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Unlocking Insights: Structural Equation Modeling Approach To Unveil The Nexus Between Industry 5.0 Evolution And Sustainable Supply Chain Dynamics

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Abstract
Modern business practices are evolving in response to concepts like the sustainable supply chain and Industry 5.0. When brought together, these two concepts drive the growth of a highly robust and long-lasting global economy. To ensure ethical and sustainable procurement, secure and effective human-bot collaboration, and monitor the origin of things, modern organizations are embracing more sustainable supply chain management techniques with the help of cobots and blockchain technology. Industry 5.0, also known as Sustainable Supply Chain Practices, is the focus of this study, which develops a theoretical model by combining frameworks from the literature on manufacturing, supply chains, and information systems. The study's analytical sample includes 342 responses collected from electronics supply chain specialists. Researchers used deductive reasoning to formulate hypotheses, drawing on prior research. Industry 5.0 innovations, Sustainable Supply Chain Practices (SSCP), Sustainable Supply Chain Performance (SCP), and Supply Chain Risks (SCR) are the constructs that are used in this study. The validity of these purported links is checked using Structural Equation Modelling (SEM). According to the SEM study, Implementing Industry 5.0 technology and sustainable supply chain practices can boost supply chain performance while decreasing risk. By combining the two schools of thought, we can create a sustainable economy that is fair to all stakeholders and fosters new forms of business that prioritize long-term viability.

Keywords: *Sustainable Supply Chain, Industry 5.0, Structural Equation Modelling, Supply Chain Performance, Supply Chain Risks, Statistical Analysis*

1. Introduction

The rise of eco-friendly supply chains and the arrival of Industry 5.0 are having a profound impact on how businesses operate and what they produce (Leng et al., 2024). Robotics, the IoT, and artificial intelligence (AI) are just a few examples of how innovative uses of cutting-edge tech reshape traditional manufacturing methods. According to (Mahroof et al., 2023), this trend is expected to persist due to the fast development of technology. It is also becoming more apparent that environmental impacts should not be the only consideration for rules and regulations controlling the transfer of goods, services, and data; social and economic considerations should also be considered. Thus, sustainability and Industry 5.0 must cooperate to create a more open, efficient, and cooperative global supply chain. It would also lend credence to fair business practices that are good for the environment (Reddy et al., 2024).

Regardless of the methods used to measure sustainability in the past, Industry 4.0 must emphasize green technologies or initiatives to protect the environment. Previous work that integrated AI algorithms with ecological management has been helpful to this project's progress. However, a more advanced technological answer is necessary to ensure environmental protection and long-term viability (Sharma & Gupta, 2024). This type of response is anticipated by Industry 5.0. Fifth Industrial Revolution, or I5.0, aims to leverage human intelligence and creativity to their fullest potential by integrating intelligent technologies with traditional manufacturing processes (Nicoletti, 2023a). Unlike Industry 4.0, which primarily focuses on automation, Industry 5.0 combines human workers with self-operating robots. The autonomous workforce follows human preferences and goals. A gain in confidence in one's abilities, decreased expenses, and a more lucrative and productive production process are all outcomes of this (Xiang et al., 2023). Environmental management is essential for every industry, including Industry 5.0, which wants to stay competitive. It is a vital link for a reliable supply chain. Every value chain stage, from raw materials to completed products, tries to dematerialize, decarbonize, and detoxify itself (Tallat et al., 2023).

Sustainable supply chain management is gaining popularity for businesses to reduce their environmental impact (Alimam, Mazzuto, Tozzi, Ciarapica, & Bevilacqua, 2023). Sustainable supply chain operations can incorporate ecologically and socially responsible practices throughout many stages of a product's life cycle (Roy et al., 2023). A Green Supply Chain is a method of sustainable supply chain management, which encompasses a variety of activities such as reusing and recycling materials, creating environmentally friendly products, purchasing them in an eco-friendly manner, managing their end-of-life, and transportation. Modern innovations such as blockchain and the IoT allow data and item tracking throughout the supply chain to occur in real-time. As a result, businesses may anticipate and prepare for potential bottlenecks in product end-of-life management, shipping, and packaging (Haloui, Oufaska, Oudani, & El Yassini, 2024).

Along with improving supply chain performance, the Industry 5.0 framework incorporates many components related to supply chain risks. Since these technologies are becoming more integrated into production processes and data security is becoming more critical in Industry 5.0, vulnerabilities in cyber-physical systems pose a significant concern (Saisridhar, Thürer, & Avittathur, 2024). Supply chains need to be flexible to stay up with the rapid technological advancements (Benzidia, Makaoui, & Bentahar, 2021). In order to successfully traverse the intricate and dynamic industrial terrain, it is essential to implement solid risk management procedures. By integrating several aspects of Sustainable Supply Chain Practices with Industry 5.0, we were able to ascertain the reliability of the factors that are essential to the Industry 5.0 electronics industry. After that, this study utilized Structural Equation Modelling. Stated differently, the present work combines current literature with theoretical frameworks from manufacturing, supply chain, and information systems personnel interviews to compile all the components and subcomponents of Industry 5.0 (I5.0), Sustainable Supply Chain Practices (SSCP), Sustainable Supply Chain Performance (SCP), and Supply Chain Risks (SCR) in the electronics industry. The goal was to enhance supply chain performance. Thus, we developed a structural equation model based on five hypotheses that ranked the most critical sub-components. The five main elements' interplay is illustrated in the relationship diagram. The survey was validated using confirmatory factor analysis. Applying this method to models previously verified by (Hu & Chen, 2023) evaluated the elements of Supply Chain Risks, Sustainable Supply Chain Practices, and Industry 5.0 Innovations. Industry 5.0, Sustainable Supply Chain Practices, and Supply Chain Risks are some of the most recent topics covered in the following research review. In Section 3, we lay out the steps to test the theories. In Section 4, the research approach is detailed. In Section 5, the data analysis is applied. Finally, the study's future scope is debated and concluded under sections 6 and 7 under the headings of the study's implications and debate.

2. Literature review

In this part, we surveyed the research on Industry 5.0, sustainable supply chain methods, and the dangers of such systems.

2.1. Research on Industry 5.0 and sustainable supply chains

An alternative to Industry 4.0's profit-driven productivity, the new paradigm known as Industry 5.0 seeks to advance sustainable development goals by focusing on people, the environment, and resilience. Within the context of Industry 5.0, (Singh & Cohen) mapped out a strategy for attaining sustainable development. Industry 5.0's sustainability promises must be realized for there to be genuine advantages, as has been highlighted by (Singh & Cohen). Their plan and model for the kind of sustainable growth that Industry 5.0 may bring about were laid out using interpretive structural modeling (ISM). In a related study of the transition from Industry 4.0 to Industry 5.0, (Ikenga & Sijde, 2024) analyzed the textile and apparel supply chains in great detail. They found and ranked important topics using a fuzzy DEMATEL method, which helps plan future studies. At the same time, (Gupta, Modgil, Choi, Kumar, & Antony, 2023) investigated the causes and effects of employee disengagement from their jobs using a structural equations model similar to Industry 5.0. In a related study, (Nitlarp & Mayakul, 2023) created a PLS-SEM model for a digital green adoption-implementation framework to enhance digital green innovation inside the Industry 5.0 ecosystem. Responding to shifts in the business world, (Ning & Yao, 2023) focused on students' ability to bounce back. The resilience of one hundred and sixteen students majoring in social science was assessed using a survey and proportionate stratified random selection. To tackle broader societal problems, (Adewusi et al., 2024) suggested a hybrid paradigm for industries 5.0 and 4.0 that blends human- and automated-driven activities. To improve sustainability, (Szelągowski & Berniak-Woźny, 2024) underlined the significance of environmental factors and advocated for implementing circular supply chain (CSC) ideas. The ever-changing dynamics of the Circular Supply Chain and Industry 5.0 as they pertain to sustainable development were illuminated (Choudhury, Behl, Sheorey, & Pal, 2021). Important implications for achieving sustainability objectives are provided by the study's comprehensive understanding of the components' harmonious interaction through identifying and defining the intricate relationships. According to (Bag, Rahman, Srivastava, & Shrivastav, 2023), intelligent manufacturing can promote sustainability in a circular economy by the Industry 5.0 revolution. According to (Salvadorinho & Teixeira, 2023), technological advancements, especially incorporating Blockchain into supply chains, played a pivotal role. (Jain & Chou, 2023) highlighted the importance of integrating BC and supply chain approaches to achieve sustainability. To accomplish the power-intensive goals of "Edge AI," the "Green IoT" paradigm encountered challenges, which aimed to decrease carbon emissions. To illustrate the practical application of Industry 5.0 principles, (Jain & Chou, 2023) showcased an innovative workshop emphasizing worker safety and data tracking. In their study, (Katuk) provided a method for evaluating the impact of both internal and external incentives on the completion of sustainability projects, focusing on India's oil and gas sectors. (Nicoletti, 2023b) utilized Structural Equation Modelling to identify the food company's supply chain vulnerabilities that the Bullwhip Effect exacerbated. (Nisar et al., 2024) proposed the idea of "The Resilient Operator 5.0" to foretell the future of human employment in innovative, robust industrial systems. In Industry 5.0, (Machado, Scavarda, Caiado, & Santos, 2024) introduced the concept of a "co-bot" crucial to next industrial revolution and stressed the importance of robots and human intelligence working together. (Abdelfattah, Salah, Dahleez, Darwazeh, & Al Halbusi, 2024) highlighted the objectives of Sustainable Supply Chain Practices and Industry 5.0 to boost sustainability, competitiveness, and efficiency. A more robust and more sustainable supply chain that meets the needs of stakeholders, consumers, and society at large can be created when businesses adopt and implement these concepts into their daily operations (Rojek, Mikołajewski, Mroziński, & Macko, 2023). Resilience, sustainability, and a focus on people are the three interconnected tenets of I5.0. Despite growing interest in Industry 5.0, studies on the topic are in their infancy, particularly in underdeveloped nations. The DEMATEL approach, which stands for decision-making trial and evaluation laboratory, (Walters & Helman, 2023) assessed organizational interdependencies. To overcome these obstacles, they methodically listed and ranked them and then suggested the GRID structure. It would help close the gap.

2.2. Related supply chain performance and sustainable risk work

In their description of the SCOR (Supply Chain Operations Reference) model, (Rolf et al., 2023) introduced a diagnostic tool that uses the green score model to assess the efficacy of Green Supply Chain Management (GSCM). As a consequence, the water content of crude palm oil was reduced by 48%. Prior work by (Kwilinski, Lyulyov, & Pimonenko, 2023) provided a novel approach to showing how the vaccine supply chain (VSC) uses KPIs. This model shows how SDGs and India's UIP (Universal Immunisation Programme) may live together. The performance indicators can be examined using the balanced scorecard (BSC) components of learning and growth, internal processes, customers, and finances. At the same time, the sustainable practices criteria (SPC) were evaluated utilizing the economic, environmental, and social dimensions.

Unlike previous studies, this one focused on the internal performance metrics of the hospital supply chain (Shaikh et al., 2024). Finding key performance indicators and understanding the interdependencies across logistics process pieces were priorities for enhancing internal operations. Their proposed approaches integrate rough set theory with the group decision-making and trial evaluation laboratory (DEMATEL) technique (Khawaldeh & Alzghoul, 2024). More precise signals and evaluation of various supply chain links are possible through the use of (Schulte & Paris, 2024) created a long-term performance evaluation technique. The study considers sustainability from a monetary, ecological, and social perspective. Now, we can talk about how the sector has evolved recently and how technology has helped it. (van de Wetering, Hendrickx, Brinkkemper, & Kurnia, 2021) found and analyzed the most essential parts and performance indicators regarding information logistics and intelligent supply chains. (Yakovenko & Shaptala, 2023) laid out the latest Industry 5.0 framework in their research, highlighting the importance of technology and organizational structure as its main components. A strong relationship between managing risks in the supply chain and an organization's success was discovered by (Yu et al., 2024). A study by (Charter, 2024) found that small-scale agropreneurs in Malaysia can increase productivity and decrease risks by using partial least squares structural equation modeling to manage hazards in the supply chain. Considering the COVID-19 pandemic, (Purcărea et al., 2022) investigated the factors influencing pharmaceutical company performance in Vietnam, paying particular attention to supply chain vulnerabilities, integration, and resilience. The investigation made use of the intelligent PLS program. (Tchuente & El Haddadi, 2023) later investigated supply chain risk management using covariance-based structural equation modeling to see how it mediates the relationship between SCI and organizational performance. In a separate study, (Khalifa Alhitmi et al., 2023) found that flexibility had less effect on risk management performance than supply chain resilience and responsiveness. Claims made in the literature on the potential weakening of these ties due to a risk management culture need to be corrected. (Foroudi, Akarsu, Marvi, & Balakrishnan, 2021) surveyed a Turkish business organization using questionnaires in their study. To analyze this data, we use the PLS method.

A plethora of research analyses and assesses Sustainable Supply Chain and Industry 5.0. However, within the context of Industry 5.0, additional research is required to identify the factors influencing Supply Chain Resilience and Sustainable Supply Chain Performance. Supply Chain Risks can be reduced, and organizational supply chains can be improved through the joint efforts of Sustainable Supply Chain Practices and Industry 5.0. To fill this information gap, our study will methodically collect and arrange all applicable Sustainable Supply Chain Practices and Industry 5.0 attributes. Researchers and practitioners can use this study to understand better the most important aspects of incorporating sustainable supply chain practices into electronic-based businesses using the Business 5.0 framework. The study has made the following contributions:

- Examine the factors that affect sustainable supply chain management and Industry 5.0.
- Examine the hazards and sustainable supply chain procedures in Industry 5.0.
- Create a new model that illustrates the relationship and dependence between sustainable supply chain management and Industry 5.0.
- Examine how one thing affects another directly or indirectly to learn more about the dependence effect.
- Sort each element in the suggested framework's sub-factors according to importance.

In conclusion, a new model has been developed to show how Industry 5.0 and Sustainable Supply Chain Performance are related and mutually impact each other. Study aims to assist experts in creating a sustainable supply chain architecture that complies with Industry 5.0 standards. Experts in the field and academia will know what factors are crucial to the situation's success and how to respond effectively to keep the supply chain running smoothly. Companies in the 5.0 industry can utilize this method to build supply networks that are strong and durable. Understanding these critical components can help a country's economy as whole, not just individual enterprises.

3. Hypotheses development

As shown in Appendices A and 5, we have collected and organized all the pertinent criteria based on our literature review. Various hypotheses were advanced to ascertain the nature of the connection between Sustainable Supply Chain Practices and Industry 5.0. An analysis was conducted using survey data to investigate the suggested connection between Sustainable Supply Chain Practices and Industry 5.0. Here are the hypotheses that have been put out.

3.1. Sustainability in supply chains and Industry 5.0

The Industry 5.0 revolution enables brilliant production, responding to customer-specific needs through a linked web of systems and devices all over the supply chain. Sustainable Supply Chain Performance has seen a dramatic adoption increase due to technological advancements made during the Industry 5.0 period. Innovations such as blockchain, artificial intelligence, the Internet of Things, and big data analytics are essential to improve supply chain operations' efficiency, transparency, and sustainability. Waste may be reduced, and resources can be better allocated through optimizing logistics, inventory management, demand forecasting, AI, and predictive analytics. Supply networks are made more transparent and traceable with blockchain technology. Advocate for ethical sourcing practices and verify eco-friendly approaches. During COVID-19, (Alnaser, Hassan Ali, Elmousalami, Elyamany, & Gouda Mohamed, 2024) performed research and discovered that decision-makers needed to transform their old supply chain networks into new information-driven ones using state-of-the-art technology to keep businesses running after the virus had passed. Because of this, established companies can use Industry 5.0 technologies, which are gaining popularity for their ability to guarantee the sustainability of supply chains over the long term through several noteworthy characteristics, allowing for robust and user-friendly operations. Now, we arrive at our first hypothesis:

H1: Technological improvements in the era of Industry 5.0 are favourably associated with the implementation of Sustainable Supply Chain Practices.

3.2. Industry 5.0, sustainable supply chains, and performance

Sustainability and resilience are becoming more critical. Therefore, experts in academia and industry are training to solve sustainability issues in the supply chain. The ultimate goal of these initiatives is to create a more efficient and environmentally friendly supply chain. With the advent of "Industry 5.0" comes a new era in manufacturing that will enhance SCM methods. This new way of thinking merges human-centered approaches with state-of-the-art technology like AI, the IoT, and automation. Industry 5.0 places a premium on social awareness, ecological responsibility, ethical discussions, and streamlining supply chain operations. Industry 5.0 aims to build more robust and efficient supply chains centered on integrating human creativity with technical improvements. Ethical sourcing reduced waste, and improved monitoring and analytics are all outcomes of a supply chain that can make smarter decisions. Products can be refurbished, recycled, and remanufactured due to this evolution, which helps reduce environmental impact and promotes the idea of a circular economy. Due to its emphasis on responsible behavior, innovation, and collaboration, Industry 5.0 is essential in fostering and expanding Sustainable Supply Chain habits to ensure a more sustainable future. With that out of the way, let's have a look at our second and third hypotheses:

H2: Supply Chain Performance and Industry 5.0's influence are favorably correlated.

H3: Supply Chain Performance Improvements in the Age of Industry 5.0 (I5.0) are mediated by Sustainable Supply Chain Practices.

3.3. Industry 5.0, sustainable supply chain management, and risks

Supply chain risks can be mitigated by implementing an exciting framework known as Industry 5.0. Supply chains can now respond swiftly with the help of real-time monitoring and predictive analytics made possible by Industry 5.0's integration of cutting-edge technologies like AI, ML, and IoT sensors. By providing a comprehensive view of operations, these tools can spot potential dangers like logistical disruptions, environmental concerns, or supplier dependency. Using Industry 5.0's optimization and real-time monitoring features, resource waste might be avoided. It lowers the danger of losing market share and reputation by offering SC transparency and responsibility, enabling a speedy response to quality concerns or customer complaints, and all of that together.

According to (Konstantopoulos, Koumoulos, & Charitidis, 2022), enterprises can use radio frequency identification (RFID) tags and Internet of Things (IoT) sensors to monitor shipments as they pass through the supply chain to reduce product loss, theft, or damage. One of the primary aims of Industry 5.0 is to improve supply chain visibility and efficiency through artificial intelligence (AI), big data analytics, and blockchain technology. Data analysis allows supply chain managers to examine several sources, including social media, economic indicators, and weather trends, to detect and reduce risks. Supply chain management benefits from Industry 5.0's increased visibility, according to (Sudan, Taggar, Jena, & Sharma, 2023), since it allows companies to monitor supply chain performance in real time. Based on what they've done, we can deduce our fourth and fifth assumptions:

H4*:* There is a positive correlation between Industry 5.0 and the variables that reduce supply chain risks.

H5*:* Industry 5.0 and the variables that mitigate supply chain risks are connected through sustainable supply chain practices.

4. Research Methodology

The research team in this study looked at thirteen different electronic businesses in Bangladesh, and their backgrounds ranged from manufacturing and supply chain management to quality assurance, marketing, and finance. It was emailed to twenty-six electronics sector executives with the reasons and explanations for each construct. These surveys were created to test how well they captured these traits. All surveys were double-checked for face validity, and participants were asked to comment on the clarity and wording of each question.

Using Google Forms, we sent out questionnaires to participants via email and several social media messaging services. A Likert scale from 1 to 5 is used to evaluate each question. The grading scale goes from 1 (strongly disagree) to 5 (strongly agree), protecting participants' privacy, identities, and data. Participants were also encouraged to omit or add any information they deemed inappropriate or unneeded. In the end, 754 people got the final survey; 62 percent commented, and 77 percent had their responses returned because they were incomplete. The results were inputted alongside 390 other responses using SPSS 24.0, a social science statistical program. For 48 of the data points, there were either missing values or outliers. Following their extraction for further analysis, 342 out of 48 data points were retained. Ages of the participants ranged from

24 to 36 for 53.39 percent, 37 to 50 for 33.97%, and 50 and up for 12.64%. About 65.35 percent of the people who completed the survey were men, while 34.6 percent were women.
Therefore, we are satisfied with this investigation's final data feed. A sample size of less than 200 responses is sufficient for Structural Equation Modeling analysis (Ahmad, Al Mamun, Masukujjaman, Makhbul, & Ali, 2023). Data analysis was carried out using the statistical software SPSS and AMOS. A structural model was evaluated according to the suggestions given after assessing construct validity, discriminant validity, and convergent validity were examined (Srhir, Jaegler, & Montoya-Torres, 2023). It was the first stage of the data analysis process.

4.1. Instrumentations

The development of our model considered four primary aspects: Industry 5.0 (I5.0), Supply Chain Performance (SCP), Sustainable Supply Chain Practices (SSCP), and Supply Chain Risks (SCR). The current literature research has been examined to classify these four main criteria. The research identified sixteen subcategories based on sustainable supply chain practices, five based on supply chain performance, and fourteen based on supply chain risks, with twelve originating from the core features of Industry 5.0 (Jamil, Mustofa, Hossain, Rahman, & Chowdhury, 2024).

5. Data Analysis and Findings

Two phases of analysis were applied to the collected data. Initially, validity, fit, and reliability of measurement model were assessed using a Confirmatory Factor investigation (CFA). We estimated the structural model using a structural equation model (SEM), which allowed us to test our theory. In addition, this study utilized non-response bias variables and multi-group analyses.

5.1. Non-response bias test

This paper investigated the potential for response and non-response biases using T-tests. We contrasted the early and late reactions for the crucial variables, looking at their means and standard deviations. It was established from the data supplied that 60 people answered later, and 230 people responded early. (Li & Yin, 2023) determines if the homogeneity of variances for each variable varies appreciably between the early and late responses. The test shows that the homogeneity of variances in this case varies very little. According to Table 1, non-response bias does not affect the valuable sample. Early and late responders to the research represent same target population.
Table 1. Independent sample t-test for non-response bias evaluation.

Empty Cell	Empty Cell	Empty Cell	Empty Cell	Empty Cell	**Levene's test for Equality of Variances**		***t*-test for equality of Means**		
Variables	**Response Type**	**N**	**Mean**	**SD**	**F**	**Sig.**	***t***	**df**	**Sig. (2-tailed)**
I5.0	Early	230	4.511	0.432	1.392	0.254	2.126	98.329	0.057
Empty Cell	Late	60	4.016	0.384					
SCP	Early	230	3.865	0.617	1.037	0.301	-1.167	84.433	0.234
Empty Cell	Late	60	3.793	0.528					
SSCP	Early	230	4.621	0.514	0.005	0.954	0.212	93.953	0.573
Empty Cell	Late	60	4.825	0.437					
SCR	Early	230	2.476	1.078	1.624	0.256	0.514	94.131	0.567
Empty Cell	Late	60	2.359	1.063					

5.2. Validating the Measurement Model

Each measurement construct was analyzed using confirmatory factor analysis (CFA) in conjunction with the SPSS Amos program. We employed maximum likelihood estimation approaches in our measurement model study to assess the precision of our model estimates compared to commonly use goodness-of-fit metrics, like the Comparative Fit Index (CFI) and the goodness-of-fit index (GFI). According to (Chiwaridzo & Masengu, 2024) results, the GFI and CFI values in Table 2 are more significant than 0.90 (GFI = 0.927; CFI = 0.953), meaning the model fit index is excellent. Dillon and Goldstein (1984) stressed the importance of considering an item's loading and value when performing factor analyses. To determine if the data sample is suitable, the Kaiser-Meyer-Olkin (KMO) value is computed using SPSS. Table 2 shows that every factor has a KMO value higher than 0.6. KMO values above 0.6 are suitable for factor analysis. The items can be filtered by examining the Corrected Item Total Correlations (CITC), as (Churchill Jr, 1979) found. According to Cronbach (1951), When a factor's impact on Cronbach's alpha was insignificant, SPSS was employed to remove it from the model. To demonstrate item dependability and factor unidimensionality, all standardized factor loadings must be greater than 0.50. With CITC >0.5, KMO >0.5, and Cronbach's > 0.70, the factor analysis identified the following combined factors and sub-factors displayed in Table 2. Significance analysis and Bartlett's test are utilized when evaluating the variables' practicability. When Bartlett's value is smaller than 0.05, it is determined that a factor is required. Industry 5.0, Sustainable Supply Chain Practices, Sustainable Supply Chain Performance, and Supply Chain Risks were all included in the exploratory factor analysis for this construct since each item in the construct has stronger correlations with its items than with items of other constructs. It is shown in Table 2 (Kotler, Kartajaya, & Setiawan, 2021).

Table 2. Supply Chain Risk Factors Measurement, Industry 5.0, Sustainable Supply Chain Practices, and Sustainable Supply Chain Performance.

Factors	Sub-Factors	CITCs	Cronbach's α	KMO Measure of Sampling	Bartlett's Test of Sphericity Significance
	MCAST	0.648			
	DT	0.652			
	SFT	0.532			
	VT	0.52			
I5.0	IAS	0.763	0.725	0.716	0.000
	EC	0.652			
	CBTS	0.503			
	IOE	0.696			
	BC	0.501			
	EC	0.66			
	GM	0.686			
	LCHM	0.663			
	RL	0.664			
	ECC	0.706			
	CAGI	0.802			
SSCP	HS	0.624	0.743	0.670	0.000
	GD	0.772			
	SPP	0.685			
	CFPR	0.664			
	GP	0.725			
	CRS	0.647			
	WPST	0.739			
	ENVF	0.69			
	ECF	0.632			
SCP	OF	0.632	0.708	0.609	0.000
	TCHF	0.53			
	SOF	0.724			
	DSU	0.757			
	FSRS	0.598			
	ISS	0.798			
	LRP	0.757			
	IISR	0.55			
SCR	MSR	0.882	0.702	0.766	0.000
	EP	0.682			
	HWG	0.618			
	IUR	0.587			
	ND	0.882			

GFI = 0.931, CFI = 0.949.

CITC = Correlated Item Total Correlation, KMO = Kaiser- Meyer- Olkin, GFI = Goodness of Fit Index, CFI = Comparative Fit Index.

5.3. SEM analysis and structural modeling

The model shown in Figure 1 is simplified in Figure 2. In structural equation modeling, the suggested correlation between variables is graphically displayed. In their study, (Hair, Sarstedt, Pieper, & Ringle, 2012) emphasized the importance of using numerous indications for a notion instead of just one. These observable indicators, represented by the retained scale elements, are the extrinsic latent variables of Industry 5.0 (I5.0), Sustainable Supply Chain Practices (SSCP), Supply Chain Performance (SCP), and Supply Chain Risks (SCR). There are four main components to the proposed link between Industry 5.0 and SSC. Precise accuracy cannot be achieved with just one endogenous latent variable.

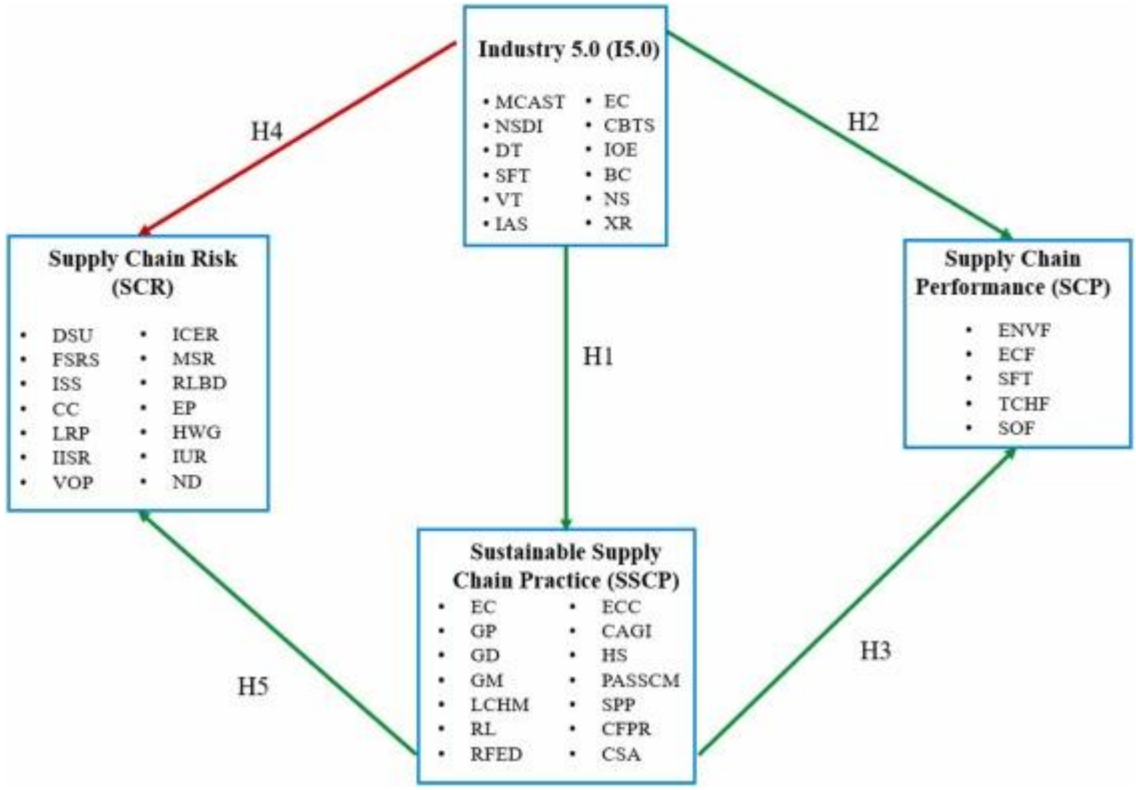

Fig. 1. Proposed hypotheses model.

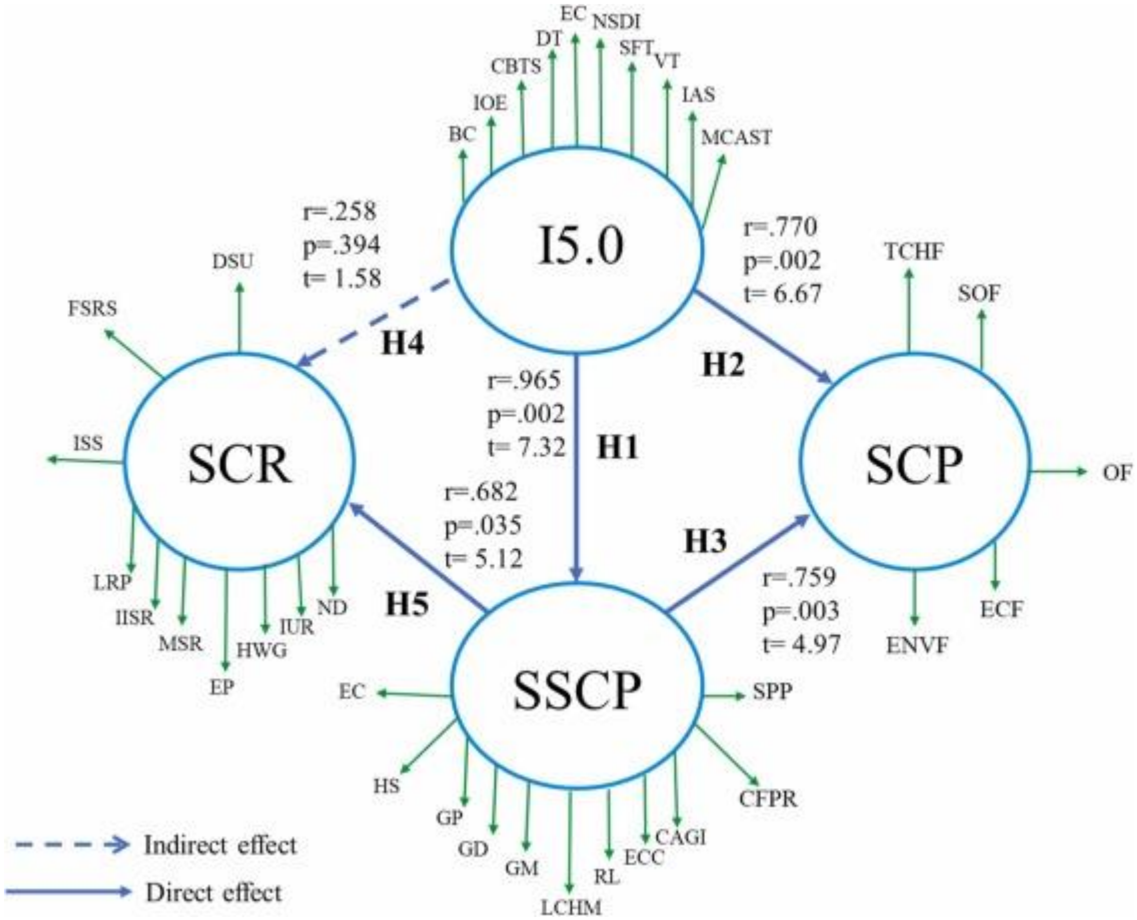

Fig. 2. Analyzing the outcome of Supply Chain Risks, Sustainable Supply Chain Performance, Industry 5.0, and Sustainable Supply Chain Practices.

The model in Figure 2 was examined using Structural Equation Modeling, and all outcomes were processed using the AMOS software. Table 3 and Figure 2 contain the t-, p-, and r-values we use to investigate further the statistical significance of the Structural Equation Modeling indicator's measurement part. Statistical significance is achieved when the p-value is smaller than 0.05, and the t-value is more significant than 2.00 at ($\alpha = 0.05$) (Mueller & Hancock, 2018). It points to a statistically significant connection between the concepts. In addition, it confirms that having informal partnerships is undoubtedly within the realm of possibility. For this purpose, we use the range of r-values proposed by Evans in his work for correlation coefficients (Maruyama, 1997); r-values more than 0.60 show a robust link. Hypotheses are considered non-significant for this inquiry when the t-value is less than 2.00, the p-value is less than 0.05, and the r-value is less than 0.60.

Table 3. Testing the hypothesis for significance.

Empty Cell	**Relationship**	**t-value**	**p-value**	**Significance**
H1	I5 to SSCP	7.29	0.001	Yes
H2	I5 to SCP	6.59	0.001	Yes
H3	SSCP to SCP	4.85	0.02	Yes
H4	I5 to SCR	1.62	0.383	No
H5	SSCP to SCR	5.31	0.041	Yes

An impressive correlation coefficient 0.965 exists between Industry 5.0 and Sustainable Supply Chain Practices. For this to be true, there must be some statistical connection between the concepts. In addition, having informal partnerships is undoubtedly within the realm of possibility. Additionally, the t-value, p-value, and r-value ranges for the correlations between supply chain risks, Industry 5.0, and sustainable supply chain practices are all above acceptable, and there is a strong association between these two variables. Consequently, these four hypotheses were approved. The results of testing H4 are not statistically significant, as shown by the following: r-value = $0.258 < 0.60$, t-value = $1.58 < 2.00$, and p-value = $0.394 > 0.05$. So, we can rule out H4. Therefore, Industry 5.0 improves Supply Chain Performance and influences Sustainable Supply Chain Practices. Industry 5.0's sustainable supply chain aims to improve supply chain efficiency without sacrificing environmental balance. Additionally, the risks and uncertainties linked to the supply chain were mitigated by implementing sustainable supply chain procedures. While Industry 5.0 did reduce some risks, the fourth quarter data show that the effect was less than expected.

5.4. Multigroup analysis

Workers were categorized as either young (24–34 years old), middle-aged (35–49 years old), or old (50 and more). No studies have yet attempted to account for workers' varying ages to compare and contrast their perspectives on introducing Industry 5.0 and the Sustainable Supply Chain. Secondly, a cutoff age based on age does not convey the divide in these opinions. Because of these considerations, drawing clear lines between the various age groups was not always easy. Despite these caveats, it is possible to classify individuals by age based on their attitudes toward technology by consulting previous studies on the technological gap. Previous research has shown a substantial digital divide between the 24-34 age brackets and the 50+ age bracket (Yuen & Lam, 2024). This research used participants between the ages of 34 and 50. According to the study, age acted as a moderator negatively. With a 49.144 Chi-square difference (df = 20, p-value <.001), it is clear that there is a notable distinction between the fully constrained and unconstrained models. The unconstrained model is acceptable to us. The model fits the older (>50) and younger (24-34) staff groups significantly differently. Tables 4, 5, 6, 7, 8, and 9 demonstrate that other age groups have different model fits.

Table 4. Comparing middle-aged employees (35−50) with younger employees (24−34) using structural equation modeling (SEM).

Model	Akaike's information criterion (AIC)	Comparative Fit Index (CFI)	Root Mean Square (RMR)	Goodness of Fit Index (GFI)	Root Mean Square Error of Approximation (RMSEA)	PCLOSE
Unconstrained	269.072	0.852	0.059	0.849	0.034	0.875
Structural weights	249.171	0.861	0.069	0.852	0.019	0.875

Table 5. Unrestricted model comparison (younger vs. middle-aged).

Model	DF	CMIN	*p*-value	NFI Delta-1	IFI Delta- 2	RFI rho-1	TLI rho-2
Structural weights	17	16.227	.241	.023	.021	-.007	-.008

*DF= Degree of Freedom, NFI= Normed Fit Index, IFI= Incremental Fit Index, RFI= Relative Fit Index TLI= Tucker Lewis Index.

Table 6. SEM analyses using multiple groups: employees aged 35–49 and employees aged 50 and above.

Model	AIC	CFI	RMR	GFI	RMSEA	PCLOSE
Unconstrained	269.071	0.851	0.049	0.859	0.031	0.874
Structural weights	271.172	0.839	0.062	0.861	0.032	0.984

Table 7. Middle-aged vs. elderly unstrained model comparison.

Model	DF	CMIN	P	NFI Delta-1	IFI Delta- 2	RFI rho-1	TLI rho-2
Structural weights	17	27.629	.131	.008	.008	-.006	-.004

Table 8. SEM multiple group analysis for the following employees: younger (24–34) and older (50+).

Model	AIC	CFI	RMR	GFI	RMSEA	PCLOSE
Unconstrained	312.781	0.851	0.07	0.862	0.04	0.872
Structural weights	287.392	0.862	0.06	0.851	0.031	0.875

Table 9. Younger vs. Elderly Model Comparison: Unstrained Model.

Model	DF	CMIN	P	NFI Delta-1	IFI Delta- 2	RFI rho-1	TLI rho-2
Structural weights	17	23.537	.034	.008	.012	-.006	-.008

There was a notable disparity in model fit between the younger and older employee groups in the multi-group structural equation modeling trials. However, neither the middle-aged nor the younger nor the older employees differed noticeably.

6. Discussion

Finding ways to combine sustainable supply chain practices with those of Industry 5.0 was the driving force behind this research. The goal was to learn how these factors interact and how combining the two models improves supply chain risk management and network efficiency. Survey research was conducted in Bangladesh based on 342 responses from supply chain specialists and industry experts from 13 well-known electronics industries. We considered their suggestions and views when we chose the factors. Additional statistical validation testing was performed after the pilot research to build the model according to the suggestions. We discarded one hypothesis since it was insignificant, but four others showed strong connections and interdependencies. Table 1 and Appendix A demonstrate that forty-eight factors were deemed genuine, whereas nine were considered invalid due to validation test failures. Results corroborated by Cronbach's alpha (>0.70), KMO (>0.50), and CITC (> 0.50) confirm findings. Table 3 also shows that the following relationships—from Industry 5.0 to Sustainable Supply Chain Practices, from Industry 5.0 to Supply Chain Performance, from Sustainable Supply Chain Practices to Supply Chain Risks, and from Sustainable Supply Chain Practices to Sustainable Supply Chain Practices—have t-values and p-values that are more significant than the validation range ($t \geq 2.00$), respectively. We deduced that this provided evidence in favor of the first five hypotheses. Reason for rejecting H4: Industry 5.0 to Supply Chain Risks provided a t-value of 1.58, below the validity range. So, although there is no substantial relationship between Industry 5.0 and supply chain risks, there is a favorable correlation between sustainable supply chains, sustainable supply chains, and performance, as well as sustainable supply chain practices and risks. In addition, we can exclude H4 because the p-values for H1, H2, H3, H5, and H4 were all greater than the 0.05 value. It sheds light on how the adoption of Industry 5.0 will pave the way for more environmentally friendly supply chain procedures, which will boost efficiency in the supply chain. If we want a more robust supply chain than I4.0, it won't be enough to implement Industry 5.0 technology; we also need to address related issues, such as reasoning and trust-building. The possibility of unforeseen catastrophes persists. Thanks to Industry 5.0's real-time monitoring and optimization of resource utilization, the likelihood of inefficient resource consumption can be decreased, and total efficiency can be increased. However, by facilitating transparency and responsibility all through the supply chain and swiftly addressing quality concerns or customer complaints, it also minimizes the chance of declining market share and reputational harm. Adopting Industry 5.0 technologies and SSCM concepts requires significant time and resource commitment. Existing company models and processes could also need some tweaking. Careful consideration of the advantages and disadvantages of any new processes or technology must precede their implementation. Unforeseen dangers may also accompany the introduction of novel procedures or technologies.

7. Implication of the Study

This study enhanced the theoretical knowledge of supply chain performance, hazards, sustainable practices, and Industry 5.0 breakthroughs. Structural equation modeling (SEM) sheds light on the complex interconnections between these concepts within the context of supply chain management. Combining Industry 5.0 principles with sustainable supply chain performance and practices theoretically accounts for the associated risks. Additional research and theoretical development are required to thoroughly understand the dynamics of modern industrial breakthroughs and sustainable supply chain management; this framework provides a rational basis for both. Using structural equation modeling, the research either confirms or enhances existing theories in risk management, performance, and Industry 5.0. It offers empirical evidence to back up, improve, or refine previously held theoretical notions, adding to their evolution.

Implications for practice: Professionals in the field can use the study's real-world results to influence strategic decisions on integrating Industry 5.0 technologies into their supply chain processes. To simplify processes, decrease dangers, and improve sustainability outcomes, it is helpful to understand how these ideas are connected. Among the practical ramifications of using Industry 5.0 technologies are guidelines for recognizing, assessing, and reducing risks to the supply chain. It helps businesses create proactive plans to reduce risk, making supply networks more resilient and adaptable. The report goes on to offer actionable advice for enhancing sustainability performance through the implementation of certain Industry 5.0 technologies that are in line with sustainable supply chain norms. Businesses can use this information to create more efficient operations while doing good for society and the environment.

8. Conclusion and Future Scope

Industry 5.0 and sustainable supply chain management strategies should complement one another regarding results. Briefly outlining the historical progression of the Industrial Revolution and how technological developments have affected the overall trajectory of numerous companies, the paper then moves on to analyze the effects of these changes. Our guiding principle in all that we do, from mass production to mass customization, is the preservation of Earth's ecosystems and resources. The study's results might tell us a lot about how the Fifth Industrial Revolution is influencing business as usual. Analyzing the improvised model's results reveals the interconnections and interdependencies among the related components.

Building structural equation modeling models requires reliable and accurate data. To ensure the models' accuracy and reliability, additional measurement items for Industry 5.0 and sustainable supply chain management techniques can be developed and tested in future studies. Examining how Industry 5.0 will affect environmentally responsible supply chain management Research in the future can look at how Industry 5.0 could affect variables like macroeconomics, social conscience, environmental regulations, stakeholder engagement, organizational culture, user acceptance, and the interaction between humans and technology about sustainable supply chain management. Structural equation modeling can help us learn about the potential effects of Industry 5.0 on these various ecosystems and investigate greener supply chain practices.

Structural equation modeling can be used to understand better how Industry 5.0 and sustainable supply chain management interact with one another and to evaluate a wider variety of qualitative and quantitative factors to make participants more sustainable.

This study does have a few caveats. While the operational approach to Industry 5.0 may be similar across borders, survey responses may vary among countries. Results from a survey of Bangladesh's Industry 5.0 electronic industry participants should be extrapolated to other countries with extreme care and precision. Recognizing Bangladesh's unique social, cultural, and industrial backdrop is the first and most crucial step in overcoming the contextual constraints. The generalizability of the situation in Bangladesh could be improved by comparing it to other countries' situations and drawing out the parallels and differences. In addition, using different sampling approaches in various countries within the Industry 5.0 electronic sector could increase the diversity of representation and make it easier to generalize the results to a global context. The study's results could be more robust and applicable using extensive statistical approaches and cross-national validations. If we want to know how far the study's findings can be applied, we need to understand how laws, markets, and technological infrastructures in other countries vary from Bangladesh.

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