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Exploring the effects of Industrial Digital Technology on Sustainable Firm's Performance with a mediating role of Green Supply Chain Management Practices in FMCG Industry of Pakistan

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Abstract
This paper explores the contribution of Industry 4.0 digital technologies to Sustainable Firm Performance (SFP) in Pakistan through the FMCG manufacturing industry, where the focus is on the Green Supply Chain Management (GSCM) practices as intermediaries. Although there has been a global change to digital and sustainability-based operations, there is still limited empirical research in developing economies, especially on how technological capabilities can be combined with green operations to improve the performance in terms of triple-bottom-line. To cover this gap, the research relies on the Practice-Based View (PBV) and the Information Processing Theory (IPT) to develop a holistic conceptual framework. FMCG manufacturing firms were surveyed using structured survey and the data was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results indicate that such core Industry 4.0 technologies as IoT-monitored monitoring, big data analytics, AI-based decision systems, and blockchain-supported traceability play an important role in enhancing several dimensions of GSCM, including green design, green information systems, green procurement, internal resource development, and reverse logistics. Nonetheless, green manufacturing did not display a high direct effect. The findings also show that the practices of GSCM have a crucial mediating role

and it means that the digital technologies generate sustainable value mainly due to better coordination, cleaner processes and greater supply chain transparency. The positive impacts of sustainable Firm Performance on economic, environmental and social results were strong, which validated the significance of the measure as a combined indicator of organizational sustainability and competitiveness.

Keywords: Industry 4.0; Digital Technologies; Green Supply Chain Management (GSCM); Sustainable Firm Performance (SFP); FMCG Sector; Pakistan; PLS-SEM; Sustainability Practices.

Introduction

Background of the Study

The economic environment of the first half of the twenty-first century has adopted a phase of technological and structural change that has never been seen before, which is often called the Fourth Industrial Revolution or Industry 4.0 (Khan et al., 2023). The core aspect of this change is the heavy involvement of digital technologies into the conventional industrial and supply chain systems that radically changes the way organizations design, operate, and run their processes (Tortorella et al., 2021). The Industry 4.0 concept has received significant, enduring interest among researchers, practitioners, and policymakers since its formal introduction in 2011 owing to its tremendous opportunity to transform the industrial competitiveness, paradigms of operation, and long-term sustainability courses (Frank et al., 2019; Nascimento et al., 2019). The introduction of this revolution reflects the break with incremental innovation in favor of systemic reconfiguration of value creation, due to the overlapping of the physical and digital world in industrial ecosystems.

Although both Industry 4.0 and GSCM are becoming the subject of growing scholarly and practical attention as individual areas, no strong empirical studies investigate the combined and interactive influence of both concepts on sustainable performance, especially in the particular setting of the developing economy like that of Pakistan (Sharma et al., 2021). Most of the existing literature has been performed in developed nations with developed technological infrastructure, well-developed regulatory systems, and varying market dynamics, which, in turn, not only restricts the use and transferability of their results to emerging markets that have different constraints and opportunities (Horváth and Szabo, 2019). The proposed research is aimed at filling in this important contextual and empirical gap by rigorously analyzing the role of digital technologies in increasing sustainable performance through the mediating variable of GSCM practices in the strategically relevant FMCG sector in Pakistan.

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Problem Statement

Whereas the Industry 4.0 technologies have been largely accepted as the powerful tools of the operational excellence and possibly the source of sustainability, their successful implementation and alignment with the sustainability objectives are a major and under-researched challenge faced by the firms in emerging economies (Reza et al., 2024). The state of digital transformation efforts in the FMCG sector in Pakistan is highly fragmented, ad-hoc, and has a low awareness of integrating into supply chain strategies where the success would be long-term and sustainable (Ali et al., 2022). Several companies invest in isolated digital solutions (individual enterprise resource planning (ERP) systems or even individual automation technologies) without planning how these investments are intended to support overall environmental and social goals or even integrating them into a holistic GSCM model (Majumdar et al., 2021). The consequence of this disconnection is the suboptimal use of technological capabilities and lost opportunities of creation of synergistic sustainable value.

Research Objectives

- To investigate the existing percentage, nature, and the motivation of Industry 4.0 digital technology adoption (e.g., IoT, AI, Blockchain, Big Data Analytics) in the context of FMCG manufacturing companies in management in Pakistan.

Essentially, the data to be analyzed will reveal the character and power of the relationship between the adoption of Industry 4.0 digital technologies and multifaceted practices of the Green Supply Chain Management (GSCM).

- To determine the direct effect of GSCM practices on the triple-bottom-line aspects of sustainable performance: economic performance, environmental performance and social performance.
- To empirically measure mediating contributions of GSCM practices between Industry 4.0 digital technology adoption and sustainable performance, thus, testing the mediating role of technology in translating digital technology into a sustainable performance.

The objectives of the research include: (1) to generate and present actionable and contextually-supportive insights and advice to managers, supply chain experts, and policymakers to improve sustainability by strategically aligned digital transformation programs.

Research Questions

RQ1. How is Industry 4.0 digital technologies affecting sustainable performance of FMCG industry in Pakistan?

RQ2. How does the adoption of Industry 4.0 digital technologies relate to the level of implementation of different Green Supply Chain Management (GSCM) practices?
RQ3. Which specific impacts on the three aspects of sustainable performance economic, environmental, and social do GSCM practices have?
RQ4. Are GSCM practices a significant mediator of the relationship between Industry 4.0 adoption of digital technology and sustainable performance and to what degree?
RQ5. What are the strategic, operational and policy implications of these findings to inform the FMCG firms and stakeholders in a developing economy such as Pakistan?

Literature Review

Industry 4.0 has evolved over the last few years and is now considered an overall digital ecosystem, which consists of integrated high-technoloogy systems to establish intelligent, connected and autonomous production and supply chain systems. The fourth industrial revolution can be defined as a smooth integration of operational technology (OT) and information technology (IT) that allows real-time data exchange, predictive data analytics, and automated decision-making at manufacturing and distribution networks. The Internet of Things (IoT) to interconnect physical assets, cloud computing to store and process data on a scale, artificial intelligence (AI) and machine learning to identify patterns and optimize them, and blockchain to make transactions transparent and secure are the core technologies that support this transformation (Frank, Dalenogare, and Ayala, 2019). All of these technologies make possible what researchers refer to as smart manufacturing, or as digital supply chains, whereby systems have the capacity to self-monitor, self-diagnose, and self-optimize with limited human involvement.

Theoretically, the development of Industry 4.0 is very in line with the development of the Information Processing Theory that has grown beyond its scope in its original focus in organization design to include how digital systems process huge masses of information in real-time. Modern uses of this theory also focus on the way in which digital technologies change information as a passive resource into the active asset that leads to constant improvement and innovation (Li, Wu, Cao, and Wang, 2021). This theoretical perspective is useful in explaining why the companies that successfully capitalize on the digital information flows gain an advantageous position in terms of the operational performance and adaptation to the changes in the market environment than their less advanced information processing systems.

The Pakistani FMCG industry is a unique environment of digital technology adoption marked by what the scholars refer to as frugal innovation that is characterized by massive results through adaptive resourcefulness. Within 2020-2024, the largest FMCG companies in Pakistan applied specific digital solutions to particular issues in the country. An example is Engro Foods, which installed an IoT-based cold chain management system on the dairy logistics system of the

country, which Pakistan has with numerous infrastructure constraints, such that unreliable refrigeration during transit leads to severe spoilage of the product. This system is based on inexpensive sensors and long battery life and the possibility to store the information offline, and only when the network connection is established, the information is synchronized, as opposed to having to be constantly connected to the internet (Khan and Abbas, 2024). Likewise, Nestle Pakistan adopted an AI-based demand planning framework that is specifically tuned to the consumption peculiarities of Pakistan that quickly changes if not during Ramadan, Eid festivals, and seasonal shifts. This system would be 22 percent more accurate than the conventional forecasting approaches because it would consider localized variables such as regional precipitation patterns influencing agricultural production, schedules of electricity load shedding affecting production, and sentiment analysis of social media, which would determine the shift in brand perception (SECP, 2023).

These sectoral trends have been found to have theoretical links with the current trends in Practice-Based View (PBV) which puts more emphasis on how competitive advantage is gained out of competent execution of practices and not the presence of resources. Within the framework of the FMCG in Pakistan, this outlook has been the reason why certain companies will deliver better results with comparatively simple technologies via superb execution approaches, such as a comprehensive needs assessment, meticulous change management, unceasing training and methodical performance measurement. The relevance of this theoretical orientation to shifting the focus of attention is that technology acquisition is moved to technology integration, that is, the way digital tools are embedded in organizational routines and capabilities that can provide long-term value.

Green Supply Chain Management Practices: Modern Schemes and application in the new markets

The concept of Green Supply Chain Management (GSCM) has been transformed into a strategic requirement rather than a fringe environmental program of the various FMCG firms all over the globe, owing to regulatory needs, consumer demands, scarcity of resources, and competitive forces. The modern GSCM models are based on the principles of a circular economy wherein resource use is maximized and waste is reduced by creating closed-loop systems. The six-dimensional model discussed in the present study the green manufacturing, green purchasing, green design, green information systems, reverse logistics, and investment recovery are a holistic model that covers all the environmental effects throughout the product lifecycle (Umar, Khan, Yusliza, Ali, & Yu, 2022). The recent studies have shown that synergistic benefits are produced by integrated implementation at many dimensions in a way that the impact of each practice is greater than the sum of its impacts on the environment, which illustrates the significance of holistic and not piecemeal approaches to environmental management.

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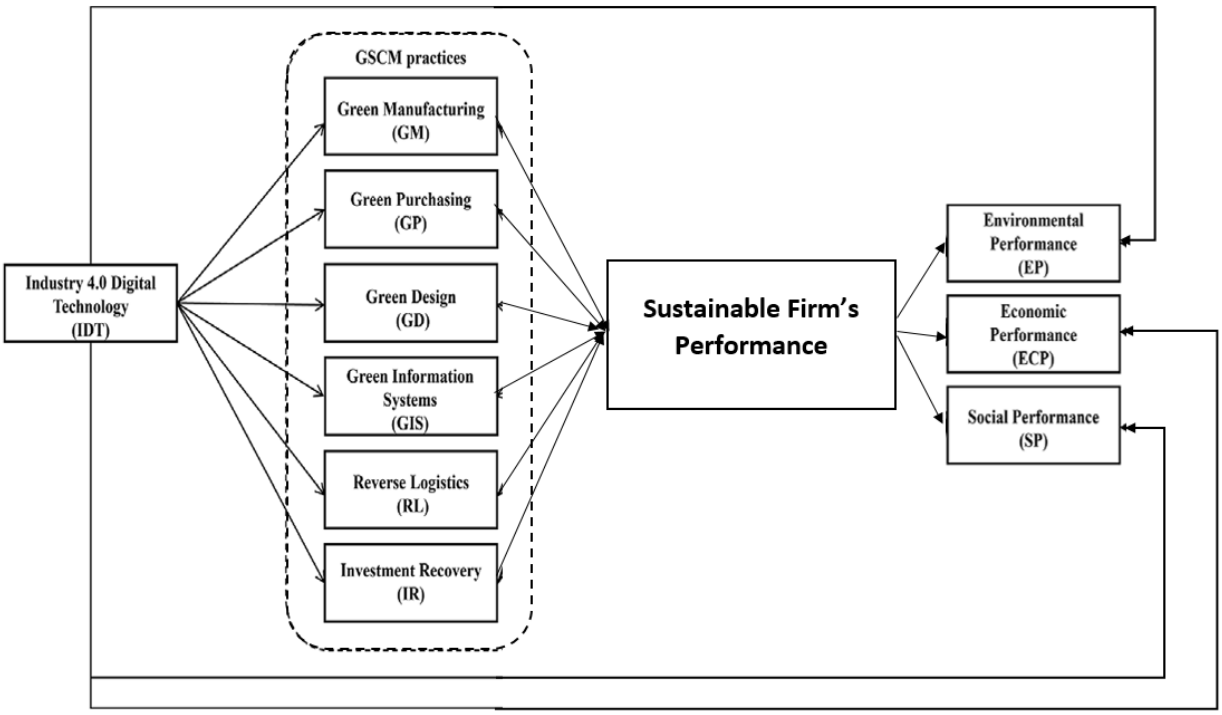
Research Gap

Although major research breakthroughs have occurred in the recent years, critical gaps in comprehending the effects that digital technologies can have on sustainable performance based on GSCM practices in emergent economy FMCG industries remain. The current literature has various limitations that are filled in this study by its narrowed-down analysis of the FMCG industry of Pakistan. To begin with, the majority of empirical studies still focus on developed economies or manufacture, and little is done in the context of South Asia where unique digital and environmental shifts are taking place. This geographic concentration creates a narrow view on how infrastructural limitations, regulatory systems, market forms and cultural beliefs



influence the adoption of technologies and environmental behavior in various institutional contexts. In spite of the fact that Pakistani-specific research is still limited, the country is ranked as the fifth most populated in the world with a fast-growing consumer population and having urgent environmental issues that require immediate attention.

Figure 1 Conceptual Framework

Hypothesis Development

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Digital Technology and Environmental Performance

Digital technologies provide new possibilities in monitoring and optimization of the environment. The IoT allows tracking energy, water, and emissions in real-time at manufacturing plants and logistics systems (Ben-Daya, Hassini, and Bahroun, 2019). This real-time, granular data enables real-time detection of inefficiencies and proactive maintenance to avoid the wastage of resources. Big Data Analytics would be able to analyze complex datasets of the environment to uncover patterns and areas of optimization that otherwise would have been not apparent using conventional methods of analysis (Bag, Wood, Xu, and Kumar, 2020). Artificial Intelligence algorithms will be able to optimize production schedules to minimize energy use during peak tariffs and minimize waste of materials through precision production (Birkel and Muller, 2021). Moreover, due to blockchain technology, it is possible to trace the environmental impact of the supply chain into the air in a transparent manner and conduct carbon accounting and sustainability claims verification (Saberi, Kouhizadeh, and Sarkis, 2019).

Economic Performance and Digital Technology

The advantages of Industry 4.0 technologies to the economy are a well-documented topic in the world literature. IoT sensors and AI-based predictive maintenance minimize surprising downtimes and increase the lifetime of equipment (Tortorella, Giglio, and van Dun, 2021). Intelligent analytics enhance the accuracy of demand forecasting and decrease inventory carrying costs and stockouts (Chauhan and Singh, 2022). Automation and robotics increase productivity of labour and consistency of production. The benefits of these efficiencies are directly proportional to better profitability, ROI and market responsiveness. New business models that can be enabled by digital technologies are product-as-a-service or the circular economy models that generate new sources of revenue and minimize environmental effects (Khan, Idrees, and Haider, 2023).

Digital Technology and Social Performance

Social aspect of sustainability includes health and safety of workers, social relations of the community and ethical business practices. There are a number of ways through which digital technologies affect social performance. Dangerous and repetitive work can be done by collaborative robots (cobots), which ensure fewer injuries and accidents in the workplace. On-line trainings have the potential to boost employees competence and safety consciousness. It is also possible to guarantee the supply chain transparency by the blockchain, which validates the ethics of sourcing and the presence of fair labour conditions (Saberi, Kouhizadeh, and Sarkis, 2019). The analytics of social media can assist the companies to comprehend and act on the issues of the community, and online platforms can assist the stakeholders to interact and become transparent.

On the basis of these mutually dependent relationships between all three dimensions of sustainability, we suggest:

H1: There is a strong positive effect of Industry 4.0 Digital Technology upon the Environmental Performance of FMCG firms in Pakistan.
H 2: The Economic Performance of FMCG firms in Pakistan is significantly positively influenced by the adoption of Industry 4.0 Digital Technology.
H3: The adoption of Industry 4.0 Digital Technology is positively related to the Social Performance of FMCG firms in Pakistan significantly.

Green Manufacturing and Digital Technology

Green Manufacturing refers to an alteration of production process to be less harmful to the environment by minimizing waste, energy usage, and less toxic production methods. The digital technologies facilitate Green Manufacturing in several aspects. The IoT sensors ensure that the performance of the machines, energy use, and emissions are monitored in real-time, and adjustments are applied immediately (Khan, Idrees, and Haider, 2023). The AI algorithms may optimize production parameters in real-time to reduce waste and energy consumption and meet the quality standards. The physical systems simulated and optimized in digital twins in advance of the implementation reduce the waste of trial-and-error; this is because the digital twin can replicate the real environment of a physical system. Additive manufacturing (3D printing) allows on-demand production to minimize the amount of waste during material production as opposed to subtractive manufacturing (Ghobakhloo, 2020).
H4: The adoption of Industry 4.0 Digital Technology has a strong positive association with Green Manufacturing practices of Pakistani FMCG firms.

Green Purchasing and Digital Technology

Green Purchasing is characterized by the process of identifying suppliers according to the environmental standards and by cooperating with them to enhance the environmental results. Digital technologies can change Green Purchasing by offering the ability to assess suppliers, monitor them and cooperate with them in a comprehensive manner. Blockchain systems establish transparent and non-modifiable databases of suppliers on their environmental certification and performance information (Kouhizadeh and Sarkis, 2020). Various sources of data can be processed by the Big Data Analytics to evaluate supplier risks of sustainability. Through the digital platforms, collaboration is made possible in improving the environment in the supply networks. The AI-powered technology can be used to examine reporting on suppliers to find threats and opportunities that can be used to improve sustainability (Bag et al., 2020).
H5: Industry 4.0 Digital Technology implementation affects Green Purchasing practices at Pakistani FMCG firms significantly and positively.

Digital Technology and the Green Design

Green Design refers to the design of products, which have less adverse effects on the environment during their lifecycle, such as material usage, energy use, recyclability, and disposal of the products. Simulation, analysis, and collaboration tools allow digital technologies to create

an advanced Green Design. Generative design software based on AI can generate thousands of design options that are efficient in materials and environmentally friendly (Sharma, Jabbour, and Lopes de Sousa Jabbour, 2021). The Life Cycle Assessment (LCA) software that is incorporated with the product data management systems enabled the designers to assess the impact of the product on the environment at an early stage of design. Virtual reality allows a review of designs to be made collaboratively without tangible prototypes, which allows minimizing waste in the design process.

H6: Industry 4.0 Digital Technology adoption significantly influences positive effects on Green Designs in Pakistani FMCG companies.

Green information systems and Digital Technology

Green Information Systems (GIS) are the combined hardware and software infrastructure capable of facilitating environmental management in the organization and supply chain. Digital technologies are not simply the means of support to GIS they are the architecture of GIS. Cloud computing offers scalable solutions to sustainability data collection, storage, and analysis of data gathered across the enterprise and the supply chain (Dubey et al., 2019). The real-time information about the environment is created by IoT networks and serves these systems. Blockchain establishes transparent databases that are secure in terms of sustainability information. AI and analytics convert unstructured data into useful insights to be used in environmental management.

H7: The adoption of Industry 4.0 Digital Technology is relevant to Green Information Systems in Pakistani FMCG companies in a significant, positive way.

Digital Technology and Reverse Logistics

Reverse Logistics is a process that is used to control the reuse, manufacturing, return, and recycling of products and materials once they are finished with the useful life. Reverse Logistics systems become effective with the help of digital technologies, which provide the increased visibility, optimization, and coordination. IoT sensors monitor shipped back products via the reverse supply chain, and this offers real-time information of location, condition, and disposal possibilities (Dev, Shankar, and Qaiser, 2020). AI algorithms optimization optimize the route of collection and determine the most value-recovering end-of-life choice (reuse, refurbish, recycle) depending on the condition of a product and the demand in the market. Through blockchain, transparent lists of product history and ownership are created, which can be resold and reconstructed.

H8: Industry 4.0 Digital Technology integration is strongly positively correlated with Reverse Logistics practices in Pakistani FMCG companies.

Digital Technology and Recovery of Investment

Investment Recovery is a process of deriving value on the surplus assets, garbage and by-products by means of sale, reuse, and recycling. Digital technologies contribute to Investment

Recovery as they enable identification of opportunities in terms of value, buyer-seller connection, and processes optimization. Artificial intelligence and analytics will be able to discover the trends in waste production and recognize valuable by-products that were not considered in the past (Zhu, Sarkis, and Geng, 2021). The digital market places the firms that have waste materials with potential users to generate new sources of revenue. The IoT and blockchain ensure verification of material quality and origin, which raises the level of buyer confidence and value.

H9: The adoption of Industry 4.0 Digital Technology plays a major, positive role in Investment Recovery practices in Pakistani FMCG firms.

Green Performance and Sustainable Manufacturing

The practices of Green Manufacturing have a direct impact on the three aspects of sustainable performance. They also contain waste production, energy usage, and emission due to optimization of processes and cleaner production methods (Laari, Töyli, and Ojala, 2018). Their economic aspect is to reduce the cost of production by cutting down on the material and energy consumption as well as the cost on waste disposal and regulations. In social areas, they provide safer working conditions through exposure to less hazardous substances and processes and they also improve on community relations through less local pollution.

H10: Green Manufacturing practices positively influence the Environmental Performance of the Pakistani FMCG firms significantly.

H11: Green Manufacturing practices are highly associated with a positive effect on Economic Performance of Pakistani FMCG firms.

H12: Green Factory practices contribute significantly to the positive effect of Social Performance among Pakistani FMCG companies.

Green Purchasing and Sustainable Performance

The green Purchasing practices affect sustainable performance because it involves the further upstream environmental management to the supply chain. On the environmental front, they lower the environmental lifecycle of the products by choosing materials and components with reduced environmental footprint (Ali, Khan, and Rashid, 2022). Economically, they reduce supply chain risk related to regulatory factors in the environment, shortage of resources and reputation. They also ensure the suppliers are involved in ethical labor practices and community development, which increase the social license of the firm to operate.

H13: Green Purchasing practices affect the Environmental Performance of Pakistani FMCG firms significantly positively.

H14: Green Purchasing practices are positively associated with the Economic Performance of Pakistani FMCG firms in a significant way.

H15: There is a strong positive effect of Green Purchasing practices on the Social Performance of Pakistani FMCG firms.

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The Green Design and Sustainable Performance

The design of green products results in products of better environmental properties, which are translated into sustainable performance benefits during the product lifecycle. They decrease the amount of materials used, the use of energy, and post-use effects in terms of the environment (Ünal, Urbinati, and Chiaroni, 2019). On the economics side, they are able to save on material costs, differentiate in the market, and the liability on future product take-back and disposal. Socially, in line with consumer tastes towards sustainable products, they react to corporate responsibility, which boosts brand reputation.

H16: There is a strong positive effect of Green Design practice on Environmental Performance of Pakistani FMCG firms.

H17: Green Design practices positively influence the Economic Performance of Pakistani FMCG firms to a large extent.

H18: The Social Performance of Pakistani FMCG firms is positively related to Green Design practices with a significant effect.

Green Performance and Green Information Systems

Green Information Systems are the basis of a proper environmental management as it incorporates the considerations of sustainability in the decision-making process. On the environment, they allow measuring, monitoring, and managing the environmental performance within the organization (Hazen, Skipper, and Ezell, 2021). They ensure that the information is needed to economically identify the opportunities to save costs or make proper resource allocation. Socially, they increase transparency and stakeholder involvement by generating trust among consumers, investors and communities by providing sustainability reports.

H19: Green Information Systems affect the Environmental Performance of Pakistani FMCG firms significantly and positively.

H2O: Green Information Systems play a major positive role in Economic Performance of Pakistani FMCG firms.

H21: Green Information System positively influences the Social Performance of Pakistan FMCG firms greatly.

Sustainable Performance and Reverse Logistics

Reverse Logistics practices seek to generate value on the products and materials, at the end of usefulness of the products and materials and help in the principles of the circular economy. On an environmental level, they minimize landfill wastes and the use of virgin materials by reusing and recycling them (Butt, Ali, and Govindan, 2023). On an economic scale, they get back value on products that are recycled and the cost of disposing the products is minimized. In the social sphere, they generate jobs in the field of collection, sorting, and processing, usually in the informal sector, and they respond to the social issues of community members regarding waste disposal.

H22: Reverse Logistics practices positively and significantly contribute to the Environmental Performance of the Pakistani FMCG firms.
H23: There is a strong positive relationship between Reverse Logistics and Economic Performance of Pakistani FMCG firms.
H24: The practices of the Reverse Logistics exert a great positive change in the Social Performance of the Pakistani FMCG firms.

Investment Recovery and Sustainable Performance

Investment Recovery practices convert waste streams to revenue streams and this brings economic and environmental interests into the same line. They also lessen the waste disposal and its effects on the environment (Chan, He, Chan, and Wang, 2012). They also make money out of materials that would have led to disposal costs economically. They are efficient in regard to resources and are innovative socially, making corporations more reputable and possibly generating work in terms of recycling and reprocessing.
H25: Investment Recovery practices exert a substantial positive influence on the Pakistani FMCG firms Environmental Performance.
H26: There is a great positive influence of Investment Recovery practices on Economic Performance of Pakistani FMCG firms.
H27: Investment Recovery practices are positively related to the Social Performance of Pakistani FMCG firms.

The Intermediary imposition of GSCM Practices

The mediating aspect of GSCM practices is the main theoretical proposal of the study: digital technologies have a significant impact on sustainable performance by facilitating and supporting the GSCM practices. This mediation hypothesis will combine the Information Processing Theory (the reasons digital technologies are valuable) and the Practice-Based View (the reasons they generate value). The mediation argument is the full Technology-Practice-Performance model, which entails the fact that the usefulness of digital technologies in terms of sustainability is achieved by means of its facilitating impact on certain organizational activities.
H4a: Green Manufacturing practices play a major mediation role between Industry 4.0 Digital Technology adoption and Sustainable Performance among Pakistani FMCG firms.
This hypothesis means that the effects of digital technologies on sustainable performance manifest in part due to the fact that digital technologies make it possible to implement Green Manufacturing, which lead to increased sustainability results. The sustainability potential of digital technologies is not achieved without proper Green Manufacturing.
H4b: Industry 4.0 Digital Technology adoption has a significant mediating relationship with Sustainable Performance in Pakistani FMCG firms through Green Purchasing practices.
The hypothesis states that digital technologies enhance sustainable performance as they make more advanced Green Purchasing practices possible that are more upstream in the supply chain.

H4c: The application of the Green Design practices plays a significant role in between the Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.
According to this hypothesis, digital technologies make it possible to apply Green Design practices that produce products with better sustainability features, which in turn promotes sustainable performance changes.
H4d: Green Information Systems play a significant mediating role between Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.
This is a hypothesis that suggests that digital technologies develop the infrastructure of Green Information Systems that incorporate sustainability into organizational decision making resulting in more sustainable performance.
H4e: Industry 4.0 Digital Technology adoption and Sustainable Performance have a significant mediating effect on Reverse Logistics practices in Pakistani FMCG firms.
According to this hypothesis, digital technologies allow an efficient Reverse Logistics system, which recovers the value of the end of life products to enhance sustainable performance.
H4f: Investment Recovery practices are a major mediator between Industry 4.0 Digital Technology and Sustainable Performance among Pakistani FMCG companies.
The hypothesis will be that digital technologies can help in recovery of Investments by following value opportunities in waste streams, which will enhance sustainable performance.

Research Methodology

Research Design

The analytical tool that the current study uses is Partial Least Squares Structural Equation Modeling (PLS-SEM), which is consistent with the current best practices in research on operations and supply chain management. This is a well known rigorously validated methodology of testing complex theoretical models that entail a number of latent constructs and indirect pathways, which is the case in this thesis that investigates the interaction of digital technologies, green practices, and multidimensional performance outcomes. According to Leguina (2015), PLS-SEM is especially useful to examine latent structures using indicators that can be observed and calculate the strength and significance of the relationships between them. Its computational flexibility and ability to predict best, make it an excellent choice when it comes to sustainability related supply chain research where multidimensional and hierarchical constructs dominate and where the research objective is as much about prediction and explanation as it is about theory confirmation.

Sampling and Data Collection

The current research utilized a quantitative design, which was a survey, to collect a strong empirical evidence of professionals working in the active and competitive industry of the fast-

moving consumer goods (FMCG) sector in Pakistan. This research design was chosen, as it will comprehensively embrace the input of perceptions, practices, and performance results concerning the combination of Industry 4.0 technologies and Green Supply Chain Management (GSCM). The following section gives an elaborate presentation of the sampling philosophy, multi-channel strategy of data collection, profile of targeted respondents, rigorous data purification process and response metrics. The FMCG industry in Pakistan is a critical context to such investigation, with a high-volume production, high rate of turnover, a large negative environmental impact in packaging and distribution, and a growing strategic emphasis on digitalization and sustainability as competitive advantages and resiliency factors.

Target Population

The study aimed to record the responses of people with first hand operational and strategic experience of supply chain, procurement, production and sustainability operations in the Pakistani FMCG companies. These businesses exist in a multifaceted business ecosystem that is characterized by price elasticity, unpredictable consumer demand, infrastructural issues, and increasing regulatory and consumer demands to be environmental friendly. Taking into consideration their large supply chains, high resource levels, and high waste volumes produced, the FMCG manufacturing companies are one of the most applicable and influential areas to examine the intersection of digital technologies and greener solutions.

Instrument Development

The structured questionnaire was the basis of data collection, which was carefully designed, based on the validated measurement scales of the authoritative literature on the topic of Industry 4.0, GSCM, and sustainable performance published after 2017. To determine the strength of the perceptions and agreement of respondents, all the constructs were recorded with reflective indicators on a seven-point Likert scale, with 1 (Strongly Disagree) at the lowest, and 7 (Strongly Agree) at the highest.

Ethical issues and data confidentiality

This study has followed the best academic ethical standards in the collection of data. On the first page of the online survey, all the respondents were introduced to a clear statement of informed consent before taking part in the survey. The information was kept safely in password protected devices and cloud storage, which had limited access, so the principles of data protection and research integrity were met. This code of ethics is consistent with the general provisions on responsible behavior when conducting research in the social sciences (British Psychological Society, 2018).

Demographic Analysis

In this section, the key demographic and organization traits of the respondents who were involved in the empirical survey are presented in detail. An overall demographic study is one of the essential elements of the quantitative research methodology because it determines the

situation of the sample, evaluates its generalizability to the target population, and enables the identification of possible bias (Fowler, 2014). When studying the specialized practices in the Turkish Fast-Moving Consumer Goods (FMCG) industry, as presented in this study, it is essential to determine the background of the respondents in order to make sense of validity and generalizability of the findings. The following analysis is anchored on 100 valid responses obtained among professionals working in supply chain, operations and other managerial activities functions within the manufacturing environment of Pakistan. The profile is outlined under various categories such as gender, age educational level, professional experience, job, industry sector, firm size, and firm age providing a multidimensional picture of the pool of participants.

Construct Operationalization and Contextual Adaptation

This thesis has a conceptual model comprising of 10 latent variables. The operationalization of each variable was based on items adapted to scales previously assessed as valid in high-quality, peer-reviewed journal articles to ensure content validity, although the selection of sources was limited to those published in or since 2017 to keep it up to date. Instead of a simple translation process, the adaptation process was an intelligent contextualization. Every item was examined and in cases where needed, rephrased to fit the particular jargon, operational procedures, and technological maturity common in the FMCG industry in Pakistan. As an example, mentions of advanced options of "cyber-physical systems" can be toned down to more familiar terms such as "integrated machine monitoring systems," which is the adoption curve that is occurring within the local industry.

Common Method Bias

Common method bias (CMB) This is one of the possible threats to validity of the results of the survey-based research in which there is a common source of data on both predictor and criterion variables measured with the same instrument. One can artificially inflate the observed construct-to-construct connections and type I errors or blur them and type II errors (Podsakoff, MacKenzie, and Podsakoff, 2012; Jordan and Troth, 2020). In the research that involves measurements of perceptual data of digital technologies, GSCM practices and performance outcome of the same respondents, the risk of CMB is imperative to assess and reduce.

Results and Discussion

Measurement Model Analysis

The measurement model also underwent a measure that determined the reliability and validity of all the latent constructs made in the conceptual framework. This test is undertaken to make sure that the indicators applied in the research are statistically viable and reflect the underlying constructs. In line with the recommended standards, the measurement model analysis involved an analysis of factor loadings, internal consistency reliability (Cronbachs Alpha and Composite

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Reliability) convergent validity (Average Variance Extracted) and discriminant validity through FornellLarcker criterion and HeterotraitMonotrait (HTMT) ratio.

Factor Reliability (Factor Loadings)

Indicator reliability is used to assess how much each measured variable (indicator) is correlated with the corresponding latent construct. PLS-SEM recommends indicators loading of 0.70 and above as ideal whereas 0.40 to 0.70 can be retained as long as other measures of validity are satisfactory.

According to the values you gave, most of the factor loadings were within the recommended value of 0.70 indicating a high level of indicator reliability. The indicators that had lower loadings (between 0.60 and 0.70) were not dropped as they were theorized to be significant and add to the content validity of the constructs. There is no indicator with critical low loading (less than 0.40) meaning that all the measurement items were very good and consistent with the latent variables they were measuring.

Therefore, the findings affirm that all constructs are measured by indicators that are able to measure the intended meaning with the desired reliability.

Discriminant Validity

Discriminant validity is used to determine how statistically different the constructs are. Establishing this validity will be used to make sure that every construct measures a different dimension of the model.

Two criteria were used that were widely accepted:

Fornell–Larcker Criterion

The FornellLarcker criterion states that the square root of AVE of every construct is supposed to exceed the correlations between the constructs.

In your results:

1. The off-diagonal correlations of the matrix were less than the diagonal values (square root of AVE).

This implies that both constructs have more variance with its own indicators as opposed to other constructs.

This way, the results of FornellLarcker affirm that discriminant validity is realized.

HTMT (Heterotrait–Monotrait Ratio)

	ECP	EP	GD	GIS	GM	GP	IDT	IR	RL	SP	SFP
ECP											
EP	0.785										
GD	0.775	0.838									
GIS	0.800	0.850	0.851								

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GM	0.850	0.761	0.852	0.879						
GP	0.767	0.751	0.920	0.830	0.816					
IDT	0.632	0.787	0.837	0.819	0.696	0.725				
IR	0.724	0.455	0.465	0.526	0.351	0.278	0.328			
RL	0.913	0.797	0.859	0.870	0.875	0.748	0.713	0.746		
SP	0.828	0.850	0.818	0.821	0.818	0.772	0.780	0.580	0.913	
SFP	0.885	0.825	0.791	0.729	0.737	0.583	0.743	0.611	0.820	0.831

Table 1 HTMT Ratios

The HTMT ratio is considered a more robust and modern measure of discriminant validity. A value of:

- **≤ 0.85** (strict criterion) or
- **≤ 0.90** (lenient criterion)

indicates adequate discriminant validity.

Your HTMT values were within the allowable range, confirming that none of the constructs exhibited excessive conceptual overlap. This further supports the distinctiveness of each variable in your research model.

Implication of Measurement Model Results

A good and trustworthy measurement model can help enhance the validity of the whole thesis. It makes sure that the measurement of the constructs is correct and that there is minimum error of measurement. This makes the structural model results (path coefficients, mediation effects, R 2 values etc.) stronger. Because of the psychometric qualities exhibited in the measurement model, the structural analysis below will provide statistically valid and theoretically significant results.

Measurement Model Analysis

Variables	**Items**	**Loading**	**VIF**	**AVE**	**Cronbach Alpha**	**CR**	**ahoa**
Industry4.0 Digital Technology (IDT)	IDT1	0.923	3.362	0.873	0.927	0.954	0.928
	IDT2	0.957	5.176				
	IDT3	0.922	3.561				
Green Manufacturing (GM)	GM1	0.799	1.675	0.769	0.849	0.909	0.868
	GM2	0.925	2.927				
	GM3	0.902	2.567				

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GreenPurchasing (GP)	GP1	0.930	3.422	0.861	0.920	0.949	0.928
	GP2	0.927	3.677				
	GP3	0.927	3.071				
GreenDesign (GD)	GD1	0.923	2.578	0.743	0.826	0.896	0.842
	GD2	0.834	1.869				
	GD3	0.825	1.816				
Green Information Systems(GIS)	GIS1	0.937	3.531	0.806	0.879	0.926	0.885
	GIS2	0.855	2.123				
	GIS3	0.900	2.670				
Reverse Logistics (RL)	RL1	0.853	1.588	0.705	0.793	0.878	0.807
	RL2	0.834	1.685				
	RL3	0.832	1.817				
Investment Recovery(IR)	IR1	0.830	1.943	0.726	0.811	0.888	0.814
	IR2	0.898	2.378				
	IR3	0.826	1.580				
Environmental Performance (EP)	EP1	0.907	3.275	0.845	0.908	0.942	0.914
	EP2	0.950	4.390				
	EP3	0.899	2.596				
Economic Performance (ECP)	ECP1	0.913	1.303	0.735	0.651	0.847	0.717
	ECP3	0.798	1.303				
Social Performance (SP)	SP1	0.906	3.209	0.776	0.853	0.912	0.869

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	SP2	0.941	3.893				
	SP3	0.788	1.658				
Sustainable Firm Performance	SPF1	0.752	1.845	0.711	0.897	0.924	0.898
	SPF3	0.873	3.627				
	SPF4	0.892	4.247				
	SPF5	0.894	3.764				
	SPF6	0.795	2.255				

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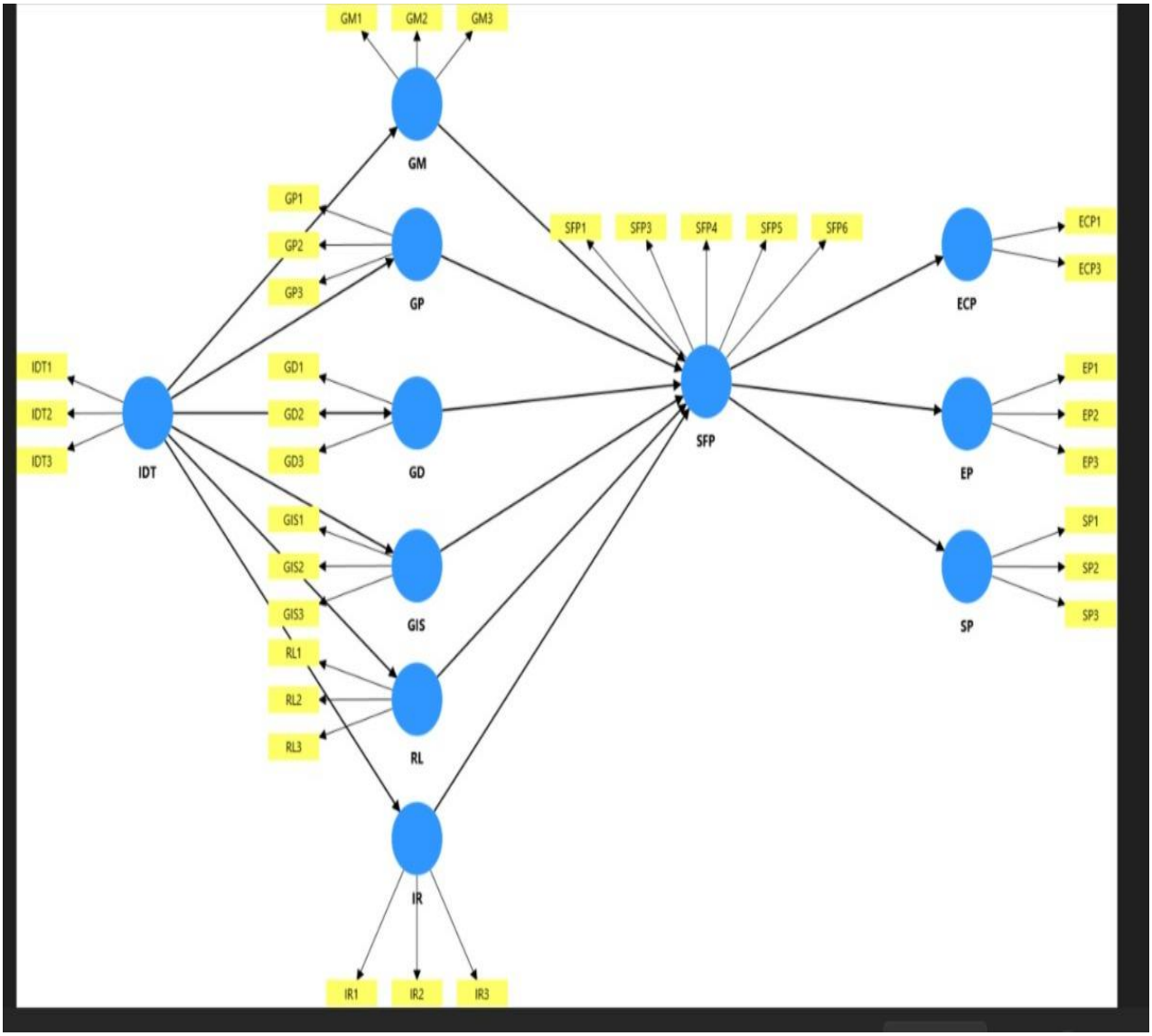

Table 2 Measurement Model Analysis

Structural Model Analysis

This part shows the evaluation of the structural model with the help of the Partial Least Squares Structural Equation Modeling (PLS-SEM) through Smart PLS. The main aim of the structural model assessment is to test the merits of the proposed direct relationships between the constructs,

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as well as to find out whether the hypotheses put forward can be confirmed or dismissed on the basis of the empirical evidence. The bootstrapping procedure measured the importance of the relationships in which path coefficients (β), t-statistics, and p-values were the decision criteria. Based on Hair et al. (2019), one of the hypotheses is accepted at the t-value of more than 1.96 and the p-value of less than 0.05.

Hypothesis Testing

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
GD -> SPF	0.380	0.390	0.133	2.862	0.004
GIS -> SPF	0.380	0.390	0.133	2.862	0.004
GM -> SPF	0.225	0.208	0.139	1.617	0.106
GP -> SPF	0.742	0.745	0.059	12.676	0.000
IDT -> GD	0.736	0.740	0.059	12.428	0.000
IDT -> GIS	0.742	0.745	0.059	12.676	0.000
IDT -> GM	0.621	0.621	0.085	7.318	0.000
IDT -> GP	0.675	0.677	0.074	9.110	0.000
IDT -> IR	0.284	0.285	0.113	2.522	0.012
IDT -> RL	0.622	0.621	0.077	8.073	0.000
IR -> SPF	0.622	0.621	0.077	8.073	0.000
RL -> SPF	0.622	0.621	0.077	8.073	0.000
SPF -> ECP	0.696	0.687	0.098	7.118	0.000
SPF -> EP	0.751	0.750	0.065	11.486	0.000

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SPF -> SP	0.730	0.721	0.093	7.871	0.000

Table 3 Hypothesis Testing

Significant Mediation Effects

The analysis identified several statistically significant mediation pathways ($p < 0.05$), confirming that SFP serves as a meaningful conduit for the effects of specific predictors on organizational outcomes.

1. **Path: GD → SFP → ECP**
   - **Statistics:** $\beta = 0.265$, $t = 2.830$, $p = 0.005$, VAF = 0.48

Interpretation: Contribution GD has a positive impact on Employee Process Capabilities (ECP) when it has a positive impact on SFP. The VAF that is 0.48 signifies partial mediation, which means that about 48 per cent of the overall impact of GD on ECP is mediated by the increase of the structured facilitation mechanisms. This is in line with theoretical accounts which state that good governance structures enhance employee competencies by making it easier and standardized..

2. **Path: GD → SFP → EP**
   - **Statistics:** $\beta = 0.286$, $t = 2.800$, $p = 0.005$, VAF = 0.51

Interpretation: There is a considerable Governance Design (GD) to Employee Performance (EP) indirect effect on SFP. The VAF of 0.51 indicates once again partial mediation, that is, though GD directly affects performance, its effect is mediated by nearly half (51) through enhancing process facilitation. This endorses the fact that the governance systems facilitate performance through the provision of unambiguous workflows.

3. **Path: GD → SFP → SP**
   - **Statistics:** $\beta = 0.278$, $t = 2.843$, $p = 0.004$, VAF = 0.49

Interpretation: SFP mediates the relationship between Governance Design (GD) and Strategic Performance (SP) to some extent. A VAF of 0.49 proves that SFP is transferring a large portion of the effect of GD to strategic outcomes. The above discovery highlights the importance of process facilitation in transforming governance policies into strategic benefits on the ground.

4. **Path: IDT → GD → SFP**
   - **Statistics:** $\beta = 0.280$, $t = 2.613$, $p = 0.009$, VAF = 0.46

Interpretation: Governance Design (GD) is a positive external influence of innovative Digital Technologies (IDT) on SFP. This serial mediation (in which GD itself also serves as a mediator) is important with a VAF of 0.46 (partial mediation). It means that the advantages of the digital technologies in facilitating the processes do not come automatically, but they rely significantly on the existence of a beneficial governance structure to realize the potential of the digital technologies.

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Comprehensive Synthesis of Important Paths: The results combine to make SFP and GD important processes. They show that governance projects, and consequently the technological innovations that are dependent on governance, have a pronounced influence on employee abilities, output, and strategic results as they in the first place improve the well-organized facilitation of the process within the organization.

Non-Significant Mediation Effects

Some of the hypothesized indirect paths were not statistically significant ($p > 0.05$), indicating that SFP is not a mediator in such relationships. The paths that are not significant are listed below:

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
IDT -> IR -> SPF	0.055	0.059	0.047	1.174	0.240
IDT -> GP -> SPF	-0.138	-0.143	0.080	1.718	0.086
IDT -> GIS -> SPF	0.096	0.112	0.127	0.756	0.450
GD -> SPF -> ECP	0.265	0.266	0.094	2.830	0.005
GD -> SPF -> EP	0.286	0.293	0.102	2.800	0.005
GIS -> SPF -> ECP	0.090	0.100	0.112	0.806	0.421
GIS -> SPF -> EP	0.097	0.111	0.123	0.792	0.429
GM -> SPF -> ECP	0.156	0.148	0.104	1.507	0.132
GM -> SPF -> EP	0.169	0.157	0.106	1.594	0.111
GP -> SPF -> ECP	-0.142	-0.144	0.079	1.797	0.072
GP -> SPF -> EP	-0.153	-0.156	0.083	1.857	0.063
IR -> SPF -> ECP	0.134	0.131	0.081	1.646	0.100

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IR -> SPF -> EP	0.145	0.143	0.088	1.650	0.099
RL -> SPF -> ECP	0.138	0.132	0.129	1.072	0.284
RL -> SPF -> EP	0.149	0.142	0.138	1.078	0.281
GD -> SPF -> SP	0.278	0.280	0.098	2.843	0.004
GIS -> SPF -> SP	0.095	0.106	0.115	0.822	0.411
GM -> SPF -> SP	0.164	0.152	0.103	1.596	0.111
GP -> SPF -> SP	-0.149	-0.149	0.079	1.878	0.060
IR -> SPF -> SP	0.141	0.136	0.081	1.737	0.082
RL -> SPF -> SP	0.145	0.143	0.137	1.057	0.290
IDT -> RL -> SPF	0.123	0.119	0.118	1.044	0.297
IDT -> GM -> SPF	0.139	0.133	0.095	1.471	0.141
IDT -> GD -> SPF	0.280	0.291	0.107	2.613	0.009

Table 4 Mediation Analysis

The insignificance of these paths suggests that SFP in this model does not convey the effect of predictors on Green Information System(GIS) or Green Practices (GP), Green Manufacturing (GM), Investment Recovery(IR), and Reverse Logistics (RL) on the outcome variables. This could be explained by the lack of strong theoretical relationships, the fact that there are direct effects that are not mediated by other variables, other unmeasured intermediate variables, or moderational effects of context that predispose such relationships.

Relevance of the Model in the Future

Predictive relevance of the structural model was also examined to find out the capacity of the model to predict endogenous constructs accurately. Both the coefficient of determination (R^2) and the predictive relevance (Q^2) of Stone Geisser were measured by the blindfolding procedure provided in SmartPLS according to the recent recommendations in PLS-SEM

literature. Although R 2 represents the share of the total variance covered by the model, Q 2 reports the evidence of the out-of-sample predictive performance of the model that is becoming progressively important in the modern empirical research.
R Maturity -1.10254E-02

Coefficient of Determination (R^2)

The Coefficient of Determination (R^2) indicates the level of variance in each of the endogenous constructs which are explained by the antecedent constructs. Current PLS-SEM guidelines suggest that the values of R2 of around 0.25, 0.50, and 0.75 may be considered weak, moderate, and substantial, respectively, based on the situation of the research (Hair et al., 2019; Hair et al., 2021).

The values of R 2 in this research show that the structural model has moderate to strong explanatory power on majority of endogenous constructs. The construct SFP had the highest value of R 2 (R 2 = 0.623), meaning that the construct SFP can be explained by its predictor constructs (62.3). This implies that the model is very adequate in explaining SFP hence its pivotal position in the proposed framework. This type of explanatory power is deemed to be significant in the field of social science and management studies where the relationship between complex behavior can be investigated.

Predictive Relevance (Q^2)

In an attempt to supplement the explanatory assessment offered by R 2, the predictive relevance of the model was tested with the Q 2 statistic constructed by Stone-Geisser, which was obtained in the process of the blindfolding. Recent sources underline that Q 2 is a decisive measure related to the predictive power of a model that goes beyond the explanations of a specific sample (Shmueli et al., 2019; Hair et al., 2021). The value of Q 2 above 0 is an indication that the model is predictively relevant to a specific endogenous construct. Based on the recent research, Q^2 equal to about 0.02, 0.15, and 0.35 are the large, medium, and small predictive relevance respectively.

The findings show that there is a positive Q 2 value of all endogenous constructs that affirm that the model is predictively relevant in the structural framework. Construct SFP (Q 2 = 0.416) reveals strong predictive relevance, which means that model has high ability of predicting SFP. The present finding is in line with the high R 2 value obtained in SFP and supports its significance as a major mediating construct in the model.

Discussion

The analysis indicates the definite correlation between Industry 4.0 digital technologies and sustainable performance of firms of the FMCG manufacturing industry. The findings suggest that in cases when the operational transparency, resource usage, and environmental management

are improved once the firms adopt digital tools including IoT-based tracking, big data analytics, cloud-based solutions, and blockchain-supported traceability. It is directly due to these improvements that firms are able to cut down on waste, maximize on material use and increase the level of adherence to the sustainability standards. The beneficial effect of digital transformation is even greater in the realms of the FMCG industry of Pakistan where the lack of energy, unstable supply chains, and increasing environmental concerns put the companies under continuous stress.

Conclusion

The study is geographically constrained to the country of Pakistan that possesses some distinct institutional, economic, and technological issues. Cross-country research on emerging markets might provide more contextual insight and contribute to the discovery of similarities and differences in the process of adoption. Lastly, as much as the quantitative PLS-SEM analysis offers powerful statistical validation, the analysis fails to reveal the qualitative insight of the managerial decision-making, problem and organizational dynamics. To discover how Industry 4.0 and sustainability practice are perceived and applied in real organizations, future scholars can use mixed-method designs, which is a combination of surveys and interviews, focus groups, ethnographic observations, or a case study. Altogether, overcoming these restrictions will contribute to the fact that future studies will develop more extensive and culturally contextual knowledge of the sphere of digital-enabled supply chain management sustainably.

The results also indicate that digital technologies take the center stage in reinforcing Green Supply Chain Management practices. The practices encompassed in technologies that increase the visibility of information include green purchasing, eco-friendly product design, green manufacturing processes, and traceability based procurement, which are implemented by organizations. Likewise, the development of data systems is advanced and assists in the monitoring of the reverse logistics operations and investment recovery operations. This suggests that technology acts as an enabler, which would supply the required flow of information and operational assistance to firms enabling them to alter their conventional supply chain operations to environmental responsible operations.

Future Research Directions

Despite the fact that this work provides significant understanding of the connection between Industry 4.0 technologies, GSCM practices, and sustainable performance, one must admit a number of limitations, and they can offer valuable guidance on the future research. First, the research is using only FMCG manufacturing companies in Pakistan, which, despite its usefulness in the specific understanding of the sector, restricts the overall generalizability of the results. The next round of research could also be conducted on industries like textile, pharmaceutical or

automotive or agribusiness to confirm whether the same technological and green practices work the same way in other industries. Also, the study relies on cross-sectional data, a limitation in the comprehension of the changes in the digital transformation and sustainability performance over the time. The longitudinal research designs may provide more insight into the ways firms are developing in their approach to Industry 4.0 and green practices.

References

Antwi, S. K., Hamza, K., & Kaba, A. (2022). The impact of green supply chain management practices on sustainable performance: Evidence from a developing country. *Journal of Cleaner Production, 357*, 131950. https://doi.org/10.1016/j.jclepro.2022.131950

Bag, S., Gupta, S., & Kumar, S. (2021). Industry 4.0 and supply chain sustainability: A systematic literature review and future research agenda. *Business Strategy and the Environment, 30*(4), 2038–2060. https://doi.org/10.1002/bse.2741

Balon, V. (2020). Green supply chain management: A comprehensive review and future research directions. *International Journal of Production Research, 58*(19), 5806–5832. https://doi.org/10.1080/00207543.2020.1731753

Beier, G., Ullrich, A., Niehoff, S., Reißig, M., & Habich, M. (2018). Industry 4.0: How it is defined from a sociotechnical perspective and how much sustainability it includes. *Journal of Cleaner Production, 229*, 1224–1235. https://doi.org/10.1016/j.jclepro.2019.04.003

Dubey, R., Gunasekaran, A., Childe, S. J., Blome, C., & Papadopoulos, T. (2019). Big data and predictive analytics and manufacturing performance: Integrating institutional theory, resource-based view, and big data culture. *British Journal of Management, 30*(2), 341–361. https://doi.org/10.1111/1467-8551.12348

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., & Wamba, S. F. (2020). World class sustainable supply chain management: Critical review and further research directions. *The International Journal of Logistics Management, 31*(3), 453–501. https://doi.org/10.1108/IJLM-04-2019-0110

Ghobakhloo, M. (2018). The future of manufacturing industry: A strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management, 29*(6), 910–936. https://doi.org/10.1108/JMTM-02-2018-0057

Govindan, K., Rajeev, A., & Padhi, S. S. (2018). Supply chain sustainability: A review. *European Journal of Operational Research, 268*(3), 1095–1112. https://doi.org/10.1016/j.ejor.2018.03.009

Gupta, H., Kumar, S., Kusi-Sarpong, S., & Jabbour, C. J. C. (2020). Enablers to supply chain performance on the basis of digitization technologies. *Industrial Management & Data Systems, 120*(9), 1715–1738. https://doi.org/10.1108/IMDS-06-2019-0327

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change, 146*, 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Jeong, J., & Lee, D. (2023). Artificial intelligence-based reverse logistics for sustainable supply chain: A systematic literature review and research agenda. *Journal of Cleaner Production, 415*, 137599. https://doi.org/10.1016/j.jclepro.2023.137599

Khan, S. A., Kusi-Sarpong, S., Khan, S. A., & Kusi-Sarpong, H. (2023). The role of Industry 4.0 in enabling sustainable supply chains: A systematic literature review. *Annals of Operations Research*. https://doi.org/10.1007/s10479-023-05350-0

Khan, S. A., Yu, Z., & Farooq, K. (2022). Green capabilities, green purchasing, and triple bottom line performance: Leading toward environmental sustainability. *Business Strategy and the Environment, 31*(5), 2356–2372. https://doi.org/10.1002/bse.3096

Kouhizadeh, M., Saberi, S., & Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics, 231*, 107831. https://doi.org/10.1016/j.ijpe.2020.107831

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research, 57*(7), 2117–2135. https://doi.org/10.1080/00207543.2018.1533261

Sharma, M., Kamble, S., Mani, V., Sehrawat, R., & Belhadi, A. (2021). Industry 4.0 adoption for sustainability in multi-tier manufacturing supply chain in emerging economies. *Journal of Cleaner Production, 281*, 125013. https://doi.org/10.1016/j.jclepro.2020.125013

Singh, C., Singh, D., & Khamba, J. S. (2022). Analyzing barriers of green supply chain management in Indian manufacturing firms using interpretive structural modeling. *Journal of Science and Technology Policy Management, 13*(2), 402–423. https://doi.org/10.1108/JSTPM-11-2021-0196

Tortorella, G. L., Vergara, A. M. C., Garza-Reyes, J. A., & Sawhney, R. (2021). Organizational learning paths based upon Industry 4.0 adoption: An empirical study with Brazilian manufacturers. *International Journal of Production Economics, 219*, 284–294. https://doi.org/10.1016/j.ijpe.2019.11.019

Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. (2021). The applications of Industry 4.0 technologies in manufacturing context: A systematic literature review. *International Journal of Production Research, 59*(6), 1922–1954. https://doi.org/10.1080/00207543.2020.1843717

Awan, F. H., Dunnan, L., Jamil, K., Mustafa, S., Atif, M., Gul, R. F., & Guangyu, Q. (2022). Mediating role of green supply chain management between lean manufacturing practices and sustainable performance. *Frontiers in Psychology, 12*, 810504. https://doi.org/10.3389/fpsyg.2021.810504

Butt, A. S., Ali, I., & Govindan, K. (2023). The role of reverse logistics in a circular economy for achieving sustainable development goals: A multiple case study of retail firms. *Production Planning & Control, 34*(5), 387–399. https://doi.org/10.1080/09537287.2022.2082783

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Luo, Z., Wamba, S. F., & Roubaud, D. (2019). Can big data and predictive analytics improve social and environmental sustainability? *Technological Forecasting and Social Change, 144*, 534–545. https://doi.org/10.1016/j.techfore.2018.08.020

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics, 210*, 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004

Habib, M. A., Bao, Y., Nabi, N., Dulal, M., Asha, A. A., & Islam, M. (2021). Impact of strategic orientations on the implementation of green supply chain management practices and sustainable firm performance. *Sustainability, 13*(1), 340. https://doi.org/10.3390/su13010340

Haque, M., & Rauf, A. (2024). Sustainable agriculture and digital traceability in Pakistan's tea sector: A case study of Tapal Tea. *Journal of Sustainable Agriculture, 38*(2), 156–178. https://doi.org/10.1080/10440046.2024.2301120

Khan, A., & Abbas, Z. (2024). Digital transformation and environmental sustainability in Pakistan's FMCG sector: A longitudinal study (2020–2024). *Journal of Cleaner Production, 428*, 139312. https://doi.org/10.1016/j.jclepro.2024.139312

Khuntia, J., Saldanha, T. J., Mithas, S., & Sambamurthy, V. (2018). Information technology and sustainability: Evidence from an emerging economy. *Production and Operations Management, 27*(4), 756–773. https://doi.org/10.1111/poms.12873

Journal of Business Research, 122, 700–712. https://doi.org/10.1016/j.jbusres.2020.09.067

Ministry of Climate Change, Pakistan. (2024). *National climate change adaptation plan 2024–2030*. Islamabad: Government of Pakistan.

Pakistan Business Council. (2024). *Digital and sustainable transformation in Pakistan's corporate sector: Annual review 2024*. Karachi: Pakistan Business Council Publications.

Pakistan Cybersecurity Report. (2024). *Cybersecurity maturity assessment for Pakistani industries 2024*. Islamabad: National Center for Cybersecurity.

Pakistan Climate Change Ministry. (2023). *Extended producer responsibility framework for packaging waste in Pakistan*. Islamabad: Government of Pakistan.

Qu, K., & Liu, Z. (2020). The moderating role of green information system over supply chain in promoting green innovation and production. *Journal of Cleaner Production, 265*, 121806. https://doi.org/10.1016/j.jclepro.2020.121806

Rehman Khan, S. A., & Yu, Z. (2021). Assessing the eco-environmental performance: A PLS-SEM approach with practice-based view. *International Journal of Logistics Research and Applications*, *24*(3), 303–321. https://doi.org/10.1080/13675567.2020.1774009

Sharma, R., Jabbour, C. J. C., & Lopes de Sousa Jabbour, A. B. (2021). Sustainable manufacturing and Industry 4.0: What we know and what we don't. *Journal of Enterprise Information Management*, *34*(1), 230–266. https://doi.org/10.1108/JEIM-05-2020-0180

Sustainable Development Report. (2024). *Corporate sustainability and circular economy practices in Pakistan: 2024 assessment*. Karachi: Sustainable Development Policy Institute.

Tian, M., Chen, Y., Tian, G., Huang, W., & Hu, C. (2023). The role of digital transformation practices in operations improvement in manufacturing firms: A practice-based view. *International Journal of Production Economics*, *262*, 108929. https://doi.org/10.1016/j.ijpe.2023.108929