital transformation projects and for the firm's organizational strategies to connect the different aspects of quality management projects to technological advancement. Promote a culture of continuous technological Innovation within the organization by fostering and encouraging R&D efforts, employee creativity, knowledge sharing, and cross-functional collaboration. There should be a better ability to leverage new technologies and use digital skills effectively in the workplace through training programs. The leadership must foster a climate conducive to Innovation within the organization, encourage experimentation and continual improvement, and quickly bring new technologies into operation without compromising the efficiency or quality of the business offering.

#### **Future Research Directions**

Other industries, including health care, logistics, banking, information technology, education, retail, and public companies, are recommended for further research to investigate the interplay within and/or across them among Quality 4.0 Systems, Technological Innovation, Organisational Ambidexterity, and Sustainable Competitive Performance. Deeper insights might also be gleaned from a comparative analysis of the influence of national technological infrastructure, institutional arrangements, and organisational cultures on the implementation of QP4.0 in developed and developing countries. Further longitudinal research is recommended to analyse the impact of implementing Quality 4.0 on organisational performance over a longer time horizon. Consequently, long-term studies might even be able to offer more concrete evidence of the sustainability of the digital transformation process and to identify the development of organisational capabilities across the various stages of Industry 4.0 digitalisation.

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