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Promoting Sustainable Product Authenticity through Digital Supply Chain Integration and Collaboration: Insights from an Experimental Study

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Abstract

Prior literature lacks explaining how digital supply chain (SC) integration affects SC collaboration and sustainable product authenticity and how these effects vary depending on the transparency level (high vs. low) across different platforms (blockchain vs. non-blockchain). We conceptualized digital SC integration using three dimensions: information, operational, and relational integration. We conducted an experiment and collected the data from 346 employees. The study findings suggested that information and relational integration are significant for SC collaboration, which, in turn, enables sustainable product authenticity. We also observed that a high transparency level positively influences the association between operational integration and SC collaboration, except in the case of a blockchain platform where the impact of transparency is weakened. These findings assisted us in obtaining a more granular understanding of how digital SC integration is instrumental in promoting SC collaboration and enhancing sustainable product authenticity. We discuss theoretical and managerial implications based on these findings.

Keywords: Blockchain, Transparency, Supply chain integration, Collaboration, Sustainability, Product authenticity, Enterprise system

Introduction

Since consumers are becoming increasingly conscious of the environmental impact of their purchases, businesses have prioritized sustainability in their supply chain management (SCM) and are collaborating with supply chain (SC) partners to ensure their products are environmentally responsible and authentic. All SC partners contribute value to the products/services; a focal firm cannot achieve sustainability if other parties do not align with the environment and society. In fact, with the growing sustainability concerns, SC collaboration has become a strategic requisite to accomplish sustainability goals (Chen et al., 2017). In recent years, developments in information technology (IT) and digital platforms have brought about a significant transformation in existing enterprise systems, including SCM (Jiang et al., 2023; Kumar et al., 2020; Peiris et al., 2015). Specifically, digital platforms have empowered organizations to improve supply chain (SC) collaboration capabilities by facilitating resource coordination and information sharing among SC partners and achieving better sustainable performance (Fawcett et al., 2008; Chen et al., 2017). Thus, SC collaboration is a vital element that drives effective sustainable SCM (Cao et al., 2010; Chen et al., 2017).

However, SC collaboration is a complex process that often faces challenges stemming from uncertain environments, such as low trust, structural conflicts, poor information sharing, and misaligned metrics (Fawcett et al., 2015). These challenges further add to the complexities and uncertainties of building a sustainable SC. For example, such SC collaboration challenges may reduce sustainable product authenticity, which is defined as the degree to which a sustainable product is real, genuine, and true. Albeit these challenges can possibly be tackled by increasing the transparency level in SC operations using digital solutions (Sodhi & Tang, 2019) to strengthen SC collaboration. Consequently, SC collaboration using digital platforms has enabled partner organizations to manage organizational resources and processes, offer real-time product traceability, and improve overall SC efficiency and better performance toward sustainability (Agrawal et al., 2023; Kumar et al., 2018). Furthermore, the recent advancements in digital SC, such as blockchain-based SC product provenance, signify a transformation towards improved data security, efficient decision-making, and advanced SC collaboration (Korepin et al., 2021).

Despite considerable IT investments in digitalizing SC, many organizations have been unable to achieve the same level of success as exemplary companies like Dell and Walmart (Fawcett et al., 2015; Fawcett et al., 2011). Digital SC integration, defined as the extent to which an organization collaborates with its SC partners and collaboratively manages its resources and capabilities through digital means (Flynn et al., 2010), is one mechanism for improving SC operations that may lead to sustainable success. It includes three sub-dimensions: information, operational, and relational integration (Leuschner et al., 2013). Information integration encompasses information communication and coordination; operational integration is about joint decision-making and coordinated activities; and relational integration is about nurturing strategic relationships. We argue that by consolidating these sub-dimensions, a digital SC platform can enable improved collaboration, lessen coordination costs (Shi & Yu, 2013), and increase sustainability evaluation and verification (Gualandris et al., 2015).

Prior scholarly research on SCM has investigated the role of IT in SC (Kumar et al., 2020; Zhou et al., 2023). However, two major research gaps exist. First, prior literature has focused on the role of IT in SC collaboration by examining individual approaches such as process coordination (Zhou et al., 2023), information sharing (Fawcett et al., 2011), and promoting relational capabilities (Pattanayak et al., 2024). However, there appears to be a lack of empirical research exploring the collective impact of digital SC integration dimensions (i.e., information, operational, and relational) on SC collaboration and, especially, sustainability verification, i.e., sustainable product authenticity. Secondly, different technologies, such as big data analytics, the Internet of Things, blockchain, and cloud computing, among others, have been investigated in the context of SC (Ali et al., 2021; Jiang et al., 2023; Shee et al., 2018). Besides, prior scholars also suggested evaluating the technology platforms that can be integrated with enterprise systems to allow improved collaboration (Peiris et al., 2015). Blockchain has been proposed as a technology solution for improved SC operations (Vazquez Melendez et al., 2024). Therefore, empirical research studies are needed to understand how the impact of blockchain-based platforms differs from that of non-blockchain-based platforms. Furthermore, digital solutions (whether blockchain or non-blockchain) for SC can be designed with various levels of transparency, thereby further complicating the design choices. Thus far, we found no study exploring the possible interplay between different transparency levels for different technology platforms in streamlining an organization's SC integration efforts for improved SC collaboration. To address these gaps, this study aims to answer the following research questions (RQs):

1) How does digital SC integration impact SC collaboration and sustainable product authenticity?
2) To what extent does the impact of digital SC integration on SC collaboration vary across different transparency levels for different platforms?

These RQs seek to extend the existing literature by exploring digital SC integration and the impact of different IT platforms thereon (Jiang et al., 2023; Zhou et al., 2023). To answer the above RQs, we used an experimental study design. We employed a factorial group approach to identify the distinctive effect of different platform types (blockchain vs. non-blockchain) and transparency levels (high vs. low) in relation to digital SC integration and SC collaboration, which in turn affects sustainable product authenticity. We collected data from 346 employees with experience in technology usage and SC decision-making. The study results revealed interesting findings. Our findings demonstrated that information integration and relational integration are significant for advancing SC collaboration which, in turn, facilitates verifying the authenticity of sustainable products. We found that operational integration positively influences SC collaboration when the transparency level is high. However, if organizations are using blockchain-based platforms, then the interaction effect of the transparency level is lessened.

Background

Digital Supply Chain Integration

SC integration is described as a strategic collaboration between SC partners and manufacturers to ensure that all processes are streamlined (Wong et al., 2011). Through this strategic collaboration, organizations collaboratively orchestrate inter and intra-organizational processes, resulting in an efficient flow of information, products, and services and boosting SC effectiveness (Cao et al., 2010; Flynn et al., 2010). The digitalization of SC integration has enabled better interfirm cooperation, improved complex information processing, and yielded real-time SC information (Lii & Kuo, 2016; Liu et al., 2016). SC integration simplifies the identification of suppliers and customers, enhances mutual control, and lessens information asymmetries (Flynn et al., 2010; Kim et al., 2011). It also helps firms to develop sustainability evaluation and verification (Gualandris et al., 2015). Moreover, by leveraging digitally enabled SC integration, organizations can monitor SC processes to derive competitive advantage and improve sustainable performance (Ali et al., 2021). This can be realized by consolidating existing knowledge and resources (for example, by extending existing enterprise systems) to transform SC and address the contemporary SC challenges (Vanpoucke et al., 2014; Peiris et al., 2015).

Prior scholars have conceptualized SC integration in diverse ways, stretching from general categorization as external integration (integration of suppliers and customers) and internal integration (a cross-functional collaboration) (e.g., Lii & Kuo, 2016; Flynn et al., 2010) to a more comprehensive configuration considering four components involving operational coordination, information integration, strategic partnership and synchronized planning (e.g., Liu et al., 2016). This diversity emphasized the importance of investigating the core SC integration dimensions that may influence SC collaboration. Building on Jiang et al. (2023), we contend that information, operational, and relational integration dimensions comprehend the key components of SC integration and extend it to digital SC integration to gain a comprehensive understanding of how digitally enabled SC integration can enhance sustainable business practices such as maintaining the authenticity of product provenance (Vazquez Melendez et al., 2024). Information integration measures the degree to which an organization discloses information with its SC partners (internal and external) about different SC activities such as production, sales, inventory holding, and delivery schedules (Kulp et al., 2004). Digital SC information integration is very important as it enables the synchronization of processes with suppliers and minimizes information distortions and time of delivery (Ali et al., 2021). Operational integration measures the extent to which SC partners, by sharing information, regularly coordinate different operational activities and processes at various phases of SC (Saeed et al., 2011). While SC information integration enables organizations to "know" their SC, SC operational integration allows them to "act" on it (Jiang et al., 2023). Additionally, organizations share SC rewards and risks with other partners to nurture relational integration for resilient SC (Chowdhury & Quaddus, 2016). This relational integration involves developing strategic relationships with SC partners (Liu et al., 2016).

Supply Chain Collaboration

In prior SC literature, SC collaboration is a well-studied construct, conceptualized in diverse ways such as trust-based and long-term relationships (Ha et al., 2011; Yazici, 2012), a distinctive dynamic capability (Soosay et al., 2008), and a strategy (Tsou, 2013). One of the key elements of SC collaboration is the mutual relationship developed among companies based on information sharing, trust, collective decision-making, and overall enhanced benefits and outcomes (Soosay & Hyland, 2015). This SC collaboration is achieved when companies integrate, coordinate, and leverage knowledge and resources across SC (Lejeune & Yakova, 2005). Predominantly, firms collaborate to enhance not only individual company's performance but also improve SC performance in an uncertain environment (Zhang & Cao, 2018). Furthermore, it has been widely recognized that companies in isolation cannot achieve sustainability and necessitate the involvement of SC partners (Varsei et al., 2014). Hence, in SC, collaboration is a pertinent strategy to stimulate sustainability performance (Kumar et al., 2018). In addition, when collectively designing new products, SC collaboration facilitates a sustainable model wherein SC actors share underused resources and foster asset reuse (De Angelis et al., 2018). Specifically, when sustainable products are designed, SC parties mutually decide on the raw material to use and where to purchase it (Farooque et al., 2019). Thus, we contend that such a collaborative process sets forth supplier monitoring to make sure that suppliers comply with social and environmental guidelines (Howard et al., 2019) that are necessary to verify sustainable practices across SC.

Sustainable Product Authenticity

Despite the different interpretations of authenticity, the consistent understanding across the literature is that authenticity captures what is real, genuine, and true (Arnould & Price, 2003; Morhart et al., 2015; Thompson et al., 2006). Therefore, drawing upon Morhart et al. (2015), we regard sustainable product authenticity as the degree to which a product is genuine, real, and true in terms of its sustainability. This authenticity, challenged by information asymmetry about product provenance, impacts consumers' intention to purchase sustainable products advertised by the firms (Kim et al., 2008). To overcome such challenges, a business can enhance the visibility of its operations, including SC processes for its customers and its own SC transparency, by collaborating with suppliers. Prior scholars have emphasized the importance of SC collaboration for organizations to improve sustainability performance (Chen et al., 2017). Moreover, by leveraging digital platforms, such collaboration can facilitate lowering the number of counterfeit products, benefiting not only the businesses but also customers in verifying the original products (Sodhi & Tang, 2019). The recent development of digital solutions has further paved the path towards product provenance. For example, blockchain has been recognized as an effective option for ensuring the provenance of SC products (Vazquez Melendez et al., 2024) and a possible solution to authenticate a product across SC (Sodhi & Tang, 2019). Thus, SC collaboration through modern digital platforms allows for greater efficiency in improving production processes and product verifiability, given the need for sustainable product authenticity.

Hypothesis Development

Digital Supply Chain Integration and Supply Chain Collaboration

Digital SC information integration refers to the exchange of information across SC networks facilitated by digital platforms. Information exchange is the primary prerequisite and basis for SC collaboration (Cao & Zhang, 2011; Sheu et al., 2006). Due to the complex nature of SC, businesses are increasingly relying on information and communication technology such as electronic data interchange, automotive network exchange, and blockchain to minimize uncertainty among partners and improve collaboration (Asante et al., 2021; Gunasekaran & Ngai, 2004). Digital SC integration, particularly information integration, allows organizations to establish strong connections with their SC partners by enabling real-time data sharing and communication (Shee et al., 2018). This connectivity reduces inefficiencies and misunderstandings and enhances trust and coordination among partners. As a result, it can be anticipated that digital information integration enhances the effectiveness of SC collaboration. Thus, we propose the following hypothesis:

H1: Digital information integration positively influences SC collaboration.

Businesses can benefit from inter-organizational systems that enable digital operation integration. These systems enable interactive activities and coordination to modify various business processes, leading to the development of specific assets tailored to other partners' needs and fostering collaboration (Zhou et al., 2023). Consequently, digital platforms have been widely adopted by businesses in established and vertically integrated SC (Zhou et al., 2022). When approaching sustainability, digitally enabled operational integration facilitates collaborative SC processes and minimizes process-related interruptions (Ali et al., 2021; Luzzini et al., 2015). By allowing partners to coordinate their operational activities more effectively, digital platforms can enhance the synchronization and alignment within the SC. Therefore, we anticipate that SC collaboration will be greatly improved when the partners coordinate different operational activities through a digital platform. Hence, we postulate:

H2: Digital operational integration positively influences SC collaboration.

Relational integration pertains to building strategic relationships with SC partners (Liu et al., 2016), which requires investing in relationship-specific assets such as interdependence and trust for the durability of these relationships (Kim, 2014). However, Verghese et al. (2022) highlighted that investing in these assets requires varied levels of intimacy. For example, a firm may be hesitant to collaborate at a low level of intimacy if it does not see an enduring relationship. Conversely, if a firm recognizes a bilateral value proposition, it is more likely to engage in collaborative efforts (Verghese et al., 2022). Moreover, the longevity of relationships and high trust among SC partners strengthen the relationship and help in addressing SC disruptions collaboratively. Organizations can advance their SC integration by building long-lasting relationships within their SC networks through digital relational integration (Cai et al., 2010; Gunasekaran & Ngai, 2004). Thus, we hypothesize that there is a relationship between digital relational integration and SC collaboration:

H3: Digital relational integration positively influences SC collaboration.

Digitally enabled Supply Chain Collaboration and Product Authenticity

Collaboration among SC partners is a significant step toward improving the visibility of SC operations and preventing fraudulent activities, thereby ensuring the authenticity of information and products. It is often difficult to verify the authenticity of products due to a lack of information about where those products came from. This lack of information directly affects whether consumers will purchase the products (Kim et al., 2008; Tan & Saraniemi, 2023). Prior scholars have pointed out that SC partners play a crucial role in addressing this issue. Collaboration among SC partners brings accountability, promotes alignment, and improves accuracy by lessening operational risks. It also helps in minimizing counterfeit products, which benefits both companies and customers (Sodhi & Tang, 2019). As a key enabler of SC collaboration, organizations are digitalizing their SC operations. This digitalization improves traceability and assists both SC partners and customers in verifying the authenticity of the products (Sodhi & Tang, 2019; Vazquez Melendez et al., 2024). Thus, it can be anticipated that SC collaboration through digital means will allow for greater traceability and accountability of SC operations and enable product authenticity. Therefore, we hypothesize:

H4: SC collaboration positively influences sustainable product authenticity.

Moderation Effect of Transparency Level and Platform Type

Transparency plays a vital role in minimizing the risk of fraud within SC networks. By enhancing the visibility of information across SC, transparency enables the evaluation and auditing of SC, building trust among SC partners (Asante et al., 2021; Kumar et al., 2020). This, in turn, builds trust among SC partners. Transparency also has the potential to strengthen trust between these partners and foster SC collaborations (Pattanayak et al., 2024). Additionally, high transparency of the records enhances the monitoring and accountability of SC activities, thus optimizing SC operations (Asante et al., 2021). Overall, SC is propelled toward a high level of transparency to strengthen collaboration by eliminating operational inefficiencies and information distortion while simultaneously enhancing trust (Akkermans et al., 2004; Asante et al., 2021). Hence, we assume that the impact of SC integration (i.e., informational, operational, and relational integration) on SC collaboration would be enhanced when the level of transparency is high. Consequently, we propose:

H5: Transparency level moderates the association between (a) information integration, (b) operational integration, and (c) relational integration and SCC collaboration such that these associations are strengthened when the level of transparency is high.

The extent to which transparency impacts SC dimensions can vary. Companies often prefer not to disclose information about their Tier-1 suppliers due to SC vulnerabilities or the risk of revealing competitive advantages (Sodhi & Tang 2019). However, when using blockchain, all the information is disseminated across all parties in the chain (Pattanayak et al., 2024). The fact that no single entity has control over information in the blockchain exposes the company to potential challenges in reversing any disclosed information (Markus & Buijs, 2022). Similarly, if a firm has revealed one of its supplier's identities, and if any adverse news about that supplier emerges in the market, then the firm cannot retract this disclosure (Sodhi & Tang, 2019). Amid this backdrop, we anticipate the interaction between transparency level and platform type such that the impact of transparency on the association between (a) information integration, (b) operational integration, and (c) relational integration and SC collaboration would be lessened for blockchain. Therefore, we propose the following hypothesis:

H6: Platform type moderates the interaction effect of transparency level on the association between (a) information integration, (b) operational integration, and (c) relational integration and SC collaboration such that the interaction effect of transparency level is lessened when the platform type is blockchain.

Methods

Experiment Design

We designed a 2x2 factorial experiment by considering platform type (blockchain-based vs. non-blockchain-based) and transparency level (high vs. low) to test our study hypotheses. We created four scenarios and user interfaces (UIs) for these four groups. The scenarios, along with the UIs, provide a concise description and visual of different types of platforms with varying levels of transparency. We presented these scenarios to the participants with the aim of providing them with a contextual basis to assess the platforms through UI. Participants were randomly assigned to one of the four groups. While assigning participants, we ensured to create comparable groups in terms of the number of participants and demographics. This helped us to eliminate any possibility of differences in measured constructs due to the variations in group compositions. While collecting data, participants were first explained the context of the scenario and then shown the visual vignette. Subsequently, they were asked to respond to the questions measuring the study constructs based on their understanding of the presented scenario and UI.

Measurement Instrument Development

We developed a structured multi-item instrument to obtain the data from the target audience. The data collection protocol started with a brief introduction to the topic of blockchain and non-blockchain platforms. Then, the first part of the questionnaire was designed to measure the demographic profile of the respondents in addition to the size of their organizations, their use of any technological platform, and how their organizations integrate sustainability into their SC. Next, the participants were tasked to read the scenario and apprehend the accompanying visual UI. The following part was structured to measure the study constructs. We adapted the measurement instruments from prior validated scales. To measure digital SC integration, we adapted four items for information integration, seven items for operational integration, and five items for relational integration from Jiang et al. (2023). The measurement items for the rest of the study constructs were also adapted - five items on SC collaboration from Fawcett et al. (2011) and three items on product authenticity (Verhaal et al., 2023). Construct items were measured on a 5-point Likert scale ranging from 1 for strongly disagree to 5 for strongly agree.

Data Collection

We recruited participants using the Prolific platform. Prior scholars have recognized the Prolific platform as a valid data collection source, enabling researchers to identify relevant participants from various organizations. However, we also tried to overcome the limitations associated with data collection via online platforms (Peer et al., 2014). For example, we included reverse-coded questions, attention checks, and randomized item orders. We recruited only those participants who were full-time employees, used the technological platforms at their workplace, and had experience in SC decision-making. A total of 500 participants accessed the study, and 477 attempted to answer the survey questions. We analyzed these 477 responses and removed 131 that were deemed incomplete or failed attention checks. Subsequently, we had 346 valid responses, each group representing 85-86 responses. The sample chosen displayed heterogeneity regarding age, gender, and educational background. Descriptive analysis revealed that 69% of the respondents were men. Most of the respondents, 65%, belonged to the age group above 36 years. Additionally, 75% of the participants possessed at least a bachelor's degree. The sample size mainly consisted of individuals employed in the manufacturing, IT, construction, and transportation industries.

Common Method Bias

To assess and manage the potential common method bias (CMB), we used statistical and procedural remedies (Podsakoff et al., 2003). To reduce the likelihood of CMB, we focused on full-time employees with prior experience in using technology and SCM. Our study included reverse-coded items and attention checks to encourage participants to pay close attention to the questions. Additionally, we used Liang's approach (Liang et al., 2007) and observed that method variance was minimal compared to substantive variance. The results showed a substantial difference between substantive variance and method variance, with a ratio of 169.00. These steps indicate that CMB is not a significant concern in this study.

Analysis and Results

To test the proposed hypotheses, we applied the partial least square (PLS) approach using the software SmartPLS4 (Ringle et al., 2005). The PLS technique is also a good fit for measuring moderating effects, which is the case in our study (Srivastava & Chandra, 2018). Additionally, PLS has been utilized in various IS studies and is acknowledged as a useful data analysis technique (Han et al., 2015).

Measurement Model

We followed a two-step analytical method including measurement properties of instruments as a first step and examining the structural association in the second step (Hair et al., 1998). We employed three types of validity tests to analyze the measurement model. First, as a primary test, we examined the convergent validity through the factor loadings to ensure the reliability of indicators that have been used to measure the study constructs. We removed two items (item 9 and item 10) that did not meet the threshold requirement of 0.7 (Appendix B). We then checked if each construct's Cronbach alpha (CA) and composite reliability (CR) values were higher than the cutoff of 0.7 (Fornell & Larcker, 1981) (see Table 1). We found CA values in the range of 0.843-0.943 and CR values within the range of 0.888-0.963, which exceeded the cutoff limit. Moreover, each construct showed an AVE value greater than the threshold criteria of 0.5 and ranged from 0.615 to 0.879, which indicates convergent validity is satisfied.

Next, to establish discriminant validity (Fornell & Larcker, 1981), first, we compared the correlations between constructs to the square root of AVE values in the correlation matrix. As presented in Table 1, all diagonal values in the correlation matrix are higher than the inter-construct correlation (off-diagonal values in Table 1). Second, we used the Heterotrait - Monotrait (HTMT) ratio of correlations and observed that the HTMT values of each construct were lower than the cutoff of 0.85 (Henseler et al., 2015) (see Table 2). Based on these outcomes, we conclude discriminant validity is established.

Constructs	CA	CR	AVE	1	2	3	4	5
1. Information integration	0.871	0.912	0.722	0.849				
2. Operational integration	0.843	0.888	0.615	0.661	0.784			
3. Product authenticity	0.943	0.963	0.897	0.305	0.295	0.947		
4. Relational integration	0.871	0.907	0.662	0.624	0.668	0.313	0.813	
5. SC collaboration	0.856	0.897	0.636	0.658	0.605	0.392	0.628	0.798

Table 1: Correlations and Square Root of AVE

Constructs	1	2	3	4	5
1. Information integration					
2. Operational integration	0.770				
3. Product authenticity	0.336	0.329			
4. Relational integration	0.713	0.781	0.345		
5. SC collaboration	0.759	0.709	0.435	0.723	

Table 2: Heterotrait-Monotrait (HTMT) Results

We also examined if multicollinearity exists in the study constructs. We calculated the variance inflation factor (VIF), found that all the VIF values were lower than 5.0, and established that there was no significant issue of multicollinearity (Hair, 2009).

Hypothesis Testing

Table 3 shows the results of the structural model analysis presenting the direct effects as well as interaction effects. First, we analyzed the direct impact of digital SC integration (informational, operational, and relational) on SC collaboration. We found mixed results with some interesting findings. Specifically, we observed that information integration has a significant impact on SC collaboration ($\beta = 0.443$, $t = 4.617$, $p < 0.001$), supporting H1. However, we found a non-significant impact of operational integration on SC collaboration ($\beta = 0.033$, $t = 0.320$, $p > 0.05$). Thus, H2 was not supported. While on the other hand, we found that relational integration has an impact on SC collaboration ($\beta = 0.341$, $t = 4.192$, $p < 0.001$), thereby supporting H3. Results also revealed that SC collaboration significantly impacts product authenticity ($\beta = 0.392$, $t = 7.456$, $p < 0.001$), thus supporting H4.

Next, we tested for the moderating impact of transparency level on the relationship between digital SC integration (informational, operational, and relational) and SC collaboration. In contrast to our hypothesis, our findings revealed a significant negative impact of transparency level on the relationship between information integration and SC collaboration ($\beta = -0.157$, $t = 2.017$, $p < 0.05$); thereby, H5a was not supported. However, the transparency level positively moderated the relationship between operational integration and SC collaboration ($\beta = 0.282$, $t = 3.338$, $p < 0.001$), thereby supporting H5b. We also found that the transparency level has a non-significant moderating impact on the relationship of relational integration with SC collaboration ($\beta = -0.058$, $t = 0.701$, $p > 0.05$). Therefore, H5c was not supported.

In the final analysis, we assessed the structural model for three-level interaction to understand how platform type affects the moderating impact of transparency level on the relationships between all dimensions of digital SC integration and SC collaboration. Results showed that platform type has a non-significant impact on the moderating impact of transparency level on the relationship between information integration and SC collaboration ($\beta = 0.106$, $t = 1.244$, $p > 0.05$). Thus, H6a was not supported. However, we observed that the platform type (when it is blockchain) significantly reduces the moderating impact of transparency level on the association between operational integration and SC collaboration ($\beta = -0.230$, $t = 2.807$, $p < 0.01$), thereby supporting H6b. Results further revealed a non-significant impact of platform type on the moderation of transparency level between the relationship of relational integration and SC collaboration ($\beta = 0.021$, $t = 0.234$, $p > 0.05$). Hence, H6b was also not supported.

Hypothesis	β	t statistics	p values	Results
Information integration → SC collaboration (H1)	0.443	4.617	0.000	Supported
Operational integration → SC collaboration (H2)	0.033	0.320	0.749	Not supported
Relational integration → SC collaboration (H3)	0.341	4.192	0.000	Supported
SC collaboration → Product authenticity (H4)	0.392	7.456	0.000	Supported
Transparency level x Information integration → SC collaboration (H5a)	-0.157	2.017	0.044	Not supported
Transparency level x Operation integration → SC collaboration (H5b)	0.282	3.338	0.001	Supported
Transparency level x Relational integration → SC collaboration (H5c)	-0.058	0.701	0.483	Not supported

Platform type x Transparency level x Information integration → SC collaboration (H6a)	0.106	1.244	0.213	Not supported
Platform type x Transparency level x Operational integration → SC collaboration (H6b)	-0.230	2.807	0.005	Supported
Platform type x Transparency level x Relational integration → SC collaboration (H6c)	0.021	0.234	0.815	Not supported

Table 3: Hypothesis Results

To further clarify the interaction effect, we plotted the simple slope of the relationship between operational integration and SC collaboration at high and low transparency levels (Figure 1, left). Similarly, we plotted the simple slope of the relationship between the interaction term of transparency level and operation integration, and SC collaboration when the platform is blockchain or non-blockchain (Figure 1, right).

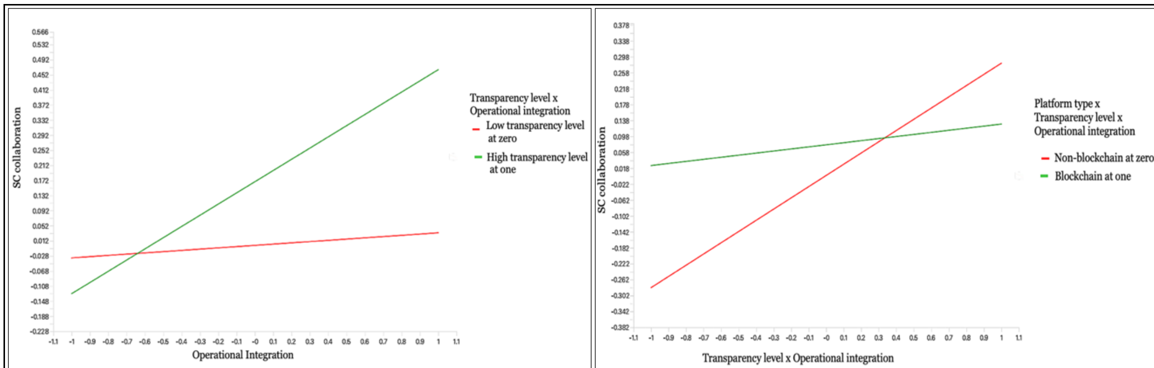

Figure 1: Interaction Effects

To better understand the effects of digital SC integration on product authenticity, we conducted the post hoc test to examine the direct effect of digital SC integration on product authenticity and the mediating effect of SC collaboration. The findings showed that informational integration ($\beta = 0.035$, $t = 0.660$, $p > 0.05$), operational integration ($\beta = 0.041$, $t = 0.510$, $p > 0.05$), and relational integration ($\beta = 0.079$, $t = 0.970$, $p > 0.05$) have non-significant direct impacts on product authenticity. We further observed that operational integration ($\beta = 0.010$, $t = 0.307$, $p > 0.05$) has a non-significant effect on product authenticity through SC collaboration. In contrast, we found that information integration has a significant impact on product authenticity through SC collaboration ($\beta = 0.131$, $t = 2.662$, $p < 0.01$). The findings further revealed that relational integration also has a significant indirect effect on product authenticity ($\beta = 0.101$, $t = 2.737$, $p < 0.01$). These results suggest that SC collaboration fully mediates the effect of informational integration and relational integration on product authenticity.

Discussion

Key Findings

Our study results showed some counterintuitive findings on how digital SC integration affects SC collaboration and sustainable product authenticity. We discuss the major study findings as follows.

First, we found that information integration and relational integration were significant predictors of SC collaboration. This aligns with the prior findings recognizing that digital information integration through a culture of information sharing and long-term relationship orientation enables improved collaboration among SC partners (Fawcett et al., 2011; Paulraj et al., 2008). However, operational integration was not a significant factor in predicting SC collaboration. This finding may be attributed to the different levels of transparency. Thus, we incorporated transparency level as a moderating factor to test the differences in the associations between digital SC integration and SC collaboration. Interestingly, we found that the relationship between operational integration and SC collaboration is strengthened when the transparency level is high. It implies that increased transparency of SC operations can help SC partners trace SC activities, reduce operational complexities, and foster collaborative processes (Dubey et al., 2020). However, the analysis revealed that a high transparency level is only advantageous for some dimensions of digital SC integration. For example, the relationship between information integration and SC collaboration is weakened when the transparency level is high. This result is counterintuitive, as it might be expected that high transparency in information integration would have strengthened the impact (Pattanayak et al., 2024). But, in case of high transparency, when a company discloses the information of all its suppliers, it opens the opportunity for the competitors to strategically use the same suppliers (Sodhi & Tang, 2019), which could affect the company's relationship with its supplier partner due to, for example, shortage of supply or increased competition. Finally, we found an insignificant interaction effect of transparency level for relational integration and SC collaboration. It implies that the transparency level alone is insufficient to strengthen the relationship between relational integration and SC collaboration.

Thereafter, we examined how platform type alters the impact of transparency level on the association between digital SC integration and SC collaboration. We found that when the platform is blockchain, it negatively affects the moderation of the transparency level on the association between operational integration and SC collaboration. This aligns with the prior findings on the grounds that blockchain with a high level of transparency may disclose competitive operational information to other SC partners (Sodhi & Tang, 2019). This implies that a highly transparent SC can increase the risk of opportunistic behavior of SC partners and reduce the competitive advantage, which, as a result, negatively affects collaborative relationships among SC partners.

Finally, our analysis revealed that SC collaboration is a significant factor in fostering sustainable product authenticity. This finding is supported by prior scholars stating that SC collaboration enabled by digital SC integration minimizes the risk of counterfeit products (Sodhi & Tang, 2019). This can be achieved through enhanced process traceability across SC, which in turn ensures product authenticity (Sodhi & Tang, 2019; Vazquez Melendez et al., 2024).

Theoretical Implications

Our study makes three distinctive theoretical contributions. First, by leveraging the conceptualization of SC integration proposed by Leuschner et al. (2013) - information, operational, and relational - we extend it to digital SC integration, specifically to explore how this digital SC integration facilitates SC collaboration and sustainable product authenticity. Indeed, prior literature has established the significance of digitalizing information sharing, operational coordination, and relational capabilities (Fawcett et al., 2011; Pattanayak et al., 2024; Zhou et al., 2023) as facilitators of SC collaboration. However, prior studies investigated these constructs independently and lacked an understanding of the integrated impact of digital SC integration to advance SC collaboration. Therefore, by exploring digital SC integration, our study revealed that information integration and relational integration are significant to achieving desirable SC collaboration. The role of operational integration was found to be more interesting, as we describe it in the next paragraph.

Second, this study extends the IS and SC literature by examining the interaction effect of platform type and transparency level for SC collaboration. Although prior studies have emphasized the significance of different IT platforms and transparent SC processes as essential for efficient SC integration and SC collaboration (Dubey et al., 2020; Jiang et al., 2023), these investigations have mainly focused on examining either the direct impact of these IT platforms or as an additional capability to SC integration (Liu et al., 2016; Zhou et al., 2023). This theoretical discourse remains silent on the interaction effect of different digital platforms (i.e., platform type) and platform attributes (i.e., transparency level) on SC collaboration. Our study found that none of them (platform type and transparency level) is necessary for all dimensions of SC integration to promote SC collaboration. For instance, as evidenced by the study results, digital operational integration itself did not contribute to fostering SC collaboration. However, when organizations were highly transparent in displaying their operational processes, SC collaboration significantly improved. Furthermore, organizations using blockchain technology did not require high transparency for operational integration, unlike those non-blockchain platforms. There could be different reasons for such a result. For example, this could be due to the inherent nature of blockchain technology to be transparent, which helps to build trust among SC partners and facilitate SC collaboration (Sodhi & Tang, 2019). The other reason could be the immutable nature of blockchain; organizations are reluctant to be highly transparent about their operations because of the risk of losing their competitive position in collaborative endeavors. These findings provide opportunities for prospective scholars to explore the reasons why organizations may be reluctant to be highly transparent, even though transparency is a most desirable attribute for SC partners.

Third, our study advances the prior findings by theorizing the impact of SC collaboration (Chen et al., 2017) in enhancing sustainable product authenticity. Given the involvement of different actors in the SC network, collaboration is crucial for verifying an organization's sustainability related practices. Prior literature has stressed the importance of SC collaboration for organizations to improve sustainability performance (Chen et al., 2017). However, as the number of SC partners increases, the complexity of SC collaboration intensifies, magnifying the need for the provenance of the SC, specifically for sustainable products (Vazquez Melendez et al., 2024). Our study contributes to SC and sustainability literature by introducing SC collaboration as a mediating mechanism to facilitate verifying product authenticity. We found that digital information, operational and relational integration foster SC collaboration as a facilitating factor to enhance sustainable product authenticity.

Implications for Firm

This study offers two significant implications for firms seeking to enhance their SC collaboration to facilitate verification of the authenticity of their sustainable practices.

First, our findings unequivocally established that SC collaboration is a key determinant for ensuring sustainable product authenticity. Therefore, organizations should prioritize building strong collaborative networks within their SCs to uphold and communicate the authenticity of their sustainable offerings. Our findings further underscore the critical nature of digital SC integration for organizations to advance their SC collaborations. However, not all dimensions of digital SC integration (i.e., information, operational, relational) are equally significant to promote SC collaboration. Hence, it is imperative for organizations to critically evaluate their prevalent relationships with SC partners and strategically decide on how to advance their SC collaborations based on the most relevant dimensions of digital SC integration. The study results imply the need for organizations to prioritize different dimensions of digital SC integration and invest their efforts accordingly rather than treating all SC integration dimensions equally.

Second, our findings revealed the interdependence between operational integration and transparency level. We suggest that organizations maintain a high level of transparency to optimize SC collaboration by using operational integration. However, in the case of a blockchain platform, the interaction impact of transparency level turns adverse for the relationship between operational integration and SC collaboration. Thus, we suggest that if organization managers consider using blockchain, they should avoid increasing transparency levels and instead invest in value-added operations, such as better inventory management and efficient order fulfillment etc., to further strengthen the SC collaboration. Additionally, organizations can adopt a strategic approach to selectively disclose their operational processes to avoid jeopardizing their competitive advantage due to high transparency.

Conclusion and Future Research

This study has developed linkages between digital SC integration (i.e., information, operational, and relational), SC collaboration, and sustainable product authenticity. Furthermore, we also investigated to what extent the impact of digital SC integration on SC collaboration varies across different transparency levels for different platforms. We observed that information integration and relational integration significantly enhance SC collaboration, which in turn improves sustainable product authenticity. We further observed that the effect of digital operational integration is contingent upon transparency level and platform type. In particular, we observed that a high transparency level positively influences the association between operational integration and SC collaboration, except in the case of a blockchain platform where the impact of transparency is weakened.

This work is not an exception to limitations. First, this study considered only three dimensions of SC integration. Other SC integration dimensions, such as internal integration and external integration, could be explored to better understand the effectiveness of digital SC integration for SC collaboration and sustainable product authenticity. Second, SC collaboration may also be influenced by many other factors (e.g., relationship management, process alignment, and investment in collaboration) in addition to SC integration dimensions. Therefore, we encourage future research investigating these factors with a more comprehensive research framework. Third, other platform characteristics, such as immutability and traceability, have not been examined, which could offer a comprehensive insight into the interaction between platform type and platform characteristics for digital SC integration and SC collaboration. Fourth, future research may focus on conceptualizing sustainable product uncertainty using economic, social, and environmental dimensions and investigate the effects of SC digital integration and collaboration on these dimensions. Lastly, in addition to sustainable product authenticity, prospective scholars may consider different constructs such as sustainable SC provenance, material conservation, and ethical sourcing to measure the sustainable performance of an organization.

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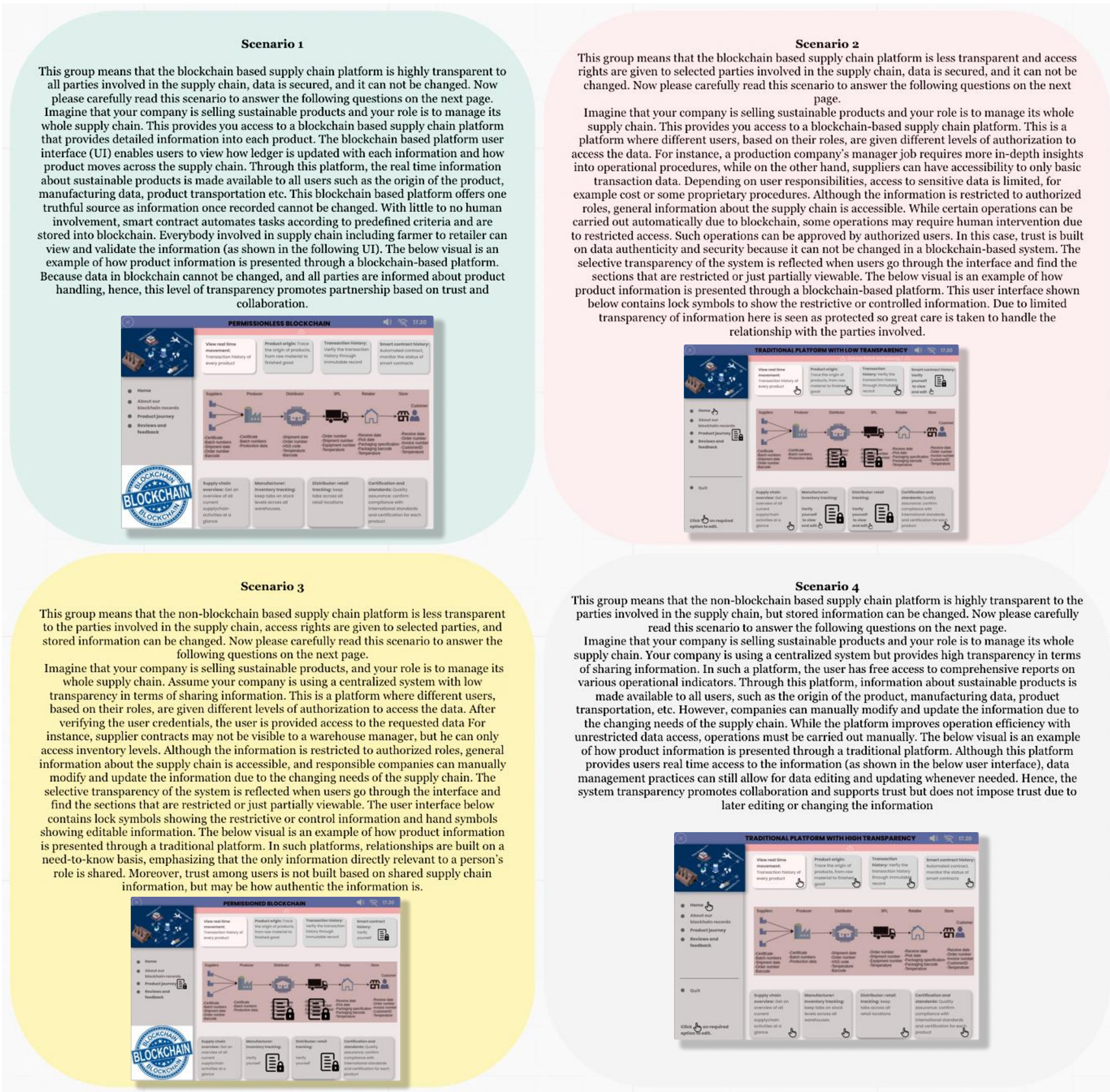
Appendix A: Scenario



Appendix B: Survey Items

Constructs and Items	Loading	Mean	SD
Digital SC integration: Information integration			
The platform described in the scenario:			
1. May provide our partners with any information that might help them.	0.832	3.812	1.013
2. May keep each other informed about events or changes that may affect the other party.	0.808	3.850	0.931
3. May enable exchange of information frequently with our partners.	0.886	3.829	0.957

4. May enable timely exchange of information with our partners.	0.870	3.867	0.909
Digital SC integration: Operational integration			
Using the platform described in the scenario:			
5. We may be able to coordinate with our partners on procurement.	0.808	3.960	0.782
6. We may be able to jointly plan the development of demand forecasts with our partners.	0.775	3.772	0.908
7. We may be able to coordinate with our partners with respect to different operational activities.	0.843	3.792	0.845
8. We may be able to coordinate with our partners on order execution.	0.773	3.945	0.760
9. We may be able to coordinate with our partners on engineering change.	Removed	-	-
10. We may be able to coordinate with our partners on new product/service introduction.	Removed	-	-
11. We may be able to coordinate with our partners on services support.	0.716	3.902	0.813
Digital SC integration: Relational integration			
Using the platform described in the scenario:			
12. We and our partners may often agree on the best interest of the supply chain.	0.725	3.751	0.844
13. We and our partners may work with one another to improve the quality of mutual cooperation in a long run.	0.831	3.942	0.799
14. We and our partners may work with one another to improve the supply chain as a whole.	0.823	3.965	0.836
15. We and our partners may build a long-term relationship.	0.825	4.055	0.822
16. We and our partners may consider our relationships as a long-term alliance or partnership.	0.856	3.957	0.840
SC collaboration			
Using the platform described in the scenario:			
17. My company aggressively shares information to help suppliers improve their capabilities.	0.719	3.251	1.174
18. My company jointly develops strategic objectives with supply chain partners.	0.839	3.679	0.946
19. My company closely monitors the supplier performance and is the basis for future business.	0.806	3.934	0.804
20. The principle of shared information governs supply chain relationships.	0.807	3.853	0.869
21. My company shares Value-added information among supply chain members	0.812	3.737	0.914
Sustainable product authenticity			
Based on the information in scenario:			
22. My company is selling authentic sustainable products.	0.943	3.855	0.868
23. My company is selling real sustainable products.	0.953	3.844	0.886
24. My company is selling genuine sustainable products.	0.945	3.792	0.901