Leveraging Supplier Integration for Sustainable Supply Chain Practices: A Governance Mechanism Perspective

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Abstract

Extant research has given insufficient attention to the influence of supplier integration on sustainable supply chain practices (SSCP), whilst also neglecting the contingent role of governance mechanisms. Using boundary theory and resource-capability-performance (outcome) theoretical framework, this study applies hierarchical linear regression and bootstrapping to analyze survey data collected from 235 Chinese manufacturing enterprises, testing a theoretical model and series of hypotheses. The findings reveal that supplier product integration directly promotes SSCP, while supplier process integration indirectly contributes to SSCP through supplier product integration. Moreover, contractual and relational governance mechanisms strengthen the impact of supplier product integration on SSCP but reduce the effect of supplier process integration. The study highlights the relevance of boundary theory in advancing SSCP and emphasizes the need for firms to integrate suppliers under varying governance mechanisms to enhance sustainability outcomes.

Keywords: supplier product integration; supplier process integration; sustainable supply chain practices; contractual governance; relational governance.

1 Introduction

Many organizations nowadays consider sustainability to be an essential component of their operations and supply chain strategy. Moreover, firms have begun to recognize the importance of close supplier involvement in responding effectively to both environmental and social sustainability challenges (Bouguerra et al., 2024). For example, Motorola has successfully implemented environmentally preferred product (EPP) programs by cooperating with its suppliers (Grant et al., 2017). Meanwhile, 3M and Intel achieved ambitious social sustainability goals through effective supplier engagement (Herrera, 2015). Nonetheless, the discourse surrounding the relationship between supplier integration and SSCP remains contentious, with the literature still at a relatively nascent stage of development (Chen et al., 2017).

On the one hand, research has demonstrated that collaboration with suppliers can enhance firms' resources and capabilities for sustainable development, leading to environmental innovations (Nayal et al., 2023). Furthermore, Marculetiu et al. (2023) asserted that supplier integration can enhance social and/or environmental sustainability, and Shah and Soomro (2021) emphasized that environmental sustainability success largely relies on supplier involvement. On the other hand, Chavez et al. (2023) argued that supplier integration hardly plays a central role in achieving internal environmental process innovations or in reaping the benefits of associated resource efficiencies. Research has also indicated that coordinating with suppliers poses challenges due to differing sustainability routines and processes (Gmelin & Seuring, 2014), which can lead to excessive resource consumption (Anderson & Jap, 2005), resource wastage, relational inertia (Villena et al., 2011), and unethical practices (Oliveira & Lumineau, 2019), ultimately undermining firms' sustainability efforts. Further research is therefore required in order to better understand the relationship between supplier integration and SSCP.

The inconsistent and conflicting conclusions of prior research may stem from a broad and one-dimensional operationalization of supplier integration in extant research (Molinaro et al., 2022). Indeed, recent studies have pointed to the importance of developing a more nuanced approach by identifying two primary categories of supplier integration: product integration and process integration (Kim & Schoenherr, 2018).

Product integration entails collaborative efforts between firms and key suppliers aimed at product development and enhancement, translating supplier knowledge into new products and facilitating cross-learning (Zahra & Nielsen, 2002). Process integration pertains to synchronization and coordination efforts between firms and key suppliers. This integration aids firms in planning and streamlining production processes, inventory management, and marketing operations in a cohesive manner, thereby enhancing supply chain efficiency and effectiveness (Rajaguru & Matanda, 2019).

Given the distinction between supplier product integration and supplier process integration, it is essential that their particular effects on SSCP are explored concurrently. Additionally, supplier process integration fosters a collaborative environment and a sense of belonging among supply chain partners (Rajaguru & Matanda, 2019), serving as a crucial prerequisite for executing complex tasks, such as product integration (Narayanan et al., 2011). Empirical research, however, has largely overlooked the interaction effects between process integration and product integration. Therefore, it is crucial to examine their correlations and elucidate the pathway from process integration to SSCP through product integration.

The governance mechanisms adopted in supply chain relationships are an important contextual factor influencing the effectiveness of collaboration (Heirati et al., 2016), such as by preventing or mitigating the manifestation of adverse outcomes in business-to-business (B2B) relationships (Verbeke et al., 2021). Governance mechanisms are often overlooked prerequisites and contingencies for engaging with suppliers (Paulraj et al., 2014), yet they play a crucial role in regulating supplier behavior (Dacin et al., 2007), including in the context of sustainability initiatives (Alghababsheh & Gallear, 2021). However, research has seldom addressed how to effectively govern supplier involvement in SSCP (Marshall et al., 2015). For example, it has been noted that the impact of governance mechanisms on firms' green behaviors has largely gone unexamined (Tachizawa & Wong, 2015). Given the limited discussion of the contingent effects of governance mechanisms on sustainability, there is an urgent need for research that investigates how the interplay between supplier (product and process) integration and these mechanisms influences SSCP.

Against this backdrop, this research not only differentiates between supplier process integration and supplier product integration but also considers two types of governance: contractual and relational governance. The study aims to examine the relationship between supplier integration and SSCP, while also exploring the mediating role of supplier product integration and the moderating role of governance mechanisms in these practices.

The paper presents three significant contributions. First, we enhance understanding of the two forms of supplier integration and illuminate their different impacts on SSCP. Second, recognizing that firms assume a dual role in boundary-spanning activities, we empirically investigate the contingent effects of governance mechanisms on SSCP. Our findings highlight the differential moderating effects of governance mechanisms on the relationship between supplier integration and SSCP, emphasizing the conditions under which supplier integration is most effective. Third, the research reveals the mediating effects of product integration, thereby opening the "black box" between process integration and SSCP. This includes uncovering (i) the direct pathway from process integration to SSCP, and (ii) the indirect pathway to SSCP through product integration.

2 Theoretical background

2.1 Resource-capability-performance (outcome) theoretical framework and Boundary theory

The resource-based view (RBV) of the firm posits that organizations can generate rents or competitive advantages by developing unique resources and capabilities (Barney, 1991). RBV elucidates how the establishment of organizational capabilities, which align with and support existing resources, can enhance marketplace advantages. While resources are essential, they alone are insufficient for a firm to achieve superior performance; the potential value of these resources is realized through resource deployment capabilities, denoting a firm's ability to transform resources into performance outputs (Ketchen Jr et al., 2007). Merely possessing resources does not create competitive advantages or superior performance unless the firm can deploy these resources effectively. Consequently, the impact of resources on firm performance is indirect, mediated through the firm's organizational capabilities. Therefore, RBV suggests a resource-capability-performance (outcome) relationship. The RBV framework has been applied in the context of sustainability to elucidate how supplier integration influences sustainability practices (Cheng, 2020; Chetthamrongchai & Jermsittiparsert, 2019; Sadiq et al., 2024; Yu et al., 2017), with the resource-capability-performance (outcome) theoretical framework derived from RBV providing an improved understanding of how competitive advantages arise from bundling resources into capabilities (Huo et al., 2016).

By developing a resource-capabilities-performance framework, this study clarifies how product integration can foster capabilities that support process integration as a resource to enhance marketplace positioning. In our study, process integration is typically viewed as a structure and set of resources (Dai et al., 2017; Pertusa - Ortega et al., 2010), enabling firms to attain, exploit, and accumulate tangible and intangible assets, including distinctive knowledge, to solve problems and improve efficiencies (Dobrzykowski & McFadden, 2020). Supplier product integration denotes product development capabilities (Koufteros et al., 2010) and reflects the ability of interfirm new product development (NPD) partnerships to synchronize resources and tasks to create superior new methods for executing NPD activities (Ettlie & Pavlou, 2006). Process integration can assist a firm in realigning processes and resources more effectively, thereby contributing to the development of critical supply chain capabilities (Chen et al., 2009). Furthermore, process integration has the potential to facilitate the creation of unique capabilities (product integration) that can enhance organizational performance (Rajaguru & Matanda, 2019). Thus, we assert that only when product integration is developed as a result of process integration do firms achieve improvements in their performance outcomes. Although the resource-capabilities-performance framework posits that aligning resources and capabilities leads to corporate competitive advantages, such as more sustainable practices, and acknowledges the relationship among supplier process integration, supplier product integration, and sustainability practices, it fails to specify the boundary conditions for this relationship.

Boundary theory suggests that an organization can secure essential resource inputs and manage its outputs by effectively managing its boundaries with other organizations

(Jia et al., 2021). Furthermore, boundary theory asserts that the organizational boundary defines a firm's sphere of influence and the limitations of organizations. In a B2B context, many firms are increasingly relying on external resources to implement sustainability strategies (Eggers et al., 2014). When organizations access abundant external resources for sustainability that are otherwise scarce internally, boundary-spanning activities are activated. Consequently, organizations are becoming more aware of the advantages of collaborating beyond their own boundaries (Ordonez-Ponce et al., 2021). Firms integrate suppliers to enhance SSCP, which aligns with the core tenet of boundary theory – that firms often lack the internal resources necessary to address sustainability challenges meaning they must rely on external relationships for critical resource inputs (Leone et al., 2022). For instance, suppliers can provide reliable information and expertise that improve firms' information processing capacities for sustainable development (Munir et al., 2020).

Boundary theory addresses issues of autonomy, emphasizing that firms must safeguard themselves from the control and influence of suppliers. In their pursuit of autonomy, organizations must defend against disruptive forces present in their environment that can interfere with their operations (Santos & Eisenhardt, 2005). If firms do not maintain their boundaries, they risk becoming excessively reliant on external entities, such as suppliers (Wang et al., 2020). These disruptive forces are impacted by environmental uncertainty (Cross et al., 2000). As posited by boundary theory, the importance of boundary-spanning activities increases in the face of greater uncertainty (Stock, 2006). Consequently, managing boundaries becomes a significant organizational challenge in the context of sustainability.

When firms engage in boundary-spanning activities related to sustainability—by relying on cooperation with suppliers for information and resources (Cross et al., 2000; Maria Stock et al., 2017)—they must consider the role of governance mechanisms as additional strategies for managing and maintaining these boundaries. Governance mechanisms serve to curb opportunism and dysfunctional conflict (Chi et al., 2020) while enhancing effective interactions (Fischer, 2013), thereby helping to ensure autonomy.

In boundary-spanning activities, key actors must effectively fulfill a dual function: processing information to facilitate inter-organizational exchanges while simultaneously serving as external representatives to protect the interests of each party (Fan & Stevenson, 2019). Boundary spanners between organizations play a crucial role in information processing and external representation during inter-organizational collaboration. In a buyer-supplier relationship (BSR), firms navigate their boundary-spanning responsibilities through supplier integration and governance mechanisms, both independently and interdependently (Liu et al., 2017). Therefore, in their pursuit of sustainability, firms must manage their boundaries with suppliers, balancing the demands of information processing against the necessity for external representation.

In summary, boundary-spanning theory offers a framework for understanding how the dual roles performed by firms may influence SSCP. Additionally, to assess the effectiveness of information processing within these roles, it is crucial to consider specific contexts that promote its emergence. Notably, supplier integration is likely influenced by governance mechanisms. These mechanisms impact environmental uncertainty and ultimately shape the nature of boundary-spanning actions while influencing the effectiveness of supplier integration (Lin et al., 2024).

2.2 Supplier integration and SSCP

Research has acknowledged the contribution that suppliers can make to making firms' operations more sustainable (Barney et al., 2021). Subramaniam et al. (2020) argued that supplier integration significantly enhances overall sustainability. In fact, collaboration with suppliers is considered vital to advancing sustainability efforts (Bouguerra et al., 2024). The sustainability benefits of supplier integration can extend to both environmental (Taylor & Vachon, 2018) and social sustainability (Zhang et al., 2017).

Supplier cooperation is essential for SSCP (Touboulic & Walker, 2015). First, firms can work alongside suppliers to acquire resources, integrate complementary and diverse sustainability knowledge, and enhance their sustainability capabilities (Agarwal et al., 2018). Supplier involvement aids companies in grasping sustainable issues (Li et al., 2017) and addresses deficiencies in technology and knowledge pertaining to sustainability (Cheng, 2020). Consequently, supplier integration can provide resources such as capabilities and expertise, empowering firms to address sustainability deficiencies (Cheng, 2020). Furthermore, supplier involvement fosters deep interaction and collaboration, facilitating the swift transfer of resources and capabilities from suppliers to firms (Im et al., 2019). Second, collaboration with suppliers is beneficial for adopting and developing internal environmental technologies (Zhu et al., 2012), strengthening the capacity to innovate in sustainable product design (Hofman et al., 2020). The integration of supplier capabilities leads to supply-side sustainability innovations (Hollos et al., 2012), while supplier involvement enhances firms' innovative capacity regarding sustainability (Melander, 2018; Oliveira et al., 2018).

Third, supplier involvement enhances supply chain transparency and mitigates risks associated with sustainability (Multaharju et al., 2017). Indeed, Tang and Musa (2011) asserted that companies should establish cooperative relationships with suppliers when confronting environmental and socio-economic challenges. Fourth, suppliers are often integrated into sustainable product development to offer expertise in eco-friendly materials (Melander, 2018). By fostering external integration with suppliers, firms can secure a reliable supply of recycled or recyclable materials and minimize waste throughout the supply chain (Di Maria et al., 2022). Therefore, we argue that supplier integration significantly contributes to the success and implementation of SSCP.

Although only a small portion of the literature distinguishes between different types of supplier integration (Chen et al., 2019), it is essential to enhance our understanding of various supplier integration approaches in relation to SSCP. Consequently, following the research of Koufteros et al. (2005), we categorize supplier integration into two types: supplier product integration and supplier process integration. These two categories have different knowledge requirements and produce different outcomes concerning time-to-market. Specifically, supplier product integration tends to slow down time-to-market whereas supplier process integration accelerates it (Perols et al., 2013).

Supplier product integration primarily focuses on components or entire subassemblies and involves suppliers in the new product development (NPD) process (Koufteros et al., 2005). This collaboration promotes a strong connection between suppliers and manufacturers, enhancing NPD by improving flexibility and encouraging innovation (Huo, Qi, et al., 2014). Consequently, this process facilitates product differentiation (Damanpour, 2010) and enhances a firm's effectiveness in product development, ultimately stimulating SSCP (Perols et al., 2013). Furthermore, integrating suppliers into the NPD process leverages their knowledge and promotes joint problem-solving (Zahra & Nielsen, 2002). It also positively influences collaboration outcomes by fostering the sharing of risks and rewards associated with innovation, allowing firms to better align themselves with technological and market demands (Petersen et al., 2003). Thus, supplier product integration can accelerate the development of green products or components by facilitating resource and capability sharing, thereby supporting the implementation of SSCP. This prompts our first hypothesis:

H1: *Supplier product integration affects SSCP positively.*

Supplier process integration entails the establishment of collaborative and synchronized processes based on frequent communication between suppliers and manufacturers (Perols et al., 2013). This integration supports product manufacturing and transportation (Huo, Han, et al., 2014; Kim et al., 2012). Additionally, supplier process integration enhances the quality of manufactured products through shared information and joint planning (Petersen et al., 2005), focusing on product design and process optimization (Koufteros et al., 2007). Process integration can eliminate redundant interfirm activities, reduce duplication, and decrease resource slack. It coordinates interfirm work procedures and promotes the exchange of knowledge and resources, while also exploring innovative business opportunities and identifying new product ideas, thereby achieving synergistic advantages (Shi & Liao, 2013). Additionally, process integration enhances space and time utilization, including warehouse effectiveness and inventory turnover, and develops unique and complementary skills to achieve synergistic effects through shared resources (Hult et al., 2007; Min et al., 2007). By integrating processes with suppliers, organizations can plan and streamline production processes, inventory management, and marketing operations in a coordinated manner, thereby enhancing supply chain efficiency and effectiveness (Rajaguru & Matanda, 2019). Consequently, supplier process integration, through innovation and process improvements, promotes SSCP. Thus, the following hypothesis is proposed.

H2: *Supplier process integration affects SSCP positively.*

Product-offering supplier process integration commences at the initial phases of product development, providing technical knowledge and cost information (Koufteros et al., 2010). Schoenherr & Swink (2012) reported that integrating processes with suppliers enhances the flow of materials and information, thereby improving operational efficiency. Information synchronization through supplier process integration further benefits the provision of parts and components (Kim & Schoenherr, 2018). Moreover, process integration is associated with reduced uncertainty, fostering exchange relationships and nurturing trust (Schoenherr et al., 2015). Therefore, we argue that supplier process integration is a prerequisite and foundation for supplier product integration as it has the potential to enhance the sharing of information and expertise, ultimately facilitating cooperation in the design and development of components or entire subassemblies.

Furthermore, supplier process integration enhances product and inventory management by ensuring uninterrupted and reliable access to pertinent customer and production data (Fatorachian & Kazemi, 2021), which in turn bolsters supplier product integration (Annarelli et al., 2021). As a result, SSCP can be effectively implemented through collaborative product design and development (Sudusinghe & Seuring, 2022). Integrating the first two hypotheses, we deduce that the impact of supplier process integration on SSCP occurs in stages. Specifically, supplier process integration influences SSCP through supplier product integration. Thus, we propose that:

H3: *Supplier process integration positively affects supplier product integration.*

H4: *Supplier product integration mediates the relationship between supplier process integration and SSCP.*

2.3 The role of governance mechanisms

Supply chain governance mechanisms have been recognized as essential for enhancing sustainability within supply chains (Um & Oh, 2020). These mechanisms facilitate information sharing and promote environmental sustainability (Wacker et al., 2016). Conversely, the absence of effective governance mechanisms for overseeing supply chain partners' sustainability efforts may hinder resource efficiency and social equity (Li et al., 2017). Furthermore, governance mechanisms play a crucial role in managing sustainability since they can significantly impact the effectiveness of supply chain collaboration and the dynamics between sustainability drivers and outcomes

(Meinlschmidt et al., 2018). It is widely acknowledged that governance mechanisms include both contractual and relational governance. Both forms of governance can effectively support the implementation of more sustainable practices (Belhadi et al., 2021).

Contractual governance emphasizes the significance of contracts and formal control mechanisms in mitigating sustainability-related risks while fostering collaborative relationships between suppliers and customers to address sustainability challenges (Belhadi et al., 2021). By leveraging resources and information obtained through exchanges and by sharing such insights with suppliers, contractual governance enables firms to achieve sustainable competitive advantages (Um & Kim, 2019). For example, contracts can establish the foundations for green collaborative initiatives (Cai et al., 2022), thereby preventing opportunistic behavior, addressing uncertainty, and mitigating the scope and severity of risks in bilateral relationships (Zhang et al., 2025). They offer a clear delineation of environmental requirements, effectively aligning responses with external demands for ecological protection (Belhadi et al., 2021). Furthermore, contracts foster a collaborative atmosphere aimed at minimizing sustainability-related risks and enhancing coordination between buyers and suppliers regarding sustainability issues (Um & Kim, 2019). Hence, we propose the following hypotheses:

H5: *Contractual governance positively moderates the relationship between supplier product integration and SSCP.*

H6: *Contractual governance positively moderates the relationship between supplier process integration and SSCP.*

Relational governance pertains to behaviors in response to risks and uncertainties within the interactions between suppliers and customers, focusing on boosting the efficiency of supply chain relationships by acquiring resources and information (Um & Kim, 2019). It is manifested through joint investments in products and processes (Bonatto et al., 2020) that facilitates the exchange of sustainability-related information and by establishing mutual trust and commitment to environmentally-friendly cooperation (Formentini & Taticchi, 2016). Furthermore, relational governance ensures that supply chain partners align their objectives, thereby minimizing conflict and opportunistic behavior (Alalwan et al., 2021). It also promotes collaborative problem-solving in sustainability matters (Shahzad et al., 2020) and generates greater relational rents for the dyad (Cislaghi et al., 2022), motivating further investment in sustainability initiatives (Bird & Soundararajan, 2020). Moreover, relational governance can overcome decoupling effects and the denial of moral responsibility (Bird & Soundararajan, 2020). Furthermore, Liao and Zhang (2020) demonstrated that relational governance is positively related to environmental innovation, which in turn contributes to the reduction of environmental pollution and damage. Finally, considering the moderating effects of social connections observed in the implementation of green supply chain management practices (Geng, Mansouri, Aktas, et al., 2017), we propose the following hypotheses:

H7: *Relational governance positively moderates the relationship between supplier product integration and SSCP.*

H8: *Relational governance positively moderates the relationship between supplier process integration and SSCP.*

Based on the resource-capability-performance (outcome) theoretical framework, boundary theory, and hypotheses H1-H8, we present our theoretical model in Figure 1. This illustrates the hypothesized relationships between supplier product integration, supplier process integration, contractual governance, relational governance, and SSCP.

Take in Figure 1

3 Research methodology

3.1 Sampling and data collection

This study focuses on the Chinese manufacturing industry, a critical sector that, on the one hand, contributed 36.5% to China's GDP in 2024 and, on the other hand, is among the most polluting industries (Data, 2025; Dey et al., 2020). As the largest developing country in the world, China faces significant environmental challenges and resource pressures (Hao et al., 2019; Xu et al., 2020). Over the past three decades, it has implemented numerous national environmental policy regulations and has encouraged firms to establish sustainable goals and develop sustainability strategies (Geng et al., 2016). Moreover, in an economy characterized by rapid development and a major manufacturing base (Luo et al., 2011), the importance of inter-firm relationships—

particularly buyer-supplier relationships—has become increasingly recognized (Lockstrom et al., 2011). Consequently, China becomes an ideal sample source for this research.

To ensure the collection of high-quality data, all the respondents are middle and senior managers of Chinese industry firms with a deep and comprehensive understanding of supplier integration, governance mechanisms, and sustainable supply chain practices. All selected respondents have at least three years of experience. For the primary survey, we used a directory provided by the China Statistics Bureau to draw a random sample of 720 manufacturing firms that operated within the four-digit Chinese Industrial Classification codes 1311–4290.

Data were collected through a cross-sectional, single-respondent survey. A cross-sectional design is favored for the current investigation due to its adaptability and cost effectiveness (Agyabeng-Mensah et al., 2022). As noted by Montabon et al. (2018), careful informant selection and clear documentation can enhance the validity of single respondent survey designs in the supply chain field. In this context, we made sure that all survey participants possess extensive knowledge in their respective fields. To further enhance validity, the two types of variables were addressed in separate sections of the questionnaire – the independent variables at the beginning and the dependent variables at the end of the survey instrument (Sturm et al., 2023).

After the survey instrument was distributed to the 720 potential respondents, we followed up with recipients via email and telephone to improve the response rate while ensuring the confidentiality of the questionnaire data. Ultimately, we obtained 235 usable responses, resulting in an overall response rate of 32.64%. Table 1 presents the company profiles, which cover various industries. In addition, the firms varied in terms of ownership type, employee count, and total assets.

Take in Table 1

To assess non-response bias, we performed t-tests where the results indicated no significant differences between early and late responses for all variables, suggesting the absence of non-response bias (Swink & Song, 2007). Given the reliance on single respondents from each participating firm and the cross-sectional nature of the data collection, the potential for common method bias (CMB) was a primary methodological consideration. To mitigate this concern, several procedural remedies were implemented. The survey targeted middle and senior-level managers within Chinese manufacturing enterprises who possess substantial supply chain knowledge, ensuring the quality and accuracy of the data provided (Lin & Fan, 2024). Participants were informed of the study's purpose and their rights, including the right to withdraw and an assurance of anonymity. All participants provided informed written consent, and their data were coded and securely archived to ensure confidentiality (Jam et al., 2025). Additionally, we conducted a single-factor confirmatory factor analysis (CFA), summarizing all variables into one factor for model fitting (Ketokivi & Schroeder, 2004). The results revealed that the single-factor model (χ^2 = 1693.326) was significantly inferior to the measurement model (χ^2 = 312.582). Furthermore, the factor analysis revealed four distinct factors with eigenvalues greater than 1.0, cumulatively accounting for 68.634% of the total variance; the first factor explained 39.592%, just under 40%. Thus, common method bias is minimal.

Lastly, we conducted the marker-variable technique to test for CMB (Lin & Fan, 2024). The education of participants was chosen as the marker factor because it was theoretically independent of endogenous variables. As shown in Table 2, the average correlations between the marker-variable, PSI, PTI, and SSCP were <0.100 and not significant, and the significant path in the original model was still significant, which confirms that common method bias is not a serious concern affecting the data or our findings.

Take in Table 2

3.2 Questionnaire design and measures

To design a reliable and effective survey tool, we conducted a comprehensive review of high-quality existing literature. The questionnaire included five key constructs: supplier product integration, supplier process integration, contractual governance, relational governance, and SSCP. We employed a seven-point Likert scale for our survey, with options ranging from 1 (disagree completely) to 7 (agree completely). A detailed list of the scales employed is available in the Appendix. The survey instrument was translated from English to Chinese and a back-translation procedure was employed to ensure linguistic equivalence (Zhang, Venkatesh, et al., 2024). To guarantee accuracy, the translation was reviewed by five academics of Chinese heritage with expertise in management. Furthermore, the instrument was pilot-tested with eight managers from the target industrial population and subsequently refined to ensure its validity (Lin et al., 2025).

According to Koufteros et al. (2005), supplier product integration pertains to the engineering activities undertaken by suppliers to develop product components and parts on behalf of enterprises. Meanwhile, supplier process integration is defined as the involvement of suppliers during the design phase of enterprise products, effectively aligning the supplier's production processes with the enterprise's product design (Koufteros et al., 2005; Koufteros et al., 2007). Both variables are assessed using a three-item scale. Contractual governance refers to the relationship between a supplier and customer that is regulated by detailed contracts specifying the respective rights and responsibilities of each party (Abdi & Aulakh, 2012). The measurement of this construct involves three items derived from Liu et al. (2010). In contrast, relational governance is characterized by a relationship in which social interactions and shared norms govern the dynamics between the supplier and customer (Zhou & Xu, 2012), and is adapted from Bouncken et al. (2016).

SSCP is understood as the responsible strategies and practices implemented by firms to pursue sustainable development (Claudy et al., 2016). This may include regulating the carbon footprint of products, applying the triple bottom line approach to product planning, and developing sustainability policies. Drawing on research by Adebanjo et al. (2016), Claudy et al. (2016), and Du et al. (2016), we utilized seven measurement items to evaluate SSCP. Additionally, ownership and total assets were included as dummies to serve as control variables. Ownership accounts for variances in firm performance and resource allocation, which further influence strategic decisions (Fitza & Tihanyi, 2017). Meanwhile, total assets represents the scale economies that enhance social performance (Li & Zhang, 2010).

3.3 Reliability and validity

Cronbach's α and composite reliability are utilized to evaluate the reliability of the constructs. As indicated in Table 3, the Cronbach's α values range from 0.873 to 0.902, while composite reliability ranges from 0.877 to 0.907, both exceeding the acceptable threshold of 0.70 (Hair et al., 2009). The correlation coefficients between the constructs are less than 0.8, suggesting adequate discriminant validity. Additionally, VIF values range from 1.465 to 3.892, not exceeding 5, which indicates the absence of multicollinearity (Jam et al., 2025). Collinearity diagnostics further confirmed this, with all results below 0.9 (see Table 4), indicating that there is no multicollinearity issue (El-Fallah & El-Sallam, 2011). Consequently, the scales are deemed reliable and exhibit internal consistency.

For content validity, instruments were selected from prior literature published in reputable journals. Following this, we conducted a CFA, based on the framework established by O'Leary-Kelly and Vokurka (1998), to evaluate convergent validity. The CFA fit indices are satisfactory (χ^2/DF = 2.201, RMSEA = 0.072, TLI = 0.937, CFI = 0.948, SRMR = 0.043), indicating that convergent validity is acceptable (Hu & Bentler, 1999). Additionally, all factor loadings are above 0.50, and the average variance extracted (AVE) estimates range from 0.589 to 0.761, surpassing the threshold of 0.50 (Hair et al., 2009). To assess discriminant validity, we compared the square root of the AVE with the correlations and calculated the heterotrait-monotrait (HTMT) ratio. As outlined in Table 5, the correlations are less than the square root of the AVE (Fornell & Larcker, 1981), and the HTMT ratios remain under the 0.9 threshold (Henseler et al., 2015), thereby confirming discriminant validity.

Take in Tables 2-4 and Figures 2-5

4 Data Analysis and Results

4.1 Hypothesis Testing

A key advantage of using multiple linear regression is its ability to precisely determine the unique contribution of a core independent variable to the variance in the dependent variable, after accounting for the effects of other control variables (Zhao et al., 2021). This provides a direct and powerful method for testing the significance of specific variables within a theoretical framework. Compared to structural equation modeling (SEM), multiple linear regression (MLR) is conceptually and analytically simpler, making it more appropriate when the sample size is modest and computational stability is required (Hair et al., 2009).

We conducted hierarchical linear regression analyses to test the hypotheses. In Model 0, the dependent variable is supplier product integration, and the independent variable is supplier process integration. In Model 1 through Model 7, the dependent variable remains SSCP. Model 1 includes only the control variables, which are ownership and assets. In Model 2, supplier process integration is the independent variable whereas Model 3 adds supplier product integration as an additional independent variable. In Models 4 and 5, we introduce contractual governance and relational governance as moderating variables, respectively. Models 6 and 7 include interactions between supplier integration and the governance mechanisms. To mitigate multicollinearity, we standardize the independent and moderating variables before calculating the interaction terms. The results of the hierarchical regression analysis are summarized in Table 6.

Hypothesis 1 and Hypothesis 2 assess the effects of supplier product integration and supplier process integration on SSCP, respectively. In Model 3, supplier product integration ($b = 0.244$, $P < 0.05$) is positively and significantly associated with SSCP, while supplier process integration ($b = 0.06$, $P > 0.1$) shows an insignificant positive effect. This result supports H1 and leads to the rejection of H2. Model 0 indicates that supplier process integration positively influences supplier product integration ($b = 0.786$, $P < 0.001$), which supports H3. Hypothesis 4 evaluates the mediating role of supplier product integration in the relationship between supplier process integration and SSCP. In Model 2, supplier process integration has a significantly positive effect on SSCP. However, after including supplier product integration in Model 3, the coefficient for supplier process integration becomes insignificant. Therefore, supplier product integration fully mediates the relationship between supplier process integration and SSCP. Furthermore, by applying the bootstrapping approach to test for mediation effects (Hayes, 2015), we find that the direct effects are weak and statistically non-significant ($b = 0.120$, $P > 0.1$) while the indirect effects are significant ($b = 0.210$, $P < 0.05$), as presented in Table 7. Thus, H4 is supported.

Take in Table 6-7

Hypotheses 5 and 6 evaluate whether the relationship between supplier integration and SSCP is influenced by the nature of contractual governance. The hypotheses suggest that this relationship is more favorable when contractual governance is robust, compared to when it is minimal. Model 4 indicates that the interaction between supplier product integration and contractual governance (b=0.215, P<0.05) has a positive impact on SSCP. In contrast, the interaction between supplier process integration and contractual governance (b=-0.282, P<0.01) has a negative influence on these practices. These findings support H5 and reject H6. Furthermore, the interaction between supplier product integration and relational governance have a significant positive correlation with SSCP (b=0.202, P<0.01), while the interaction between supplier process integration and relational governance is negatively and significantly related to these practices (b=-0.297, P<0.001). Hence, H7 is supported, and H8 is rejected.

When integrating the findings from Hypotheses 5 to 8, we can conclude that the relationship between supplier integration and SSCP varies according to the governance mechanism employed. To illustrate these differences clearly and avoid making arbitrary judgments based solely on coefficient values, we have plotted the interaction terms in Figures 2 to 5. Figures 2 and 3 indicate that the relationship between supplier process integration and SSCP is positive at low levels of both contractual governance and relational governance (represented by the solid line), while it turns negative at high levels of both governance forms. Conversely, Figures 4 and 5 demonstrate that the relationship between supplier product integration and SSCP is negative at low levels of contractual governance and relational governance (solid line) but becomes positive at high levels of both governance mechanisms (dotted line). We summarize the comprehensive results from the hypothesis tests in Table 8.

Take in Table 8

4.2 Endogeneity Check

We took two steps to address potential endogeneity concerns and validate our results. First, we confirmed the causal direction by comparing our hypothesized model with a reverse-causality model. Our proposed model (SRMR=0.0513, RMSEA=0.078) demonstrated a significantly better fit than the alternative (SRMR=0.1516, RMSEA=0.156), strongly supporting our theory. Second, to address simultaneity, we opted for the Gaussian copula (GC) method—an advanced, instrument-free approach—instead of the traditional instrumental variable (IV) method, which is often limited by the difficulty of finding suitable instruments (Eckert & Hohberger, 2023). Prior to conducting this analysis, we assessed the normality of the data using the Kolmogorov–Smirnov test with Lilliefors correction and the Shapiro-Wilk test (see Table 9). The results indicated that none of the constructs followed a normal distribution, which is a requirement for the Gaussian Copula approach. Subsequently, we analyzed all combinations of Gaussian copulas incorporated into the models. Table 10 reveals that all coefficients of the copula terms are statistically insignificant, suggesting that endogeneity is not a major concern.

Take in Tables 9-10

4.3 Robust Check

To address potential heteroskedasticity, we conducted the Breusch-Pagan and White tests. As heteroskedasticity was detected in some models, we used robust standard errors for all subsequent analyses to ensure the validity of our results. Furthermore, we performed several sensitivity analyses to confirm the robustness of our findings. First, we re-estimated the model after removing the “ownership” control variable. The results, as presented in Table 11, remained consistent. Second, we transformed “ownership” and “asset” into dummy variables. As shown in Table 12, this modification did not substantially alter the outcomes. Finally, to mitigate the influence of outliers, all continuous variables were winsorized at the 5% level (i.e., the top and bottom 5% of values were replaced with the values at the 95^{th} and 5^{th} percentiles, respectively) (Chindasombatcharoen et al., 2024). The regression results after winsorization (see Table 13) remained significant, indicating that our conclusions are not driven by extreme values and that they remain reliable.

To test the robustness of the mediating effect, we employed the Sobel test (Mehnaz et al., 2024). The Sobel test assesses the significance of a mediating effect by calculating its standard error and a corresponding Z-statistic. After controlling ownership and total assets, the result for the mediation path was significant (see Table 14), with Z-values exceeding 3.053. This confirms that the observed mediating effect is robust.

Take in Table 11-14

5 Discussion

Many previous studies support the argument that supplier integration promotes sustainability and SSCP through resource sharing (Dai et al., 2015). For example, external resources from suppliers are considered essential for the success and implementation of green practices (Yen, 2018). When embarking on sustainable supply chain initiatives, firms often collaborate with suppliers to access resources, including cutting-edge environmental technologies and eco-friendly materials (Somjai & Jermsittiparsert, 2019). Furthermore, suppliers provide innovative solutions that contribute to sustainability (Windahl & Lakemond, 2006). Collaboration between buyers and suppliers fosters organizational learning through knowledge exchange, enhances the efficiency and effectiveness of sustainability-related policies, and ultimately facilitates the implementation of SSCP (Oelze et al., 2016). However, our findings indicate that not all forms of supplier integration positively affect SSCP. Specifically, while supplier product integration positively influences these practices, supplier process integration does not demonstrate the same beneficial effects.

Supplier product integration emphasizes the importance of engaging in new product development through a close relationship between buyers and suppliers, whereas supplier process integration focuses on collaborative and synchronized processes for manufacturing and delivering products (Feyissa et al., 2019). Supplier product integration aids firms in executing product engineering activities and developing green components or entire subassemblies for environmental protection, thereby contributing to sustainability (Koufteros et al., 2005). Consequently, supplier product integration fosters SSCP. In contrast, supplier process integration involves firms coordinating with suppliers in new product design and sharing information related to materials and scheduling. Although process integration enhances information sharing by strengthening trust and commitment in relationships and fostering effective partnerships (Ray et al., 2004), achieving seamless information exchange among supply chain partners can be demanding (Lewis et al., 2014). Furthermore, relying solely on information exchange regarding sustainability metrics may not yield a more sustainable supply chain

(Meckenstock et al., 2016). Collaborative practices involving information sharing are not consistently implemented within firms and may prove ineffective for ensuring environmental and social sustainability (Shoukohyar & Seddigh, 2020). This is because SSCPs, such as ISO 14000, do not necessarily mandate information exchange and sharing (Curkovic & Sroufe, 2011). Koufteros et al. (2005) asserted that supplier process integration has a non-statistically significant relationship with quality performance and innovation. More recently, Nair et al. (2021) noted that process integration, particularly during a recession, can hinder operational performance due to the economic risks associated with the additional investments required to enhance integration with suppliers. This highlights why supplier process integration may not facilitate more SSCP.

Additionally, we have discovered that supplier process integration positively influences supplier product integration. This finding contradicts the conclusions of Koufteros et al. (2010), which indicated that supplier product integration predicts supplier process integration. We propose that supplier process integration facilitates the exchange of information and resources and fosters trust (Schoenherr & Swink, 2012), thereby significantly contributing to supplier product integration, particularly in the areas of parts and component design and development collaboration. Moreover, supplier process integration establishes norms for green technology information exchange and the maintenance of trusted relationships (Wong et al., 2020). In supplier product integration, firms actively collaborate with suppliers to develop eco-friendly components, ultimately leading to a manufacturing process that reduces pollution, ensures that new products meet environmental standards, and enables firms to successfully implement SSCPs (Sudusinghe & Seuring, 2022).

Meanwhile, although the indirect effects observed in our research appear weak, they are significant. One reason for this finding may be that our supplier product integration measure could be augmented by additional variables. More specifically – and although our measure is similar to that used in several other recent studies that defined supplier product integration as the development of product components and parts with suppliers – some researchers now contend that supplier product integration should also include technology updates through cooperation with suppliers (Kim & Schoenherr, 2018).

Moreover, although our research has advocated the supplier process integration-supplier product integration-SSCM framework, process integration could include innovation capabilities and absorption capabilities (Peng et al., 2013), creating alternative indirect paths from process integration to SSCM and weakening the effects of supplier product integration. Additionally, we find that supplier product integration has a weak effect on SSCM ($b=0.244$, $p<0.05$). This may be explained by previous studies, which have demonstrated that an overdependence on suppliers for NPD may result in disruption risk (Świerczek, 2014), a lack of objectivity and opportunistic behavior, and rigidities that hinder creativity (Yang et al., 2024). Thus, supplier process integration indirectly impacts SSCP through its effect on supplier product integration.

In summary, relational governance and contractual governance have been empirically validated as complementary rather than substitutive, playing crucial roles in sustaining bilateral relationships (Cao & Lumineau, 2015; Um & Kim, 2019). Furthermore, extensive prior literature has highlighted the distinct functions of contractual and relational governance. For example, contractual governance addresses information uncertainty, whereas relational governance alleviates information equivocality (Aben et al., 2021). Wang et al. (2024) asserted that contractual governance intensified the adverse effects of the pandemic on buyers' opportunism, while relational governance mitigated the negative impact of the pandemic on inter-firm conflict. Finally, Lu et al. (2019) asserted that contractual governance enhances the positive impacts of quality management practices on project performance, whereas the moderating effect of trust remains insignificant.

Contrary to these previous findings, we argue that the moderating effects of governance mechanisms on SSCP vary depending on the type of supplier integration. Our results indicate that both relational governance and contractual governance positively moderate the relationship between supplier product integration and SSCP, while they negatively moderate the relationship between supplier process integration and SSCP. Supporting our findings, several studies have shown similar moderating effects of contractual governance and relational governance. For instance, Zhang et al. (2023) found that contractual control and trust diminish the positive impact of conflict event strength (criticality and disruption) on cooperation. Meanwhile, Um and Kim (2019) noted that governance mechanisms, including both contractual and relational governance, positively moderate the relationships between performance and transaction cost advantage, as well as between supply chain collaboration and transaction cost advantage.

Supplier process integration is recognized as a critical stucture for coordinating and deploying resources, streamlining business processes, and ultimately minimizing duplication of effort while achieving efficiency and effectiveness (Lee, 2011). However, supplier process integration can introduce opportunism risks (Jiang et al., 2013). Moreover, during process integration, participating firms often attempt to impose their respective schemas on joint decisions (Kobarg et al., 2020) and struggle for control over the development process, thus causing conflict (Chen & Liu, 2023).

In summary, governance mechanisms tend to amplify the issues related to opportunism and conflict, prompting firms to refrain from disclosing information regarding sensitive environmental challenges and financial matters, ultimately obstructing the implementation of SSCP. Furthermore, process integration allows a firm to effectively synchronize supply with demand and ensure standards compliance in the absence of direct authority or ownership, primarily by automating the enforcement of activity and output standards (Rai et al., 2015). Specifically, the presence of process integration might inhibit contractual flexibility and demonstrate commitment, fostering trust in the relationship (Schoenherr et al., 2015). Thus, supplier process integration does not inherently necessitate governance mechanisms for oversight and control, as suppliers' activities can be readily observed within the framework of this integration (Perols et al., 2013). In addition, process integration, as an early stage of a buyer-supplier relationship, is inherently characterized by high uncertainty (Luo et al., 2012). The effectiveness of both contractual and relational, trust-based governance is relatively diminished under conditions of high environmental uncertainty compared with low environmental uncertainty, because such conditions introduce information overload and cognitive limitations (Krishnan et al., 2016). Consequently, governance mechanisms—including both relational and contractual governance—can undermine the benefits of supplier process integration and negatively influence the relationship between supplier process integration and SSCP.

Supplier product integration is crucial to the success of new products, as it enhances the capacity to meet both technological and market demands (Petersen et al., 2003) while yielding benefits such as improved product quality and reduced time to market (Primo & Amundson, 2002). During product integration, suppliers are tasked with complete responsibility for product engineering; although buyers provide performance specifications, these may lack detailed parameters. This dynamic foster an extraordinary level of trust between buyers and suppliers, necessitating that suppliers navigate environmental uncertainties and risk challenges (Koufteros et al., 2010). Nevertheless, relational governance in bilateral relationships deters partners from engaging in opportunistic behavior (Plambeck et al., 2012). It enhances supply chain transparency and mitigates environmental risk (Lee et al., 2012). Additionally, control and power diminish uncertainty within bilateral relationships, facilitating effective resource management (Ireland & Webb, 2007). Furthermore, supplier product integration involves a series of activities, including negotiation, planning, coordination, and monitoring, which can incur substantial transaction costs (Mahoney, 1992). However, informal mechanisms can alleviate the complexities and costs associated with monitoring and coordination in the context of sustainability (Kale & Singh, 2007). Thus, relational governance and contractual governance play essential roles in eliminating uncertainties and reducing the transaction costs involved in supplier product integration, thereby reinforcing the positive impacts of supplier product integration on SSCP.

6 Conclusions

To unpack the complex relationship between supplier integration, governance mechanisms, and SSCP, we gathered data from Chinese manufacturing firms and employed hierarchical multiple regression analysis to test our hypotheses and theoretical framework. The findings revealed that supplier product integration has a significant positive impact on SSCP; however, supplier process integration does not demonstrate a significant relationship with these practices. Furthermore, supplier product integration serves as a full mediator in the relationship between supplier process integration and

SSCP. Significantly, both contractual and relational governance mechanisms positively moderate the relationship between supplier product integration and SSCP while negatively moderating the association between supplier process integration and SSCP.

6.1 Research implications

Drawing from boundary theory and focusing on key boundary-spanning activities, our research highlights that SSCP cannot be effectively achieved without external resource inputs or consideration being given to regulatory constraints. Moreover, based on the resource-capability-performance (outcome) theoretical framework derived from RBV, we elaborate that bundling resources into capabilities results in SSCP. This paper investigates the antecedents of SSCP within the buyer-supplier relationship, differentiating between two different constructs of supplier integration – supplier product integration and supplier process integration – and explaining the impacts of process integration on SSCP through product integration. It also explores the roles of two forms of governance mechanisms, namely relational governance and contractual governance, in the interplay between supplier integration and SSCP.

First, a resource-capability-performance (outcome) theoretical framework is usually applied to understand how firms transfer resources into capabilities and, in turn, into performance (Huo et al., 2016), while boundary theory has traditionally been employed to elucidate boundary-spanning activities in buyer-seller relationships (Zhang et al., 2011). The former fails to point out contingent conditions whereas the latter alone cannot appropriately explain the alignment between a resource and capability in buyer-seller relationships. Thus, combining these theories, our study emphasizes the unique boundary-spanning approaches of supplier integration in the context of SSCP, providing a more nuanced understanding of its role. Given the limited focus of boundary theory and the resource-capability-performance (outcome) theoretical framework on organizational behavior and human resource strategies (Piszczek & Berg, 2014), along with the absence of a comprehensive framework for operations management (Ordonez-Ponce et al., 2021), this research expands the application of boundary theory and the resource-capability-performance (outcome) theoretical framework to SSCM. Additionally, we introduce governance mechanisms as a boundary condition for mitigating external control and addressing environmental uncertainty and unpredictability (Stock & Zacharias, 2011), while revealing the contingent effects of varying governance mechanisms.

Second, the increasing sustainability demands placed on firms encourages them to collaborate with suppliers (Klassen & Vachon, 2003). Recent evidence indicates that supplier involvement is essential for the sustainability of new products; however, the role of supplier involvement in SSCP remains underexplored (Blome, Paulraj, et al., 2014). Suppliers often struggle to engage effectively in SSCP (Caniëls et al., 2013), and firms frequently lack a clear understanding of how to collaborate with suppliers to implement SSCP successfully. This challenge is further complicated by prior studies on supplier involvement in SSCP, which have yielded mixed results. Cooperation with suppliers can facilitate the development and application of reusable packaging, help to implement reverse logistics (Dadhich et al., 2015), and secure the reliable supply of recycled or recyclable materials, minimizing waste throughout the supply chain (Di Maria et al., 2022). Moreover, integration with suppliers facilitates shared environmental planning, enables collaboration to reduce or prevent pollution, aids in the establishment of joint environmental goals and the implementation of unified purchasing policies and practices, thereby enhancing sustainability (Di Maria et al., 2022). However, Mont and Leire (2008) specifically noted that suppliers do not function as external drivers of a firm's sustainable purchasing practices. Furthermore, Chavez et al. (2023) found that suppliers hardly play a central role in innovating internal environmental processes or in making resource efficiency savings (Chavez et al., 2023). This paper discusses the different effects of the two dimensions of supplier integration on SSCP, revealing that not all forms of supplier integration enhance SSCP. Specifically, only supplier product integration directly promotes these practices. This finding may elucidate the contradictory results observed in extant literature.

In particular, we have examined the complex relationship between supplier process integration and supplier product integration, demonstrating the mediating effects of supplier product integration on the relationship between supplier process integration and SSCP. The resource-capability-performance (outcome) theoretical framework suggests that only when there is fit or alignment between resources and capabilities can firms achieve improvements in sustainability. We expand the resource-capability-performance (outcome) theoretical framework into the sustainability context to explain how a firm's process integration influences its product integration activities to improve sustainability practices. This insight provides a plausible explanation for the conflicting conclusions regarding the relationship between supplier integration and SSCP. It enriches comparative research on the effects of supplier-customer collaboration on SSCP and addresses a gap in the literature regarding the role of supplier integration in SSCP. This conclusion elucidates the pathway by which supplier process integration influences SSCP.

Third, governance mechanisms play a crucial role in advancing knowledge within sustainable supply chains. Relational governance mechanisms encourage knowledge sharing and address information asymmetry in a dyad (Aben et al., 2021), while contractual governance mechanisms mitigate opportunistic behaviors that arise from uncertainty and asset specificity (Zhang et al., 2025). Consequently, relational governance mechanisms may generate greater relational rents for the dyad (Cislaghi et al., 2022), which motivates investments in sustainability initiatives (Bird & Soundararajan, 2020). Meanwhile, contractual governance mechanisms transfer sustainability-related concepts between suppliers and customers, fostering supply chain partners' willingness and commitment to sustainable collaboration practices (Zhang, Moosmayer, et al., 2024). However, previous research has seldom explored the application of governance mechanisms in SSCM (Aitken & Harrison, 2013; Gimenez & Sierra, 2013) and has largely neglected the indirect impacts of these mechanisms (Sheng et al., 2018). Our study has examined the moderating effects of governance mechanisms on the relationship between supplier integration and SSCP, revealing their distinctive impacts. The findings indicate that both transactional and relational governance enhance the effects of supplier product integration on SSCP, yet they weaken the influence of supplier process integration on those same practices. Based on boundary theory, when firms engage in boundary-spanning activities, such as supplier integration to acquire information and resources for sustainability initiatives (Cross et al., 2000; Lau et al., 2010; Maria Stock et al., 2017), they should consider governance mechanisms as necessary means to manage and maintain their boundaries and protect their autonomy and independence. This insight deepens our understanding of the interplay among governance mechanisms, supplier integration, and SSCP, shedding light on the underlying reasons for the varying moderating effects of governance mechanisms.

Finally, most previous investigations into the relationship between supplier integration and sustainability originate from a specific industry or regional context, without considering the governance mechanisms as boundary conditions. For instance, Espino-Rodríguez & Taha (2022) contended that in the hotel industry of Egypt supplier integration is pivotal in enhancing the overall benefits of the supply chain, particularly regarding sustainability objectives. Khan et al. (2022) used a sample of Malaysian Electrical and Electronics firms and found that organizations promote sustainable management through effective supplier integration. Cheng (2020) maintained that technology firms in Taiwan that collaborate with their suppliers gain improved access to strategic sustainability resources, knowledge, technologies, and capabilities, empowering them to address sustainability deficiencies . Di Maria et al. (2022) collected data from Italian manufacturing firms, asserting that integration with suppliers facilitates shared environmental planning and the establishment of joint environmental goals, thereby enhancing sustainability. However, significant differences in economic structures, policy directives, cultural environments, and levels of social development across various countries and regions and industry gaps may pose substantial challenges when attempting to directly apply the findings from these regions and industries to China’s manufacturing context (Lin et al., 2023).

Our study has adopted a tailored research approach by situating the investigation within the Chinese manufacturing context and exploring the relationship among supplier integration, governance mechanisms, and sustainable supply chain practices within this specific environment. This effort not only addresses notable gaps in existing research, which often lacks a Chinese manufacturing perspective, but also enriches the empirical foundation of global sustainable supply chain management by incorporating more diverse datasets. Consequently, this contributes to a collective broadening of research and enhances the analytical depth whilst providing valuable insights into the interplay between supplier integration and governance mechanisms on SSCP in China.

6.2 Practical implications

In striving for a sustainable supply chain, firms with limited resources should prioritize investments in supplier product integration over supplier process integration. Collaborating with suppliers to perform the product engineering of component parts, develop components or even entire subassemblies aimed at reducing waste and pollution, can effectively drive SSCP. First, firms should integrate environmental protection principles into their strategic planning to steer cooperation with their suppliers (Geng, Mansouri, & Aktas, 2017; Lee et al., 2015). Second, this product-focused collaboration should also be informed by conducting joint market research with suppliers to better understand consumer needs for green products and identify emerging technological trends (Lee & Kim, 2011; Saether et al., 2021). Third, firms can work collaboratively with suppliers to jointly develop and implement new environmentally friendly materials to further sustainability efforts (Ramanathan et al., 2021). Additionally, establishing trust-based relationships with suppliers through regular communication, visits, and joint initiatives will enhance cooperation during the development of components or subassemblies, ultimately facilitating SSCP (Boscari et al., 2024).

While product integration is the priority, firms can still strategically use supplier process integration to promote sustainability. With supplier process integration, firms can engage suppliers in environmentally friendly design modifications to promote sustainability. Practical steps include involving suppliers in the early stages of product development, asking suppliers for their input on the design of component parts, and making use of supplier expertise in product development (Suurmond et al., 2020).

Engaging in supplier integration alone is not enough for the implementation of sustainability because the development of integration systems with suppliers would require considerable investments in infrastructure, incurring high cost (Chavez et al., 2022), while an over dependence on suppliers may lead to a loss of objectivity and opportunistic behavior (Yang et al., 2024). Thus, firms need to design appropriate governance mechanisms for eliminating potential risks. For instance, when engaging with suppliers for the eighth consecutive year, HP implements a mandatory Supplier Code of

Conduct, which all contracted suppliers must sign, to formally oversee and govern their behavior for sustainable development (HP, 2023).

Moreover, governance mechanisms must be approached with careful consideration when evaluating the impact of supplier integration on SSCP. First, when pursuing supplier product integration, firms can enhance supplier accountability and reduce transaction costs by fostering a trust-based relationship and by utilizing contracts. To establish this necessary trust, managers must ensure a supplier keeps their promises, is consistently trustworthy, and remains evenhanded in negotiations (Xu et al., 2022). Second, with supplier process integration, firms can more readily observe and evaluate supplier behaviors, allowing them to substitute this collaborative oversight for traditional governance mechanisms (Rai et al., 2015). Additionally, firms may implement blockchain governance to enable the autonomous execution and enforcement of agreements, thereby enhancing cooperation and coordination in place of conventional governance mechanisms (Petersen, 2022). Consequently, governance mechanisms should be applied judiciously, aligned with the specific form of supplier integration.

The aforementioned supplier integration and governance strategies must be built upon a foundation of comprehensive internal sustainability policies, because sustainable management practices would not succeed without sustainability policies (Bakos et al., 2020; Gunarathne & Lee, 2020). A clear sustainability policy can empower managers to commit time and resources to engaging in sustainability practices and provide assistance and support to supply chain integration (Khatter et al., 2021). For example, as a global leader of innovative new energy technologies, CATL has established a comprehensive policy framework, including a Supply Chain Sustainability Management Policy, Supplier Code of Conduct, and a Due Diligence Management Policy for Responsible Mineral Supply Chains. These policies empower CATL to mitigate sustainability risks, foster sustainable transformation across the supply chain, and holistically drive the achievement of carbon neutrality targets for both the company's operations and its broader value chain (CATL, 2024).

In practice, firms should first integrate environmental protection principles into their strategic planning to steer cooperation with their suppliers (Shah & Soomro, 2021). This includes managing a product’s carbon footprint, using the triple bottom line for product planning, and including sustainability in the product development budget. This commitment extends to the broader supply chain, requiring firms to select suppliers and partners based on sustainability criteria, implementing environmental and social certifications and both pollution emission reduction and waste recycling programs (Kusi-Sarpong et al., 2023).

6.3 Limitations and future research

Despite this paper offering valuable theoretical and managerial insights, it is not without its limitations. First, our analysis relies on cross-sectional data, which restricts our ability to draw causal inferences among constructs. Therefore, future research may benefit from a longitudinal approach and quasi-experimental methods to delineate causal relationships accurately and provide a more comprehensive understanding of how relationships evolve over time. Second, despite efforts to mitigate common method bias and statistical tests indicating that common method bias is not an issue, data collected from a single respondent may still create the opportunity for common method bias, as limited and subjective perspectives or cognitive biases might not fully capture broader organizational or contextual factors. To reduce these risks, future studies could adopt a multi-informant approach, gathering data from multiple individuals within the same organization and providing a more nuanced view of how SSCP is implemented and perceived across an organization.

Third, data were only collected from the Chinese manufacturing industry, which may make generalization difficult. Future research should try to replicate the research in other countries (regions) as well as other sectors, such as in services. This would help to validate the proposed framework and improve its generalizability. Finally, our examination treats SSCP as a singular construct. We have not differentiated the effects of supplier integration across various dimensions of SSCP. For instance, Gualandris and Kalchschmidt (2014) employed sustainable process management (SPM) and sustainable supply management (SSM) to capture these practices comprehensively. Future investigations could expand upon this framework to analyze a theoretical model that incorporates SPM, SSM, supplier integration, and governance mechanisms. Additionally, our study has addressed the distinct moderating effects of two forms of governance, concentrating on contractual and relational governance. Previous research has explored the complementarity or substitutability of transactional governance and relational governance concerning sustainability (Zhu et al., 2017). Therefore, future inquiries could further investigate the interplay between transactional governance and relational governance within the context of supplier integration and SSCP.

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Appendix A: Complete list of item scales

Sustainable supply chain practices (sourced from: Claudy et al., 2016, Du et al., 2016, and Adebanjo et al., 2016)

1. We develop sustainability policies.
2. We manage our product's carbon footprint.
3. We use triple bottom line for product planning.
4. We include sustainability in your product development budget.
5. We select suppliers and partners based on sustainability criteria.
6. We implement environmental and social certifications.
7. We implement pollution emission reduction and waste recycling programmes.

Contractual governance (sourced from: Liu et al., 2010)

1. Our collaboration with supplier is regulated through a comprehensive and clearly worded contract.
2. The contract with supplier describes in detail every aspect that we think is of interest.
3. We and our supplier fixed all the collaboration related details in a contract

Relational governance (sourced from: Zaheer et al., 1998)

1. Our supplier keeps promises made to our firm.
2. Our supplier is always trustworthy.
3. Our supplier has always been evenhanded in its negotiations with us.

Supplier product integration (sourced from: Koufteros et al., 2005)

1. Our suppliers do the product engineering of component parts for us.
2. Our suppliers develop component parts for us.
3. Our suppliers develop Entire subassemblies for us.

Supplier process integration (sourced from: Koufteros et al., 2005)

1. Our suppliers are involved in the early stages of product development.
2. We ask our suppliers for their input on the design of component parts.
3. We make use of supplier expertise in the development of our products.

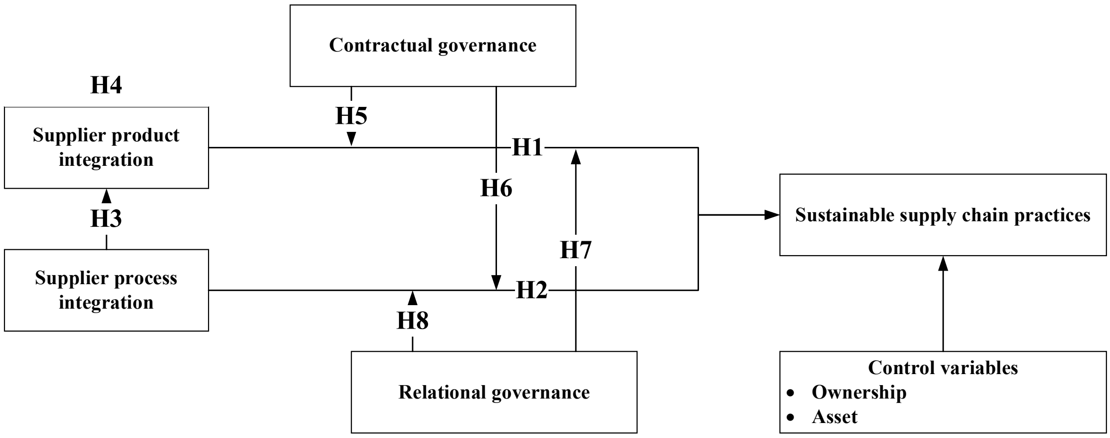

Figure 1 The theoretical model

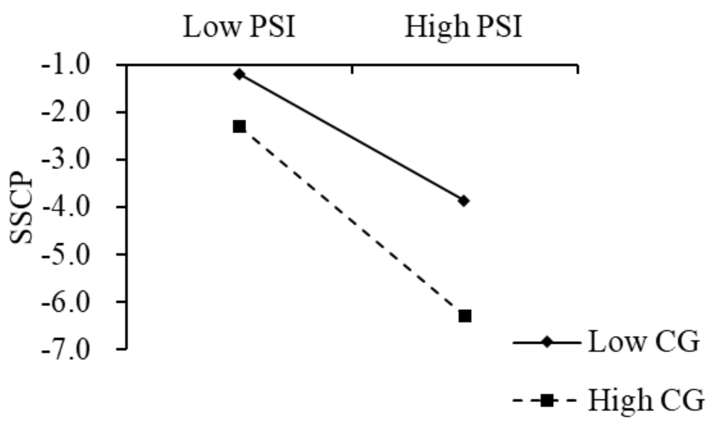

Figure 2 PSI and SSCP: the moderating role of CG

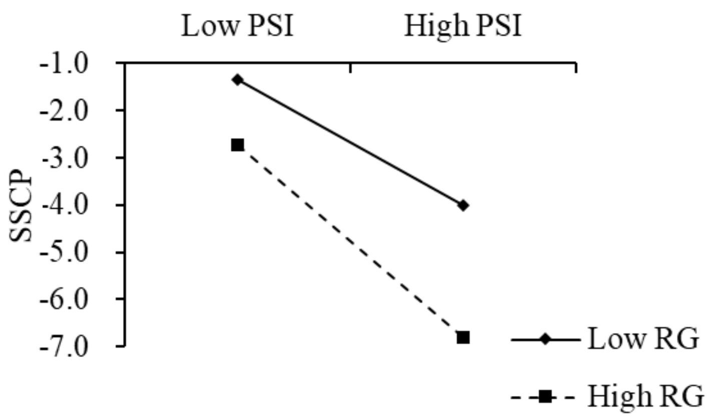

Figure 3 PSI and SSCP: the moderating role of RG

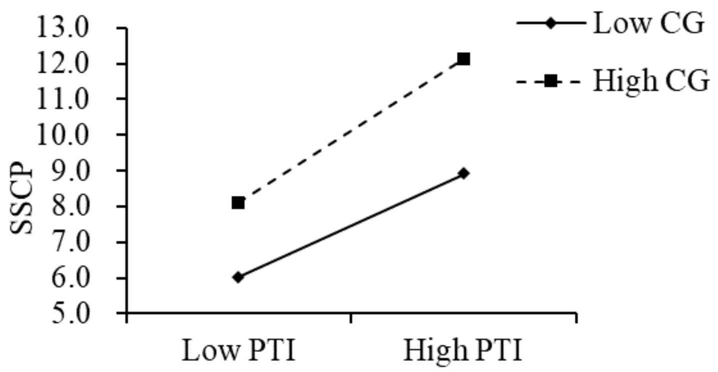

Figure 4 PTI and SSCP: the moderating role of CG

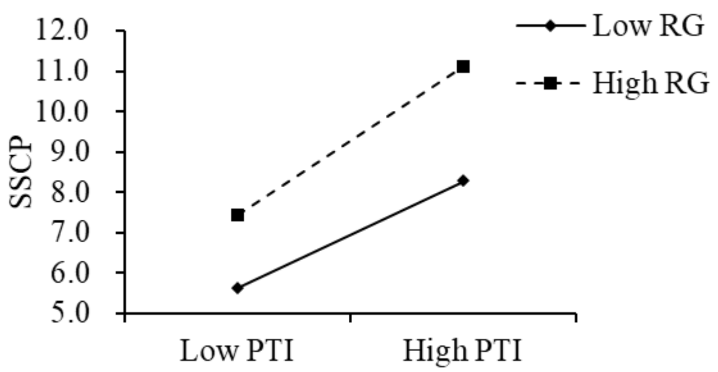

Figure 5 PTI and SSCP: the moderating role of RG

Table 1 Profile of sampled firms

Ownership	Total (N = 235)
State-owned enterprise	52(22.1%)
Collective enterprises	5(2.1%)
Private enterprises	126(53.6%)
Joint ventures	23(9.8%)
Wholly Foreign-Owned Enterprise	29(12.4%)
Industry	
Food and Beverage Manufacturing	29（12.3%）
Textile and apparel	3（1.3%）
Paper and Printing Industry	1（0.4%）
Chemical and related product manufacturing	15（6.4%）
Pharmaceutical and medical	13（5.5%）
Rubber and plastic	5（2.1%）
Nonmetallic mineral products	2（0.9%）
Smelting and pressing	5（2.1%）
Metal products	7（3.0%）
Chemical and related products	25（10.6%）
Transport equipment	13（5.5%）
Electrical machinery and equipment	16（6.8%）
Communication equipment and computer equipment	22（9.3%）
Instrumentation Manufacturing	6（2.6%）
Others	73（31.2%）
Number of employees	
<50	24（10.2%）
50-99	28（11.9%）
100-299	44（18.7%）
300-999	36（15.3%）
1000-1999	22（9.4%）
2000-4999	21（8.9%）
≥5000	60（25.6%）
Total sales last year	
<5 million	11（4.7%）
5 -10 million	20（8.5%）
10 -20 million	16（6.8%）
20 -50 million	21（8.9%）
50 -100 million	25（10.6%）
≥100 million	142（60.5%）
Total assets	
<5 million	12（5.1%）
5 -10 million	79（3.0%）
10 -20 million	20（8.5%）
20 -50 million	27（11.5%）
50 -100 million	13（5.5%）

≥100 million	156（66.4%）

Table 2 Common method bias

Path	Model (not contain marker factor)	Model (contain marker factor)
PSI-SSCP	0.343***	0.362***
PTI-SSCP	0.341***	0.311***
PSI-PTI	0.869***	0.923***
Edu-PTI		0.221ns
Edu-SSCP		0.162ns

Table 3 The results of confirmatory factor analysis

Construct	Item	Factor loading	VIF	Cronbach's a	CR	AVE
PSI Supplier Process Integration	PSI1	0.851	2.629	0.876	0.880	0.711
	PSI2	0.895	3.071			
	PSI3	0.780	2.021			
PTI Supplier Product Integration	PTI1	0.878	3.417	0.902	0.905	0.761
	PTI2	0.917	3.395			
	PTI3	0.820	2.381			
CG Contractual Governance	CG1	0.825	2.497	0.874	0.882	0.714
	CG2	0.913	3.402			
	CG3	0.792	2.129			
RG Relational Governance	RG1	0.825	2.223	0.873	0.877	0.704
	RG2	0.900	2.879			
	RG3	0.789	2.312			
SSCP Sustainable Supply Chain Practices	SSCP1	0.803	2.488	0.898	0.907	0.589
	SSCP2	0.816	2.682			
	SSCP3	0.827	2.793			
	SSCP4	0.892	3.892			
	SSCP5	0.817	2.697			
	SSCP6	0.578	1.490			
	SSCP7	0.574	1.465			

AVE: average variance extracted; CR: composite reliability

Table 4 Correlational matrix

	Mean	SD	PSI	PTI	CG	RG	SSCP
PSI	4.747	1.232	**0.843**	0.886	0.400	0.458	0.423
PTI	4.580	1.360	0.788**	**0.872**	0.425	0.551	0.455
CG	5.284	0.948	0.348**	0.374**	**0.845**	0.837	0.543
RG	5.187	0.947	0.401**	0.489**	0.727**	**0.839**	0.444
SSCP	5.058	1.137	0.372**	0.407**	0.479**	0.389**	**0.767**

Bivariate correlations and HTMT ratios are at the lower and upper part of the diagonal, respectively, while the diagonal elements are the square root of AVE (highlighted in bold)
*p < .05, **p < .01, and ***p < .001.

Table 5 Collinearity Diagnostics

Eigenvalue	Condition Index	Variance decomposition proportions				
		Intercept	TG	RG	PTI	PSI
4.896	1.000	.00	.00	.00	.00	.00
.062	8.890	.06	.04	.02	.17	.09
.020	15.598	.54	.07	.12	.14	.21
.014	18.873	.40	.12	.00	.58	.65
.008	24.574	.00	.77	.85	.11	.05

Table 6 Standardized estimates of regression analyses

		Model 0	Model 1	Model 2	Model 3	Model 4	Model 6	Model 5	Model 7
Dependent variable		PTI				SSCP			
Control variables	Ownership	0.000	0.144*	0.141*	0.141*	0.134**	0.100+	0.149**	0.114*
	Asset	0.029	0.300***	0.280***	0.273***	0.117**	0.104*	0.136**	0.123**
Independent variables	PSI	0.786***		0.252***	0.06	0.073	0.142+	0.110	0.172*
	PTI				0.244*	0.163*	0.132+	0.141+	0.117
Moderation variables	CG					0.438***	0.419***		
	RG							0.314***	0.304***
Two-way interactions	PSI×CG						-0.282**		
	PTI×CG						0.215*		
	PSI×RG								-0.297***
	PTI×RG								0.202**
Adjusted R^2		0.617	0.096	0.155	0.175	0.318	0.337	0.256	0.284
R^2 change		0.613	0.104	0.063	0.085	0.113	0.024	0.052	0.034
Highest VIF		1.014	1.007	1.014	2.643	2.723	2.920	2.925	2.967
Model F		125.434	13.280	15.235	13.273	22.832	18.013	17.064	14.291
DF		3	2	3	4	5	7	5	7

$^{+}$ α=0.1，* α=0.05，** α=0.01，*** α=0.001

Table 7 Results of mediation analysis

path	Parameter	Estimate	Boot LLCI	Boot ULCI	P
	indirect effect	0.210	0.034	0.344	<0.05
PSI→PTI→SSCP	direct effect	0.120	-0.052	0.292	>0.1
	total effect	0.330	0.222	0.438	<0.01

Boot LLCI and Boot ULCI refer to the lower bound and upper bound of the 95% confidence interval, respectively, of the indirect effect estimated by the bias-corrected percentile Bootstrap method.

Table 8 Summary of hypothesis tests

Hypotheses	Results
H1: Supplier product integration→sustainable supply chain practices	Supported
H2: Supplier process integration→sustainable supply chain practices	Rejected
H3: Supplier process integration→supplier product integration	Supported
H4: Supplier process integration→supplier product integration→sustainable supply chain practices	Supported
H5: Contractual governance×supplier product integration→sustainable supply chain practices	Supported
H6: Contractual governance×supplier process integration→sustainable supply chain practices.	Rejected
H7: Relational governance×supplier product integration→sustainable supply chain practices.	Supported
H8: Relational governance×supplier process integration→sustainable supply chain practices.	Rejected

Table 9 Tests of Normality

Variables	Kolmogorov-Smirnov test with Lilliefors correction			Shapiro-Wilk test		
	statistic	df	sig.	statistic	df	sig.
PTI	.122	235	.000	.957	235	.000
PSI	.111	235	.000	.967	235	.000

Table 10 Gaussian copula approach for assessment of endogeneity

Test	Construct	Coefficient	P values
Gaussian copula of model 1 (endogenous variables; PTI)	^{C}PTI	-0.117	0.638
Gaussian copula of model 2 (endogenous variables; PSI)	^{C}PSI	0.035	0.905
Gaussian copula of model 3 (endogenous variables; PTI PSI)	^{C}PTI	-0.179	0.517
	^{C}PSI	0.145	0.642

Note: *c* indicates the copula term in the model.

Table 11 Results of sensitivity analyses

		Model 0	Model 1	Model 2	Model 3	Model 4	Model 6	Model 5	Model 7
Dependent variable		PTI				SSCP			
Control variable	Asset	0.027	0.145**	0.123**	0.117**	0.108*	0.095*	0.126**	0.113**
Independent variables	PSI	0.866***		0.331***	0.121	0.073	0.151*	0.111	0.180*
	PTI				0.243*	0.162+	0.128+	0.143	0.116
Moderation variables	CG					0.443***	0.419***		
	RG							0.308***	0.299***
Two-way interactions	PSI×CG						-0.323***		
	PTI×CG						0.257***		
	PSI×RG								-0.335***
	PTI×RG								0.232***
N		235	235	235	235	235	235	235	235

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12 Regression results with dummy variables

		Model 0	Model 1	Model 2	Model 3	Model 4	Model 6	Model 5	Model 7
Dependent variable		PTI				SSCP			
Dummy variables	Ownership								
	Asset								
Independent variables	PSI	0.873***		0.316***	0.102	0.0522	0.118	0.0954	0.151+
	PTI				0.245**	0.163*	0.134+	0.138	0.118
Moderation variables	CG					0.445***	0.430***		
	RG							0.323***	0.313***
Two-way interactions	PSI×CG						-0.242**		
	PTI×CG						0.165*		
	PSI×RG								-0.254***
	PTI×RG								0.173**
N		233	233	233	233	233	233	233	233

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 13 Results after winsorization

		Model 0	Model 1	Model 2	Model 3	Model 4	Model 6	Model 5	Model 7
Dependent variable		PTI				SSCP			
Control variables	Ownership	0.001	0.146**	0.144**	0.143**	0.134**	0.100*	0.149**	0.114*
	Asset	0.027	0.156**	0.133**	0.127**	0.117**	0.104*	0.136**	0.123**
Independent variables	PSI	0.866***		0.330***	0.120	0.073	0.142+	0.110	0.172*
	PTI				0.242*	0.163+	0.132+	0.141	0.117
Moderation variables	CG					0.438***	0.419***		
	RG							0.314***	0.304***
Two-way interactions	PSI×CG						-0.282***		
	PTI×CG						0.215**		
	PSI×RG								-0.297***
	PTI×RG								0.202***
N		235	235	235	235	235	235	235	235

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 14 Sobel Test

Path	Sobel-value	S.E.	Z-value	Results
PSI→PTI→SSCP***	0.214	0.070	3.053	Support