CENTRAL ASIAN JOURNAL OF INNOVATIONS ON TOURISM MANAGEMENT AND FINANCE

https://cajitmf.centralasianstudies.org/index.php/CAJITMF

Volume: 05 Issue: 04 | July 2024 ISSN: 2660-454X

Article

Industry 4.0 and Corporate Technological Responsibility of Manufacturing Firms in Nigeria

Lucy Cecilia Mmadubuobi*, Gilbert Ogechukwu Nworie, Obianuju Precious Aziekwe

Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

* Correspondence: lc.mmadubuobi@unizik.ed.ng

Abstract: The study examined the relationship between industry 4.0 and corporate technological responsibility of manufacturing firms in Nigeria. Proxies of industry 4.0 were artificial intelligence, internet of things (IoT), big data analytics. The study deployed descriptive survey research design. A sample size of 452 respondents was obtained based on the number that responded to the research instrument administered online. The questionnaire was developed in line with four (4) point Likert scale. The responses were presented using frequency analysis while the Spearman Ranked Order Correlation Analysis was used in testing the three null hypotheses of the study. The first finding from Hypothesis I reveals a significant inverse relationship between AI adoption and corporate technological responsibility, with the Spearman's rho correlation coefficient of -0.567 (p-value = 0.000); the second finding from Hypothesis II indicates a strong positive relationship between IoT adoption and corporate technological responsibility, with a Spearman's rho correlation coefficient of 0.548 (p-value = 0.000); the third finding from Hypothesis III demonstrates an even stronger positive relationship between big data analytics and corporate technological responsibility, with a Spearman's rho correlation coefficient of 0.850 (p-value = 0.000). In conclusion, responsible implementation of Industry 4.0 practices will help balance technological advancement with ethical responsibility, ensuring sustainable and socially responsible growth. The study recommends that Chief Technology Officers (CTOs) of manufacturing firms should integrate ethical guidelines and social impact assessments into their AI deployment strategies to ensure that the technology is used responsibly.

Keywords: Industry 4.0, Artificial Intelligence, Internet of Things, Big Data Analytics, Corporate Technological Responsibility

Citation: Lucy Cecilia Mmadubuobi, Gilbert OgechukwuNworie, Obianuju Precious Aziekwe. Industry 4.0 and Corporate Technological Responsibility of Manufacturing Firms in Nigeria Central Asian Journal of Innovations on Tourism Management and Finance 2024, 5(4), 67-80.

Received: 12th July 2024
Revised: 14th July 2024
Accepted: 16th July 2024
Published: 22th July 2024

1. Introduction

The advent of the Fourth Industrial Revolution, often referred to as Industry 4.0, marks a transformative era characterized by the fusion of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics, big data analytics, and cloud computing (Malik et al., 2024; Margherita & Braccini, 2024; Zhong & Moon, 2023). This era signifies a paradigm shift in how industries operate, with an unprecedented level of automation, interconnectivity, and data-driven decision-making. In the context of manufacturing sector, embracing Industry 4.0 is not merely an option but a strategic imperative for enhancing competitiveness, productivity, and sustainability (Kılıç & Atilla, 2024). As Nigerian manufacturing firms strive to integrate these cutting-edge technologies, the concept of Corporate Technological Responsibility (CTR) which is more popularly called corporate digital responsibility (CDR) emerges as a crucial consideration (Wynn & Jones, 2023). CTR encompasses the ethical and responsible deployment of

technology within corporate practices, ensuring that technological advancements align with societal values, environmental sustainability, and ethical standards (Cheng & Zhang, 2023).

Effective Corporate Technological Responsibility is increasingly recognized as a fulcrum of sustainable and ethical business practices. The integration of advanced technologies presents both opportunities and challenges (Lobschat et al., 2021). On one hand, it offers significant potential for innovation, operational efficiency, and market differentiation. On the other hand, it raises critical ethical, environmental, and social concerns that require careful consideration (Angermann, 2023). It has been argued that the adoption of Industry 4.0 technologies have given rise to a number of problems such as increase unemployment (Satyro et al., 2022), environmental hazards as a result of air pollution, the poor discharge of waste, and the intensive use of raw materials (Oláh et al., 2020); ethical problems (Rahanu et al., 2021); data insecurity (Garg et al., 2021); et cetera. CTR mandates that companies not only focus on technological advancement for profit maximization but also address the broader implications of their technological choices. This includes minimizing environmental impact, ensuring data privacy and security, promoting digital inclusion, and upholding ethical standards in AI and automation (Cheng & Zhang, 2023). For manufacturing firms, effective CTR is essential for building trust with stakeholders, maintaining regulatory compliance, and fostering long-term sustainability. It also positions firms to be responsible stewards of technology, balancing economic growth with societal well-being.

Industry 4.0, also known as the Fourth Industrial Revolution, involves the integration of digital technologies into manufacturing processes, creating what is often termed a "smart factory." This revolution is driven by several key technologies, including AI, IoT, robotics, big data analytics, and cloud computing (AL-Khatib et al., 2024). These technologies enable real-time data collection, analysis, and decision-making, leading to improved efficiency, reduced costs, and enhanced product quality. In the manufacturing sector, the adoption of Industry 4.0 technologies is still in its nascent stages but holds immense potential for transformation (Pozzi et al., 2023). The main concepts underpinning Industry 4.0 include cyber-physical systems (CPS), which integrate physical machinery with digital systems; the IoT, which connects devices and enables seamless communication; and big data analytics, which leverages vast amounts of data to drive hints and optimize operations. Corporate Technological Responsibility (CTR) in this context refers to the ethical and responsible use of these technologies, ensuring that their deployment aligns with societal and environmental considerations.

As firms increasingly adopt Industry 4.0 technologies, they are compelled to address a number of complexities or challenges emanating from ethical, social, and environmental considerations (Javaid et al., 2022). Firstly, the automation and AI components of Industry 4.0 necessitate a reevaluation of labor practices and workforce dynamics. As was argued by Stefanini and Vignali (2024), companies must address the potential displacement of workers through reskilling and upskilling initiatives, ensuring that technological advancements do not exacerbate unemployment or social inequality. Secondly, the extensive use of data analytics and IoT devices raises significant concerns regarding data privacy and security. Firms must implement robust data protection measures to safeguard sensitive information and comply with regulatory frameworks. Thirdly, the environmental impact of advanced manufacturing technologies must be carefully managed (Channi & Kumar, 2024). This involves adopting sustainable practices, such as reducing energy consumption, minimizing waste, and utilizing eco-friendly materials (Malik et al., 2024). Lastly, the ethical deployment of AI and automation is crucial. Companies must ensure that these technologies are used transparently and fairly, avoiding biases and ensuring that they enhance rather than undermine human decision-making.

Therefore, the integration of Industry 4.0 technologies within manufacturing firms presents both opportunities and responsibilities. Embracing Corporate Technological Responsibility is essential for ensuring that these technological advancements contribute positively to society and the environment (Cheng & Zhang, 2023). By prioritizing ethical

considerations, data privacy, environmental sustainability, and workforce development, Nigerian manufacturing firms can harness the full potential of Industry 4.0 while maintaining their commitment to responsible corporate citizenship. Industry 4.0 technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics, and big data analytics help to enhance operational efficiency, productivity, and innovation in firms. The principles of Corporate Technological Responsibility (CTR) requires that firms adopting these technologies should ensure that technological advancements are implemented ethically, sustainably, and inclusively, fostering a balance between economic growth, environmental stewardship, and social well-being. Firms would prioritize reskilling and upskilling their workforce to adapt to new technological demands, safeguard data privacy, reduce their environmental footprint, and ensure ethical use of AI and automation (Cordeiro et al., 2024).

However, while there is a growing awareness of the potential benefits of Industry 4.0, the adoption and integration of these technologies remain limited. Many firms lack the necessary infrastructure, technical expertise, and financial resources to fully implement Industry 4.0 solutions. Additionally, there is often insufficient emphasis on Corporate Technological Responsibility (CTR). Issues such as inadequate data protection, environmental neglect (Malik et al., 2024), and ethical concerns surrounding AI and automation are prevalent. Workforce displacement due to automation is a growing concern, with limited efforts towards reskilling and upskilling employees (Stefanini & Vignali, 2024). Consequently, the sector is not realizing the full potential of Industry 4.0, and its technological advancements are not being leveraged responsibly.

The limited adoption of Industry 4.0 technologies means that firms are not as competitive or innovative as they could be, potentially losing ground to international competitors who are further along in their digital transformation journeys (Pozzi et al., 2023). The neglect of Corporate Technological Responsibility (CTR) worsens social and environmental issues, such as increased unemployment due to automation, data breaches, and environmental degradation (Satyro et al., 2022; Oláh et al., 2020; Rahanu et al., 2021; Garg et al., 2021). This not only undermines public trust in the manufacturing sector but also poses reputational risks. Moreover, the failure to fully integrate Industry 4.0 technologies and principles of CTR hinders sustainable development and economic growth, leaving the sector ill-prepared to meet future challenges and opportunities. Without addressing these gaps, Nigerian manufacturing firms risk falling behind in the global industrial domain, unable to capitalize on the transformative potential of Industry 4.0. Among the numerous existing studies on the topic such as Hossain et al. (2024), Narkhede et al. (2024), Stefanini and Vignali (2024), AlZayani et al. (2024), Palsodkar et al. (2024), Margherita and Braccini (2023), Kamble and Gunasekaran (2023), Yavuz et al. (2023), Ferreira et al. (2023), Kong and Liu (2023), Khan et al. (2023), Bai et al. (2022), this is the first in Nigeria that examines the nexus between Industry 4.0 and corporate technological responsibility of firms in Nigeria.

1.1 Research Questions

Though the main aim of the study is to examine the relationship between industry 4.0 and corporate technological responsibility of manufacturing firms in Nigeria, this research specifically addresses the following research questions:

1. What is the relationship between artificial intelligence adoption and corporate technological responsibility among manufacturing firms in Nigeria?
2. How does Internet of Things adoption relate to corporate technological responsibility among manufacturing firms in Nigeria?
3. To what extent does big data analytics relate to corporate technological responsibility among manufacturing firms in Nigeria?

Literature Review

Conceptual Clarifications

Industry 4.0

Industry 4.0, also known as the Fourth Industrial Revolution, refers to the current trend of automation and data exchange in manufacturing technologies (Pozzi et al., 2023). It encompasses a range of contemporary technologies such as cyber-physical systems, the Internet of Things (IoT), cloud computing, and cognitive computing (Javaid et al., 2022). These technologies facilitate a smart factory environment where machines can communicate and collaborate with each other, as well as with humans, to optimize production processes (Zhong & Moon, 2023). The core idea behind Industry 4.0 is the integration of digital and physical systems to create highly flexible, efficient, and customized manufacturing operations. This integration allows for real-time data collection and analysis, enabling manufacturers to make more informed decisions, reduce downtime, and enhance productivity. The concept also emphasizes the importance of interoperability, where various systems and devices can seamlessly work together. Ultimately, Industry 4.0 aims to revolutionize the manufacturing industry by leveraging advanced technologies to create more adaptive, intelligent, and sustainable production systems (Pandya & Kumar, 2023).

Artificial Intelligence

Artificial Intelligence (AI) refers to the simulation of human intelligence processes by machines, particularly computer systems. These processes include learning (the acquisition of information and rules for using it), reasoning (using rules to reach approximate or definite conclusions), and self-correction. AI systems are designed to perform tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and language translation (Pandya & Kumar, 2023). There are various types of AI, including narrow AI, which is designed to perform a narrow task (e.g., facial recognition or internet searches), and general AI, which has the potential to perform any intellectual task that a human can do (Martinez, 2018). AI technologies are built on complex algorithms and data processing capabilities that allow them to learn from experience and adapt to new inputs. The ultimate goal of AI research is to create systems that can perform tasks autonomously, efficiently, and effectively, potentially transforming various industries by enhancing operational efficiencies and enabling new capabilities (Chung et al., 2022).

Internet of Things

The Internet of Things (IoT) refers to the interconnected network of physical devices, vehicles, buildings, and other objects embedded with sensors, software, and other technologies with the aim of connecting and exchanging data with other devices and systems over the internet. Each thing in the IoT ecosystem is uniquely identifiable through its embedded computing system but can interoperate within the existing internet infrastructure. The concept of IoT extends to various aspects of daily life, including smart homes, where appliances and systems can be controlled remotely, and smart cities, which use data to improve infrastructure, public services, and more (Mu et al., 2024). IoT enables objects to be sensed or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, resulting in improved efficiency, accuracy, and economic benefit (Pandya & Kumar, 2023). The seamless communication between devices and the analysis of vast amounts of data generated by these devices can lead to innovative applications and services, driving significant advancements in automation and smart technology.

Big Data Analytics

Big Data Analytics refers to the complex process of examining large and varied data sets, or big data, to uncover information such as hidden patterns, correlations, market trends, and customer preferences. This data is typically characterized by its volume, velocity, and variety, making traditional data processing software inadequate to deal with it. The

primary goal of big data analytics is to help organizations make better business decisions by enabling data scientists, predictive modelers, and other analytics professionals to analyze vast amounts of transactional data, as well as other forms of data that may be left untapped by conventional business intelligence programs (Pandya & Kumar, 2023). Big data analytics can help organizations harness their data and use it to identify new opportunities, leading to smarter business moves, more efficient operations, higher profits, and happier customers (Narkhede et al., 2024). The hints gained from big data analytics can also drive innovation by providing a deeper understanding of complex phenomena and enabling the creation of new products and services tailored to emerging trends and consumer demands.

Corporate Technological Responsibility

Corporate Technological Responsibility (CTR) which is more popularly termed corporate digital responsibility refers to the ethical and responsible management of technology by corporations to ensure that their technological advancements and applications benefit society while minimizing any negative impacts. This concept encompasses a wide range of practices, including the development and deployment of technologies in a way that promotes sustainability, equity, privacy, and security (Wynn & Jones, 2023). CTR involves the commitment of companies to adopt best practices in the use of technology, ensuring transparency, accountability, and fairness. It also includes the proactive management of technological risks and the safeguarding of stakeholder interests, particularly in relation to data privacy and cybersecurity (Kunz & Wirtz, 2024). Furthermore, CTR encourages companies to contribute positively to the technological literacy and digital inclusion of the communities they serve. By embracing CTR, corporations can foster trust with their stakeholders, enhance their reputation, and contribute to the broader societal good, while also driving innovation and competitiveness in a responsible manner (Cheng & Zhang, 2023; Angermann, 2023). Ultimately, CTR aims to balance the pursuit of technological advancement with the need to address ethical, social, and environmental considerations.

2.2 Development of Hypotheses from Stakeholder Theory

Stakeholder theory was propounded by R. Edward Freeman in 1984 (Meshack et al., 2022). The theory emerged as a response to the growing recognition that businesses operate within a complex network of relationships with various groups, including customers, employees, suppliers, communities, and investors, each of whom can affect or be affected by the company's actions. Freeman's work was groundbreaking in that it expanded the traditional view of a firm's responsibilities beyond shareholders to include a broader range of stakeholders. This paradigm shift highlighted the importance of understanding and addressing the interests of all stakeholders to achieve long-term success and sustainability (Okafor et al., 2024).

The central tenet of stakeholder theory is that organizations should create value for all stakeholders, not just shareholders (Ukoh et al., 2024). According to the theory, businesses have a moral and ethical obligation to consider the interests and well-being of all parties affected by their operations. This includes actively engaging with stakeholders to understand their needs and concerns and making decisions that balance these various interests. The theory posits that by addressing the needs of all stakeholders, firms can foster trust, collaboration, and loyalty, which are essential for sustainable business performance. Furthermore, stakeholder theory argues that businesses that manage their stakeholder relationships effectively are better positioned to address risks, capitalize on opportunities, and enhance their reputation and legitimacy in the eyes of the public (Ukoh et al., 2024).

Stakeholder theory is particularly relevant to the topic of the effect of Industry 4.0 on Corporate Technological Responsibility (CTR) of manufacturing firms in Nigeria. As these firms integrate advanced technologies such as AI, IoT, and big data into their operations, the impact on various stakeholders becomes significant. The adoption of Industry 4.0

technologies can lead to substantial changes in the workforce, supply chain, customer interactions, and community relations. Stakeholder theory provides a framework for understanding and managing these impacts responsibly. By applying stakeholder theory, manufacturing firms can ensure that their technological advancements are implemented in a way that considers the ethical, social, and environmental implications for all stakeholders (Channi & Kumar, 2024). This approach not only helps in mitigating negative consequences but also enhances the firm's reputation, promotes sustainable practices, and fosters stronger stakeholder relationships. In lin with the argument above, the study hypothesises that:

1) There is a positive relationship between artificial intelligence adoption and corporate technological responsibility among manufacturing firms in Nigeria.
2) Internet of Things adoption positively relates to corporate technological responsibility among manufacturing firms in Nigeria.
3) Big data analytics positively relates to corporate technological responsibility among manufacturing firms in Nigeria.

2.3 Empirical Evidence

Hossain et al. (2024) utilized the dynamic capability theory to explore the impact of adopting Industry 4.0 technologies and paradoxical leadership on the corporate sustainable performance of manufacturing small and medium-sized enterprises in Malaysia. The study posits organizational ambidexterity as a mediator and strategic flexibility as a moderator. Conducted as a cross-sectional, quantitative study, it collected 395 valid responses using a simple random sampling technique and a structured close-ended questionnaire. Data analysis was performed using structural equation modelling. The findings reveal that Industry 4.0 technologies significantly influence corporate sustainable performance and that organizational ambidexterity mediates this relationship.

Narkhede et al. (2024) analyzed the suitability of Industry 4.0 technologies in areas such as new product development, supply chain management, internal logistics management, production planning execution and control, quality management, and maintenance management. This study employs a systematic literature review methodology to comprehensively analyze relevant sources to present valuable perspectives and practical suggestions customized to the requirements of different essential work functions within manufacturing small and medium-sized enterprises. The findings of the systematic literature review indicate that big data analytics, robotics, and automation are perceived as highly sustainable, while blockchain and cloud technology are viewed as having lower sustainability from the perspective of small and medium-sized enterprises.

Stefanini and Vignali (2024) investigate how the implementation of Industry 4.0 enabling technologies can enhance the economic, environmental, and social sustainability of the food sector. A systematic literature review, using a combination of 12 keywords, was carried out on the Scopus database with defined inclusion and exclusion criteria to answer four selected research questions. Overall, 50 relevant papers were retrieved and analyzed using Mendeley and Excel with descriptive statistics. VOSviewer was used for co-occurrence and co-authorship analysis. Results illustrate that interest in the topic has grown, particularly in Italy, and summarize the benefits achievable by implementing Industry 4.0 technologies in food industries. Social impacts include new job positions, ergonomic design of workplaces, changes in educational institutions, improved nutrition, and better animal welfare. Positive aspects are related to economic growth, improving food chain performances, and decreasing companies' costs. Finally, it allows for energy, water, CO2 emissions, and food savings.

AlZayani et al. (2024) investigated the influence of smart technologies on small and medium-sized enterprises' sustainability and measured the mediation effect of small and medium-sized enterprises' sustainability strategy in the relationship between smart

technologies and small and medium-sized enterprises' sustainable performance in the Kingdom of Bahrain. The sustainability concept for this study includes environmental sustainability, social sustainability, and profitability factors. The study applied the quantitative analysis method. The sample size was 403 small and medium-sized enterprises from Bahrain. The study concludes that smart technology has a major effect on sustainable performance factors.

Palsodkar et al. (2024) examined how to integrate Industry 4.0 and agile new product development practices to evaluate the penetration of sustainable development goals in manufacturing industries. From the literature, various agile new product development practices, Industry 4.0 technologies, performance metrics, their interconnection, and their contribution toward achieving sustainable development goals are extracted. The weights of selected Industry 4.0 and agile new product development practices are computed by the robust best worst method, and the fuzzy-VIKOR method is used to rank the selected performance metrics. To test the robustness of the developed framework, sensitivity analysis is also performed. The results show that among the various Industry 4.0 and agile new product development practices, "multi-skilled employees" have the highest weight, followed by "customer requirement analysis and prioritization." For performance metrics, "the number of innovative products launched per year" is ranked first, with the "average time between two launches" in second place.

Margherita and Braccini (2023) investigated the implementation of Industry 4.0 technologies in flexible manufacturing to enhance sustainable organizational value through a multiple case study of four Italian manufacturing companies. The study found that these technologies support sustainable organizational value when applied with a focus on workers. In such settings, organizations leverage workforce activities to continuously optimize the technologies and utilize their adaptive features to improve processes consistently.

Kamble and Gunasekaran (2023) explored the impact of Industry 4.0 technologies and circular economy practices on sustainable performance in Indian manufacturing organizations. By surveying 238 manufacturing practitioners in India, the study examined how circular economy practices mediate and moderate the relationship between Industry 4.0 technologies and sustainable performance. The findings indicate that creating a circular economy environment is not essential for implementing Industry 4.0 technologies. However, these technologies do facilitate the development of an efficient circular economy, which in turn supports achieving sustainable organizational goals.

Yavuz et al. (2023) used a natural resource-based view and the technology-organization-environment framework to test a model where sustainable operations practices mediate the effect of Industry 4.0 technologies on sustainable performance. Data from 302 participants in Turkey's technology development regions were analyzed using partial least squares structural equation modeling. The results showed that sustainable operations practices mediate the impact of Industry 4.0 technologies on sustainable performance.

Ferreira et al. (2023) examined the role of digital technologies in promoting environmental and social sustainability in European manufacturing multinational enterprises using the Resource-Based View. The research model included five digital technologies—Artificial Intelligence, Cloud Computing, Robotics, Big Data Analytics, and Blockchain—and their influence on sustainable practices. Using Partial Least Squares to analyze data from 764 European manufacturing multinational enterprises, the study found that while digital technologies generally enhance environmental and social sustainability, the impact varies by technology, suggesting that companies can prioritize investments based on expected returns.

Kong and Liu (2023) studied the effects of digital technologies on corporate social responsibility (CSR) among firms listed on China's stock markets from 2009 to 2019. Their findings indicate that digital transformation significantly boosts CSR performance. This

relationship held true even when considering the exogenous shock of China's 4G-LTE policy. Mechanistic analysis revealed that digital technologies help companies improve pollution control and internal control efficiency, thereby enhancing CSR. The positive impact was more pronounced in firms with low financing constraints and higher regulatory pressure.

Khan et al. (2023) synthesized research on how Industry 4.0 technologies and various innovations contribute to sustainable development. Analyzing 58 journal articles, the review highlighted that Industry 4.0 facilitates multiple types of innovation—process, product, business model, supply chain, organizational, open, and marketing—which support triple bottom line sustainability, circular economy, sustainable business models, and the achievement of sustainable development goals.

Bai et al. (2022) explored the potential of Industry 4.0 technologies to achieve the United Nations' sustainable development goals through a circular economy approach. The paper presented a framework to evaluate the relationship between Industry 4.0 technologies, sustainable development goals, and circular economy practices. Using a predictive method that integrated DEMATEL and a linear model, the study evaluated these relationships with data from the electronics industry, identifying circular economy practices as a crucial link between Industry 4.0 technologies and sustainable development goals.

2. Materials and Methods

The study deployed descriptive survey research design. The research design that was adopted by the study is justified because the study primarily attempts to survey the opinion of a sample that is taken out of a population in order to elicit information as regards a particular issue of concern (Nworie & Oguejiofor, 2023; Nworie et al., 2023). The population of the study consists of all staff in the information and communication units of Nigerian manufacturing firms. A definite population could not be obtained for a scope as wide as this. Hence, sample size of 452 respondents was obtained based on the number that responded to the research instrument administered online. The questionnaire was developed in line with four (4) point likert scale that were ranked "strongly agree", "agree", "disagree" and "strongly disagree" with each rank corresponding to 4,3,2, and 1, respectively. The responses were presented using frequency analysis while the Spearman Ranked Order Correlation Analysis was used in testing the three null hypotheses of the study.

3. Results and Discussion

Data Presentation

Table 1. Data Presentation

S/N	**Artificial Intelligence (AI)**	**SA**	**A**	**D**	**SD**
1	The integration of AI in manufacturing processes reduces operational costs.	352	36	40	24
2	AI-driven predictive maintenance decreases equipment downtime.	314	84	42	12
3	AI technology enhances decision-making processes.	344	42	48	18
4	AI adoption provides a competitive edge for manufacturing companies.	350	36	48	18
S/N	**Internet of Things (IoT)**	**SA**	**A**	**D**	**SD**
5	IoT devices improves real-time monitoring capabilities in manufacturing companies	354	48	36	14

6	The use of IoT streamlines supply chain management.	182	50	134	86
7	IoT implementation brings economic benefits that strengthens firm value.	188	52	126	86
8	IoT has plays a significant role in reducing production costs.	180	42	136	94
S/N	**Big Data Analytics**	**SA**	**A**	**D**	**SD**
9	Big Data Analytics provides useful hints that enhance production processes.	108	90	142	112
10	The use of Big Data Analytics improves customer service.	150	48	130	124
11	Big Data Analytics helps to identify and mitigate risks.	126	60	114	152
12	Big Data Analytics enhances firm ability to forecast market trends.	144	24	144	140
S/N	**Corporate Technological Responsibility**	**SA**	**A**	**D**	**SD**
13	Our company ensures the ethical use of technology in all our operations.	96	48	162	146
14	We prioritize data privacy and security in our technological implementations.	78	54	178	142
15	Our company see no need to employ more staff when technology can perform the job better	90	60	162	140
16	We actively seek to reduce the environmental impact of our technological processes.	132	42	108	170

Source: Field Survey (2024)

The frequency table presents data on various aspects of technology integration in manufacturing, with responses measured on a Likert scale of Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD). For Artificial Intelligence (AI), the first item highlights that a significant majority of respondents, 352, strongly agree that the integration of AI in manufacturing processes reduces operational costs, while 36 agree, 40 disagree, and 24 strongly disagree. This indicates a strong consensus on the cost-reduction benefits of AI in manufacturing. The second item shows that 314 respondents strongly agree that AI-driven predictive maintenance decreases equipment downtime, with 84 agreeing, 42 disagreeing, and 12 strongly disagreeing, demonstrating broad support for AI's role in minimizing downtime. The third item reveals that 344 respondents strongly agree that AI technology enhances decision-making processes, 42 agree, 48 disagree, and 18 strongly disagree, again indicating a strong belief in AI's positive impact on decision-making. The fourth item indicates that 350 respondents strongly agree that AI adoption provides a competitive edge for manufacturing companies, with 36 agreeing, 48 disagreeing, and 18 strongly disagreeing, showing strong support for the competitive advantages of AI.

For the Internet of Things (IoT), the first item shows that 354 respondents strongly agree that IoT devices improve real-time monitoring capabilities in manufacturing companies, with 48 agreeing, 36 disagreeing, and 14 strongly disagreeing, indicating strong support for IoT's monitoring benefits. The second item is less favorable, with 182 respondents strongly agreeing that IoT streamlines supply chain management, 50 agreeing, but a significant number, 134, disagreeing and 86 strongly disagreeing, showing a divided opinion on IoT's effectiveness in supply chain management. The third item also shows a split opinion, with 188 respondents strongly agreeing that IoT implementation brings economic benefits that strengthen firm value, 52 agreeing, 126 disagreeing, and 86 strongly disagreeing. The fourth item is similarly divided, with 180 respondents strongly agreeing that IoT plays a significant role in reducing production costs, 42 agreeing, 136 disagreeing, and 94 strongly disagreeing.

For Big Data Analytics, the first item reveals mixed opinions, with 108 respondents strongly agreeing that Big Data Analytics provides useful hints that enhance

production processes, 90 agreeing, 142 disagreeing, and 112 strongly disagreeing. The second item shows that 150 respondents strongly agree that the use of Big Data Analytics improves customer service, 48 agreeing, but a significant number, 130, disagreeing, and 124 strongly disagreeing, indicating diverse views on its impact on customer service. The third item shows that 126 respondents strongly agree that Big Data Analytics helps identify and mitigate risks, 60 agreeing, 114 disagreeing, and 152 strongly disagreeing, reflecting mixed opinions. The fourth item indicates that 144 respondents strongly agree that Big Data Analytics enhances a firm's ability to forecast market trends, 24 agree, but 144 disagree, and 140 strongly disagree, showing a split view on its forecasting capabilities.

For Corporate Technological Responsibility, the first item shows that 96 respondents strongly agree that their company ensures the ethical use of technology in all operations, 48 agreeing, but a significant number, 162, disagreeing, and 146 strongly disagreeing, indicating a divided perspective on ethical technology use. The second item reveals that 78 respondents strongly agree that they prioritize data privacy and security in technological implementations, 54 agreeing, but 178 disagreeing, and 142 strongly disagreeing, indicating concerns about data privacy and security. The third item shows that 90 respondents strongly agree that there is no need to employ more staff when technology can perform the job better, 60 agreeing, but 162 disagreeing, and 140 strongly disagreeing, reflecting mixed views on staff employment vs. technology use. The fourth item indicates that 132 respondents strongly agree that their company actively seeks to reduce the environmental impact of technological processes, 42 agreeing, but 108 disagreeing, and 170 strongly disagreeing, showing varied opinions on environmental responsibility.

Test of Hypotheses

Hypothesis I

1) There is a positive relationship between artificial intelligence adoption and corporate technological responsibility among manufacturing firms in Nigeria.

Table . Correlations for Hypothesis I

			Corporate Technological Responsibility
Spearman's rho	Artificial Intelligence	Correlation Coefficient	-.567**
		Sig. (2-tailed)	.000
		N	452

Source: SPSS V. 25

The first hypothesis investigates the relationship between artificial intelligence (AI) adoption and corporate technological responsibility among manufacturing firms in Nigeria. According to Table 2, the Spearman's rho correlation coefficient for this relationship is -0.567 with a p-value of 0.000. This negative correlation indicates a significant inverse relationship between AI adoption and corporate technological responsibility. As AI adoption increases, corporate technological responsibility tends to decrease among the surveyed manufacturing firms in Nigeria.

One possible explanation for this result is that the integration of AI in manufacturing processes might prioritize efficiency and cost reduction over ethical considerations (Stefanini & Vignali, 2024). Firms may focus on leveraging AI to enhance operational

performance without equally investing in the frameworks needed to ensure ethical AI usage, such as robust data privacy measures and transparency in AI decision-making processes. More also, it is possible that this negative relationship is because the advent of AI has replaced human capital with machine, resulting in loss of job (Stefanini & Vignali, 2024). This finding however negates the positions of Kamble and Gunasekaran (2023) that these technologies do facilitate the development of an efficient circular economy, which in turn supports achieving sustainable organizational goals (Ferreira et al., 2023).

Hypothesis II

2) Internet of Things adoption positively relates to corporate technological responsibility among manufacturing firms in Nigeria.

Table 3. Correlations for Hypothesis II

			Corporate Technological Responsibility
Spearman's rho	Internet-of-Things	Correlation Coefficient	.548**
		Sig. (2-tailed)	.000
		N	452

Source: SPSS V. 25

The second hypothesis examines whether the adoption of the Internet of Things (IoT) positively relates to corporate technological responsibility among manufacturing firms in Nigeria. Table 3 shows a Spearman's rho correlation coefficient of 0.548, with a p-value of 0.000. This result signifies a strong and statistically significant positive correlation, suggesting that increased IoT adoption is associated with higher levels of corporate technological responsibility in Nigerian manufacturing firms.

The likely reason for this result is that IoT technologies inherently improve transparency and real-time monitoring capabilities within manufacturing processes. By enabling real-time tracking of operations and supply chains, IoT can help firms to better manage their resources, reduce waste, and monitor compliance with ethical standards. Consequently, the adoption of IoT can drive firms to be more proactive in maintaining responsible technological practices, thereby enhancing their overall corporate technological responsibility. This aligns with the position by Ferreira et al. (2023) and Kong and Liu (2023) that these technology promote CTR.

Hypothesis III

3) Big data analytics positively relates to corporate technological responsibility among manufacturing firms in Nigeria.

Table 4. Correlations for Hypothesis III

			Corporate Technological Responsibility
Spearman's rho	Big Data Analytics	Correlation Coefficient	.850**

	Sig. (2-tailed)	.000
	N	452

Source: SPSS V. 25

The third hypothesis explores the relationship between big data analytics and corporate technological responsibility among manufacturing firms in Nigeria. As shown in Table 4, the Spearman's rho correlation coefficient is 0.850, with a p-value of 0.000. This high positive correlation indicates a very strong and statistically significant relationship, meaning that greater adoption of big data analytics is strongly associated with enhanced corporate technological responsibility among the manufacturing firms in the study.

The reason behind this robust relationship could be that big data analytics equips firms with the ability to gather and analyze vast amounts of information, leading to better decision-making and strategic planning. With access to detailed hints, firms can more effectively identify areas where ethical improvements are needed, such as data privacy, risk management, and sustainability practices. As a result, the comprehensive capabilities of big data analytics in providing actionable hints strongly support the enhancement of corporate technological responsibility (AlZayani et al., 2024).

4. Conclusion

Industry 4.0, characterized by advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and big data analytics, is transforming the manufacturing sector globally, including in Nigeria. These technologies offer opportunities for increased efficiency, innovation, and competitiveness. However, their adoption also raises concerns about corporate technological responsibility, which involves the ethical and responsible use of technology in ways that align with societal values, environmental sustainability, and ethical standards. The study found a significant inverse relationship between AI adoption and corporate technological responsibility. This suggests that as AI adoption increases, the level of corporate technological responsibility decreases, perhaps because AI implementation often prioritizes operational efficiency and cost reduction over ethical considerations and social impacts. For example, AI-driven automation can lead to job displacement, raising ethical concerns about the social responsibilities of companies toward their employees. Additionally, the use of AI in decision-making processes can sometimes result in biased or unethical outcomes if not properly managed. Therefore, the recommendation is for the Chief Technology Officers (CTOs) of manufacturing firms to integrate ethical guidelines and social impact assessments into their AI deployment strategies to ensure that the technology is used responsibly.

Based on the findings, the integration of IoT technologies enhances a company's commitment to ethical practices and sustainability. IoT devices facilitate real-time monitoring and data collection, which can improve transparency and accountability in manufacturing processes. For instance, IoT can help track environmental metrics such as energy consumption and emissions, enabling companies to implement more sustainable practices. The recommendation here is for the heads of sustainability departments to leverage IoT technology to continuously monitor and improve the environmental and ethical impacts of their operations. Finally, the use of big data analytics contributes positively to a company's ethical and responsible practices. Even, big data analytics can help in identifying areas where waste can be reduced, thereby supporting environmental

sustainability efforts. Based on this finding, the recommendation is for data analytics teams to prioritize the inclusion of ethical and sustainability metrics in their data analyses to support responsible decision-making processes.

In conclusion, AI adoption currently presents challenges that need addressing through more robust ethical frameworks. In contrast, IoT and big data analytics show promising positive effects, reinforcing the importance of these technologies in promoting responsible corporate practices. For manufacturing firms in Nigeria, responsible implementation of Industry 4.0 practices will help balance technological advancement with ethical responsibility, ensuring sustainable and socially responsible growth.

REFERENCES

AL-Khatib, A. W., Shuhaiber, A., Mashal, I., & Al-Okaily, M. (2024). Antecedents of Industry 4.0 capabilities and technological innovation: a dynamic capabilities perspective. *European Business Review*, *36*(4), 566-587.

AlZayani, F., Mohammed, A., & Shoaib, H. M. (2024). The impact of smart technologies on SMEs' sustainability: the mediation effect of sustainability strategy. *Competitiveness Review: An International Business Journal*, *34*(1), 28-50.

Angermann, N. P. (2023). *The challenge of corporate digital responsibility: an analysis of key elements for CDR implementation* (Doctoral dissertation).

Bai, C., Orzes, G., & Sarkis, J. (2022). Exploring the impact of Industry 4.0 technologies on social sustainability through a circular economy approach. *Industrial Marketing Management*, *101*, 176-190.

Channi, H. K., & Kumar, R. (2024). Digital technologies for fostering sustainability in Industry 4.0. In *Evolution and Trends of Sustainable Approaches* (pp. 227-251). Elsevier.

Cheng, C., & Zhang, M. (2023). Conceptualizing corporate digital responsibility: a digital technology development perspective. *Sustainability*, *15*(3), 2319.

Chung, K., Thaichon, P., & Quach, S. (2022). Types of artificial intelligence (AI) in marketing management. In *Artificial intelligence for marketing management* (pp. 29-40). Routledge.

Cordeiro, R. F., Reis, L. P., & Fernandes, J. M. (2024). A study on the barriers that impact the adoption of Industry 4.0 in the context of Brazilian companies. *The TQM Journal*, *36*(1), 361-384.

Ferreira, J. J., Lopes, J. M., Gomes, S., & Rammal, H. G. (2023). Industry 4.0 implementation: Environmental and social sustainability in manufacturing multinational enterprises. *Journal of Cleaner Production*, *404*, 136841.

Garg, D., Mustaqueem, O. A., & Kumar, R. (2021). Industry 4.0 technologies and ethical sustainability. In *Advances in Industrial and Production Engineering: Select Proceedings of FLAME 2020* (pp. 189-199). Springer Singapore.

Hossain, M. I., Kumar, J., Islam, M. T., & Valeri, M. (2024). The interplay among paradoxical leadership, industry 4.0 technologies, organisational ambidexterity, strategic flexibility and corporate sustainable performance in manufacturing SMEs of Malaysia. *European Business Review*, *36*(5), 639-669.

Javaid, M., Haleem, A., Singh, R. P., Suman, R., & Gonzalez, E. S. (2022). Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. *Sustainable Operations and Computers*, *3*, 203-217.

Kamble, S. S., & Gunasekaran, A. (2023). Analysing the role of Industry 4.0 technologies and circular economy practices in improving sustainable performance in Indian manufacturing organisations. *Production planning & control*, *34*(10), 887-901.

Khan, I. S., Ahmad, M. O., & Majava, J. (2023). Industry 4.0 innovations and their implications: An evaluation from sustainable development perspective. *Journal of Cleaner Production*, *405*, 137006.

Kılıç, C., & Atilla, G. (2024). Industry 4.0 and sustainable business models: An intercontinental sample. *Business Strategy and the Environment*, *33*(4), 3142-3166.

Kong, D., & Liu, B. (2023). Digital technology and corporate social responsibility: evidence from China. *Emerging Markets Finance and Trade*, *59*(9), 2967-2993.

Kunz, W. H., & Wirtz, J. (2024). Corporate digital responsibility (CDR) in the age of AI: implications for interactive marketing. *Journal of Research in Interactive Marketing*, *18*(1), 31-37.

Lobschat, L., Mueller, B., Eggers, F., Brandimarte, L., Diefenbach, S., Kroschke, M., & Wirtz, J. (2021). Corporate digital responsibility. *Journal of Business Research*, *122*, 875-888.

Malik, A., Sharma, S., Batra, I., Sharma, C., Kaswan, M. S., & Garza-Reyes, J. A. (2024). Industrial revolution and environmental sustainability: an analytical interpretation of research constituents in Industry 4.0. *International Journal of Lean Six Sigma*, *15*(1), 22-49.

Margherita, E. G., & Braccini, A. M. (2023). Industry 4.0 technologies in flexible manufacturing for sustainable organizational value: reflections from a multiple case study of Italian manufacturers. *Information Systems Frontiers*, *25*(3), 995-1016.

Margherita, E. G., & Braccini, A. M. (2024). The impact of Industry 4.0 technologies and the soft side of TQM on organisational performance: a multiple case study analysis on manufacturing organisations. *The TQM Journal*, *36*(3), 812-831.

Martinez, R. (2018). Artificial intelligence: Distinguishing between types & definitions. *Nev. LJ*, *19*, 1015.

Meshack, A., Orji, M. G., Aggreh, M. S. & Nworie, G. O. (2022). Achieving Sustainable Development Agenda of 2030: The Role of Accountants. *Britain International of Humanities and Social Sciences (BIoHS) Journal*, *4*(3), 543-556. DOI: 10.33258/biohs.v4i3.788

Mu, X., & Antwi-Afari, M. F. (2024). The applications of Internet of Things (IoT) in industrial management: a science mapping review. *International Journal of Production Research*, *62*(5), 1928-1952.

Narkhede, G., Mahajan, S., Narkhede, R., & Chaudhari, T. (2024). Significance of Industry 4.0 technologies in major work functions of manufacturing for sustainable development of small and medium-sized enterprises. *Business Strategy & Development*, *7*(1), e325.

Nworie, G. O. & Oguejiofor, B. C. (2023). Management Information System and Performance of Cement Firms in Southeast Nigeria. *International Journal of Accounting and Management Information Systems*, *1*(1), 1–15. https://doi.org/10.35912/ijamis.v1i1.1366

Nworie, G. O., Okafor, T. G., Igwebuike, C. C. & Onyali, C. I. (2023). Utilizing Cost-Volume-Profit Analysis for Informed Decision Making in Small Business Management. *Central Asian Journal of Innovations on Tourism Management and Finance*, *4*(2), 102-115. https://cajitmf.centralasianstudies.org/index.php/CAJITMF/article/view/429/451

Okafor, O. O., Nworie, G. O., & Onyebuchi, M. H. (2024). Assessing Financial Returns Through Environmental Responsibility Disclosure Among Listed Oil and Gas Firms in Nigeria. *International Journal of Research Publication and Reviews*, *5*(4), 545-557. https://ijrpr.com/uploads/V5ISSUE4/IJRPR24579.pdf

Oláh, J., Aburumman, N., Popp, J., Khan, M. A., Haddad, H., & Kitukutha, N. (2020). Impact of Industry 4.0 on environmental sustainability. *Sustainability*, *12*(11), 4674.

Palsodkar, M., Yadav, G., & Nagare, M. R. (2024). Integrating Industry 4.0 and agile new product development practices to evaluate the penetration of sustainable development goals in manufacturing industries. *Journal of Engineering, Design and Technology*, *22*(4), 1351-1392.

Pandya, D., & Kumar, G. (2023). Applying Industry 4.0 technologies for the sustainability of small service enterprises. *Service Business*, *17*(1), 37-59.

Pozzi, R., Rossi, T., & Secchi, R. (2023). Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies. *Production Planning & Control*, *34*(2), 139-158.

Rahanu, H., Georgiadou, E., Siakas, K., Ross, M., & Berki, E. (2021). Ethical issues invoked by Industry 4.0. In *Systems, Software and Services Process Improvement: 28th European Conference, EuroSPI 2021, Krems, Austria, September 1–3, 2021, Proceedings 28* (pp. 589-606). Springer International Publishing.

Satyro, W. C., de Almeida, C. M. V. B., Pinto Jr Jr, M. J. A., Contador, J. C., Giannetti, B. F., de Lima, A. F., & Fragomeni, M. A. (2022). Industry 4.0 implementation: The relevance of sustainability and the potential social impact in a developing country. *Journal of Cleaner Production*, *337*, 130456.

Stefanini, R., & Vignali, G. (2024). The influence of Industry 4.0 enabling technologies on social, economic and environmental sustainability of the food sector. *International Journal of Production Research*, *62*(10), 3800-3817.

Ukoh, U. M., Nduokafor, C. O. & Nworie, G. O. (2024). Sustainability Reporting among Oil and Gas Firms: a Strategic Tool for Enhanced Firm Value. *International Journal of Economics and Financial Management*, *9*(2), 144-166**.** https://doi.org/10.56201/ijefm.v9.no2.2024.pg144.166

Wynn, M., & Jones, P. (2023). Corporate responsibility in the digital era. *Information*, *14*(6), 324.

Yavuz, O., Uner, M. M., Okumus, F., & Karatepe, O. M. (2023). Industry 4.0 technologies, sustainable operations practices and their impacts on sustainable performance. *Journal of Cleaner Production*, *387*, 135951.

Zhong, Y., & Moon, H. C. (2023). Investigating the impact of Industry 4.0 technology through a TOE-based innovation model. *Systems*, *11*(6), 277.