

ORIGINAL RESEARCH ARTICLE

The analysis of lean and agile supply chain strategy on environmental performance with mediating of supply chain responsiveness: Evidence from manufacturing industries in Malaysia

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ABSTRACT

Environmental concerns have garnered increasing global attention, prompting discussions on how to integrate these issues into business operations and strategies. While lean supply chain strategy (LSC) and agile supply chain strategy (ASC) are recognized for their environmental benefits to organizations, the impact of LSC and ASC on the environmental performance of firms remains relatively unexplored. This study aims to analyze the influence of LSC and ASC within various functional areas of manufacturing firms on their environmental performance. To gather data, a quantitative survey methodology was employed, involving 299 manufacturing firms in Malaysia. Out of the collected responses, 231 were deemed usable for analysis. The survey results reveal that lean supply chain strategy and agile supply chain strategy positively affect environmental performance. Moreover, supply chain responsiveness (SCR) partially mediates the relationship between LSC and ASC on environmental performance. This study contributes to the existing literature and practices in supply chain management strategy and sustainable performance in manufacturing industries.

Keywords: lean supply chain strategy; agile supply chain strategy; supply chain responsiveness; environmental performance

1. Introduction

Globalization has brought countries closer together and shifted a significant portion of manufacturing operations to Southeast Asia, where cheaper production processes prevail. It is crucial to address environmental issues in this region proactively to prevent an escalating environmental burden. Recognizing the detrimental effects of environmental pollution, governments, communities, and manufacturing industries in these nations have recognized the urgency and taken appropriate action against this problem^[1]. However, many countries in this region face severe poverty and a lack of basic facilities. Manufacturing industries are considered the primary drivers of social development and economic growth in these nations^[2]. Unfortunately, rapid industrialization has resulted in various social and environmental problems due to a lack of consideration for their impact on the environment.

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Over the past five decades, Malaysia has undergone rapid economic, social, and environmental transformations, with this trend persisting to the present day^[3]. Meanwhile, Mallak et al.^[4] highlight that the manufacturing industries have experienced significant growth, leading to a shift in Malaysia's economy from agriculture to industry. In 2018, the Malaysian manufacturing sector contributed 23% to the gross domestic product (GDP), with manufactured products accounting for 70% of the country's total exports^[5]. While industrialization has brought about substantial economic and social advancements, it has also resulted in adverse environmental effects, such as air pollution, water pollution, land pollution, and the degradation of natural resources. Hence, achieving a balance between a high standard of living and environmental preservation is crucial for Malaysia.

In Malaysia, the escalating levels of industrialization and consumption have led to a significant increase in solid waste generation, emerging as a prominent concern in recent years^[4]. Of particular concern are the scheduled or unsafe wastes, which pose a direct threat to human health. These issues have prompted manufacturers to reassess their production systems and strive for more sustainable practices, aiming to achieve efficiency and environmental consciousness in their manufacturing processes.

There is a prevailing assumption that adopting a lean supply chain strategy approach, which primarily focuses on waste elimination, holds significant potential for improving the environmental performance of organizations. This includes aspects such as reduced energy consumption, minimized raw material usage, and decreased generation of toxic waste in the manufacturing process^[6,7]. However, the evidence supporting this assumption is largely implicit rather than explicit, and the causal relationship between lean supply chain strategy and environmental performance remains unproven^[8-10]. Moreover, contradictory findings have been observed in some cases^[11,12]. Consequently, this raises the question of whether a lean supply chain strategy can genuinely contribute to the environmental performance of manufacturing firms when compared to traditional mass or batch manufacturing methods.

On the other hand, an agile supply chain strategy is closely linked to environmental performance. The concept of an agile supply chain strategy, as proposed by Payne and Peters^[13] in 2004, emphasizes the importance of agility in influencing industries' strategic readiness. Companies that adopt an agile supply chain strategy exhibit strong performance when responding to incidental events, enabling them to effectively navigate unexpected occurrences. According to the study of Navid and Ismaeli^[14], agility is a key characteristic of an excellent supply chain. In particular, Creswell^[15] defines an agile supply chain strategy as a critical element for reducing inventory, adapting to market changes in a cost-effective manner, enabling faster responses to customer demands, and fostering more collaborative relationships with suppliers. It is imperative for companies to incorporate agility into their supply chains to enhance business value by effectively managing disruptions and achieving sustainable performance with minimal resource utilization, as highlighted by Ciccullo et al.^[7].

The primary objective of this research is to analyze the real impact of lean supply chain strategy and agile supply chain strategy in various areas of manufacturing companies on their environmental performance within Malaysia. By identifying the relationship between lean supply chain strategy and agile supply chain strategy in different manufacturing domains and environmental performance, this study aims to enhance the environmental performance of the manufacturing sector.

2. The literature review and hypothesis development

2.1. Theory of resource-based view (RBV)

The resource-based view suggests that businesses sustain their strategies and gain advantages from strategic capital^[16]. Building on this concept, this study considers supply chain strategies as valuable tools for enhancing environmental performance and efficiency. The primary objective of the supply chain strategy is to enhance consumer responsiveness within the supply chain of the focal company^[17]. Lean Supply Chain Strategy (LSC) outlines how an organization can leverage competitive advantages, such as cost efficiency, response time, and flexible supply chain capabilities^[18]. Supply chain strategy can be broadly categorized into two groups, as discussed in previous literature: lean and agile^[19-21]. While a lean supply chain strategy focuses on streamlining the entire supply chain, an agile supply chain strategy emphasizes the ability to adapt and reconfigure the supply chain in uncertain and competitive conditions^[21]. Drawing on the RBV, this study recognizes lean supply chain strategy and agile supply chain strategy as valuable resources and examines their impact on environmental performance, as depicted in **Figure 1**.

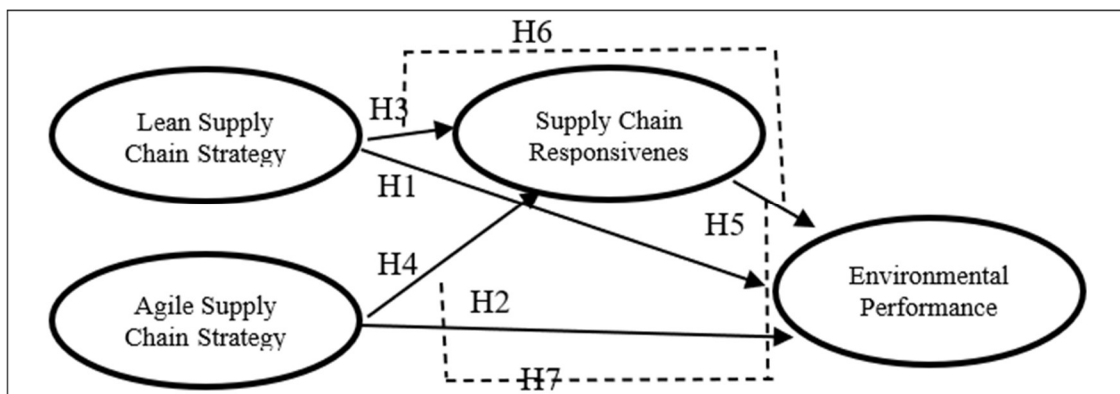


Figure 1. Conceptual model.

2.2. Theory of relational view (RV)

The theory of relational view (RV) posits that competitive advantage can be derived from external resources, particularly through the integration between companies that cannot be easily imitated by competitors^[22-24]. This integration fosters mutually beneficial conditions between the involved parties, leading to enhanced performance. The application of the supply chain becomes more effective when specific assets, skills, and complex information are involved, making replication challenging. In the context of the manufacturing industry, collaborative knowledge acquisition processes between customers and suppliers can result in relational performance gains. Suppliers contribute specialized manufacturing knowledge, while buyers actively participate in the production schedule process. This direct participation involves the exchange of information and joint efforts to acquire supplier knowledge. An example of information exchange is when material producers employ PPIC (production planning inventory controlling) staff to coordinate the supply chain's timely and responsive delivery of raw materials based on customer needs. Drawing on the RV, this research acknowledges supply chain responsiveness as an external resource that mediates the relationship between lean supply chain strategy and agile supply chain strategy in terms of environmental performance, as depicted in **Figure 1**.

2.3. Relationship between lean supply chain strategy and environmental performance

Lean supply chain strategy, can be traced back to the innovative practices of the Toyota Production System (TPS) in Japan during the 1950s. In the aftermath of World War II, Japanese manufacturers faced

resource shortages in terms of human, financial, and material resources. To overcome these challenges, they developed a process-oriented system known as the Toyota Production System (TPS)^[25]. Since then, lean supply chain has been implemented by manufacturers across various industries worldwide. While the underlying principles of lean supply chain remain relatively constant, numerous practices have been implemented to create value in product manufacturing. Over the years, innovative practices have emerged to further advance the objectives of lean supply chain^[26]. Lean supply chain strategy is a multi-dimensional approach that encompasses various organizational practices^[27]. Initially focused on manufacturing operations, lean principles gradually extended to other business functions such as suppliers, customers, and production support functions^[20,28,29]. Scholars and practitioners have dedicated efforts to refine these practices and establish a set of best practices, while others aim to categorize lean supply chain tools and techniques based on their implementation areas, such as internal and external lean supply chain practices^[30,31]. The key characteristic of lean supply chain strategy is the efficient utilization of resources^[32], achieved through waste reduction in various areas of manufacturing, including human effort, transportation, manufacturing space, processing, and inventory. This approach aims to enhance responsiveness to customer demand while producing high-quality products^[33].

As highlighted by Piercy and Rich^[34], the elimination of waste presents a significant opportunity for manufacturing improvement. It is observed that in most manufacturing operations, only 5% of activities add value, 35% are necessary but non-value adding, and a substantial 60% are non-value adding and unnecessary. Scholars strongly believe that lean supply chain strategy not only enhance manufacturing performance but also improve the environmental performance of production systems^[27]. Waste elimination and continuous improvement, inherent in lean supply chain practices, play a particularly crucial role in this regard^[18,35]. While environmental wastes are not explicitly categorized as lean supply chain wastes, they are encompassed within the concept of the seven deadly wastes, and implementing lean supply chain practices can yield significant environmental benefits^[36]. Additionally, lean supply chain strategy has the potential to improve environmental performance by promoting resource and energy efficiency^[27,34,37,38]. Therefore, the main hypothesis of this study is:

H1: Lean supply chain strategy has a positive effect on environmental performance.

2.4. Relationship between agile supply chain strategy and environmental performance

Previous studies have established the significant impact of an agile supply chain on operational and financial performance^[21,39-41]. By implementing an agile supply chain system, companies can enhance their competitiveness by maintaining adequate safety stock levels to meet increased demand from volatile markets and satisfy customer needs. The development of social and environmental performance is considered an integral part of agile functions, as highlighted by Gligor^[40] and Dubey et al.^[42].

Enabling efficient information exchange within the supply chain (SC) has been shown to reduce waste and have a significant positive impact on environmental performance^[43,44]. Conversely, collaborating with suppliers for sustainable purchasing and product improvement has been found to reduce the use of harmful materials in manufacturing^[45]. According to the findings of Mathiyazhagan et al.^[10], improved knowledge transmission supports suppliers in eliminating waste, reducing pollution, and reducing emissions, thereby enhancing firms' reputations and improving environmental performance. Consequently, various established agile supply chain characteristics such as data and knowledge management, alliances, and cooperation can be linked to sustainability performance^[6]. Based on this, the hypothesis can be stated as follows:

H2: Agile supply chain strategies have a positive impact on environmental performance.

2.5. Mediation effect of supply chain responsiveness on the relationship between lean supply chain strategy and environmental performance

Yang et al.^[46] discovered that implementing a lean supply chain strategy has a positive impact on environmental performance. Existing literature also indicates that this strategy leads to a reduction in air emissions, solid waste, and the use of toxic/hazardous chemicals^[47,48]. Additionally, supply chain management (SCM) can contribute to the reduction of packaging waste and unnecessary materials, as suggested by the Environmental Protection Agency^[49] and other integrated strategies. For example, Cherrafi et al.^[50] and Iranmanesh et al.^[51] highlighted the potential benefits of employing supplier networks to achieve energy-saving gains.

The collaboration between supply chain responsiveness, operations systems, and logistics processes is instrumental in cultivating trust and substantial support, thereby mitigating the uncertainty associated with dynamic scenarios and consistently diminishing overall inventory costs^[26]. This synergy not only enhances the effectiveness of production operations but also indirectly increases environmental performance by reducing the flow of dangerous chemicals into the production line. Consequently, this fosters a safer working environment that safeguards employee health^[52] and enlarges both the working conditions for employees and the quality of life within communities, thereby making a necessary contribution to sustainable performance. Then, the hypothesis is as follows:

H6: Supply chain responsiveness mediates between lean supply chain strategy and sustainable firm performance.

2.6. Mediation effect of supply chain responsiveness on the relationship between agile supply chain strategy and environmental performance

Establishing relations between the Agile Supply Chain (ASC) and Supply Chain Resilience (SCR) significantly impacts environmental performance within the supply chain strategy^[53]. To reinforce the supply chain, a flexible and responsive supplier network is necessary, allowing suppliers to adjust their production schedules according to the manufacturer's demands. Timely and regular knowledge sharing with key suppliers is essential to promptly address issues like delivery delays promptly^[54]. As demonstrated above, effective collaboration between the focal firm and its supplier network ensures timely supplier involvement and the establishment of cooperative relations, which are vital for fostering an agile supply chain strategy.

Furthermore, a strong supplier network enhances a firm's responsiveness to market fluctuations by improving adaptability and facilitating knowledge exchange and interaction^[46]. When a manufacturing company can effectively synchronize with its suppliers and customers, it gains a competitive advantage in handling diverse market variations. For instance, implementing a Vendor Managed Inventory (VMI) system with support from suppliers can lead to reduced inventory levels, achieved through coordinated online scheduling for raw material sourcing between manufacturers and suppliers, enabled by virtual cooperation.

Implementing robust supply chain responsiveness can significantly enhance manufacturers' cost efficiency, economic performance, and delivery speed^[19,52,53,55]. This approach proves environmentally and financially beneficial by reducing waste and non-value-added activities, leading to lower consumption of materials, energy, and resources, thereby reducing production costs and supply disruptions^[7,56]. Additionally, the effective utilization of information technology within the supply chain strategy enables the exchange of information, resulting in waste reduction and having a significant impact on environmental performance^[42,52,53]. Then, it is hypothesized that:

H7: Supply chain responsiveness mediates the relationship between agile supply chain strategy and environmental performance.

3. Methodology research

3.1. Sample and data collection

This study focused on manufacturing firms that had implemented a supply chain management strategy in different regions of Malaysia. The term “firm” includes both companies and individual units or sites within those companies. The population frame was obtained from the Federation of Malaysian Manufacturers (FMM) directory for the year 2017^[57], which listed a total of 1089 manufacturing firms in Malaysia. Due to the expected low response rate for the mail survey^[58], all 451 firms were purposefully sampled and included in the study. A mail survey was conducted targeting these 451 manufacturing firms. Out of the 451 firms surveyed, 231 firms completed the questionnaire with comprehensive information, which was used for statistical analysis. **Table 1** below provides the sample profiles of the respondents.

Table 1. The respondents profile.

Demographic	Frequency	Percentage
Usable respondent data	231	100%
Area manufacturing		
Rubber and plastic products	83	35.93%
Food products	58	25.11%
Chemical and chemicals products	41	17.75%
Computer, electronic and optical products	49	21.21%
Years establishment in Malaysia		
Less than 5 years	80	34.63%
Between 5 to 10 years	30	12.99%
More than 10 years	121	52.38%
Number of full-time employees		
Between 75 to 200 workers	117	50.65%
More than 200 workers	114	49.35%
Current position in the company		
Managing director or above	65	28.14%
Supply chain manager	60	25.97%
Purchasing manager	43	18.61%
Operation manager	46	19.91%
Plant manager	12	5.19%
Others	5	2.16%

3.2. Measurement items

In this research, the investigators constructed and utilized a framework aligned with the existing literature. They identified and defined four variables related to environmental performance based on the literature review, which included lean supply chain strategy (LSC), agile supply chain strategy (ASC), and supply chain responsiveness (SCR). To assess the respondents’ perspectives, a six-point scale ranging from “Strongly disagree” (1) to “Strongly agree” (6) was employed, wherein they were asked to indicate the significance of lean supply chain strategy and agile supply chain strategy in enhancing their environmental performance.

The measurement of Lean Supply Chain Strategy (LSC) comprised twenty-eight items across six dimensions, including supplier involvement practices, customer involvement practices, just-in-time manufacturing, waste management, cost management, and inventory management^[59-61]. Agile supply chain strategy was assessed using eleven items, covering aspects like responding quickly, marketing capability, and information technology^[40,42].

Supply Chain Responsiveness (SCR) was evaluated through nine items across three dimensions, which included responsiveness in the operations system, logistics process, and supplier network^[42,45,53]. Environmental performance was measured using six items, reflecting efforts to minimize the emission of hazardous substances or waste, reduce energy consumption, manage direct and indirect material usage, limit the use of hazardous materials, improve overall environmental conditions, and enhance compliance with environmental regulations and standards^[51].

4. Data analysis and result

The objective of this study was to examine the direct and indirect influence of lean supply chain strategy (LSC) and agile supply chain strategy (ASC) on environmental performance in the Malaysian manufacturing industry, with the mediating effect of supply chain responsiveness (SCR). To achieve this, the researchers utilized the PLS-SEM (Partial Least Squares-Structural Equation Modeling) method, employing statistical software called Smart-PLS, to evaluate the comprehensive measurement model.

4.1. Measurement model convergent validity and discriminant validity have been tested

Convergent validity assesses the extent to which measurements of a single construct agree. To evaluate convergent validity in this study, significant factor loads exceeding 0.7, composite reliabilities surpassing 0.8, and average extracted variance (AVE) greater than 0.5 were tested for all constructs^[62]. In this model, all factor loads exceeded 0.7, and items with factor loads below 0.70 were removed. These results indicate that the model meets the criteria for convergent validity. The internal reliability of scales was assessed using Cronbach's α . **Table 2** presents the loading factor, Average Variance Extracted (AVE), composite reliability, and rho-A of all constructs.

Table 2. Convergent validity.

Constructs	Items	Loading	Average variance extracted (AVE)	Composite reliability	Rho-A
LSC	LCIP1	0.809	0.690	0.899	0.853
	LCIP2	0.844			
	LCIP3	0.859			
	LCIP4	0.809			
	LCM1	0.829	0.717		
	LCM2	0.859			
	LCM3	0.885			
	LCM4	0.864			
	LCM5	0.794			
	LIM1	0.866	0.706		
	LIM2	0.900			
LIM4	0.747				
LJIT1	0.853	0.720	0.911	0.873	

Table 2. (Continued).

Constructs	Items	Loading	Average variance extracted (AVE)	Composite reliability	Rho-A
	LJIT2	0.819			
	LJIT3	0.882			
	LJIT4	0.838			
	LSIP1	0.787	0.601	0.883	0.835
	LSIP2	0.757			
	LSIP3	0.828			
	LSIP4	0.762			
	LSIP5	0.738			
	LWM1	0.874	0.756	0.925	0.894
	LWM2	0.895			
	LWM3	0.867			
	LWM4	0.840			
ASC	ASC1	0.720	0.561	0.934	0.923
	ASC10	0.728			
	ASC11	0.735			
	ASC2	0.727			
	ASC3	0.770			
	ASC4	0.727			
	ASC5	0.748			
	ASC6	0.767			
	ASC7	0.796			
SCR	RLP1	0.734	0.665	0.854	0.750
	RLP2	0.890			
	RLP3	0.895			
	ROS1	0.918	0.833	0.937	0.899
	ROS2	0.905			
	ROS3	0.914			
	RSN1	0.937	0.871	0.933	0.927
	RSN2	0.927			
	RSN3	0.935			
EF	EF1	0.831	0.751	0.940	0.935
	EF2	0.856			
	EF3	0.907			
	EF4	0.903			
	EF5	0.876			
	EF6	0.824			

The newly recommended approach was employed to assess the discriminant validity using the heterotrait-monotrait ratio of correlations, and the results are presented in **Table 3**. A discriminant validity analysis was confirmed, as all HTMT values were found to be less than 0.90, as per Gold et al.^[63] criteria. The measurement

model demonstrated sufficient discriminant ability for all constructs. The estimation model accounted for the relationships between variables and their respective items. The goodness-of-fit of the model was deemed acceptable with a Standardized Root Mean Square Residual (SRMR) of 0.061 and a Normal Fit Index (NFI) of 0.918, satisfying the criteria with SRMR value <0.08 and an NFI value >0.9 ^[64]. In conclusion, the framework fit well with the data and was adequate for testing the study's hypotheses.

Table 3. Discriminant validity.

Constructs	ASC	LSC	SCR	EF
ASC	0.749			
LSC	0.529	0.709		
SCR	0.699	0.547	0.761	
EF	0.706	0.509	0.678	0.763

4.2. Hypothesis examining

The research examined the structural relationships of the variables by conducting path analysis to assess various mediatory effects. Smart-PLS program was utilized for hypothesis evaluation in the research model. The results presented in **Table 4** display the standardized path coefficients of the research model. As shown in **Table 4** and **Figure 2**, the path coefficients from lean supply chain strategy (LSC) to environmental performance were found to be positive and significant ($\beta = 0.175$; p -value < 0.05), as were the path coefficients from agile supply chain strategy (ASC) to environmental performance ($\beta = 0.359$; $p < 0.01$). Therefore, hypotheses H1 and H2 were supported. Similarly, the relationship between LSC and SCR ($\beta = 0.247$, $p < 0.05$) and ASC and SCR ($\beta = 0.469$, $p < 0.05$) was both significant, as was the direct relationship between SCR and EF ($\beta = 0.298$, $p < 0.05$), which was also positive and significant. Therefore, H3, H4, and H5 are supported.

Table 4. Hypothesis testing.

Hypothesis and relationship	Original sample (O)	T-statistics	P-values	Result
H1: LSC → Environmental performance	0.175	3.332	0.001	Significant
H2: ASC → Environmental performance	0.359	10.878	0.000	Significant
H3: LSC → Supply chain responsiveness	0.247	3.766	0.000	Significant
H4: ASC → Supply chain responsiveness	0.469	8.236	0.000	Significant
H5: SCR → Environmental performance	0.298	4.198	0.000	Significant
H6: LSC → SCR → Environmental performance	0.073	2.718	0.007	Significant
H7: ASC → SCR → Environmental performance	0.169	3.758	0.000	Significant

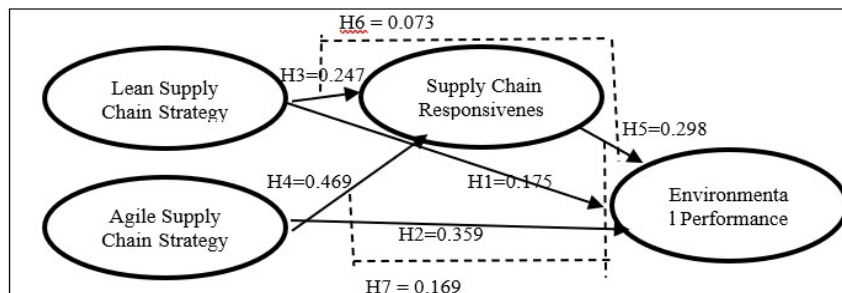


Figure 2. Result of path analysis.

Furthermore, the indirect relationship of lean supply chain strategy on environmental performance through supply chain responsiveness as a mediator was also found to be positive and significant ($\beta = 0.073, p < 0.05$), supporting hypothesis H6. Similarly, the indirect effects of agile supply chain strategy on environmental performance through supply chain responsiveness as a mediator were positive and significant ($\beta = 0.169, p < 0.05$), confirming hypothesis H7.

Based on the findings above, it can be concluded that supply chain responsiveness partially mediates the relationship between lean supply chain strategy and agile supply chain strategy on environmental performance. The R2 value, presented in **Figure 2**, shows that the lean supply chain strategy, agile supply chain strategy, and supply chain responsiveness account for 85.3% of the environmental performance variance.

5. Discussion

The findings of the present study establish that lean Supply Chain Strategy (LSC) significantly influences the environmental performance of manufacturing firms in Malaysia, corroborating similar findings by Mathiyazhagan et al.^[10], Dieste et al.^[37] and Nawanir et al.^[65]. The lean supply chain strategy approach focuses on waste and time reduction in the production process and adopts the just-in-time concept to minimize raw material inventories. Implementation of lean supply chain strategy leads to improved environmental performance by reducing the cost of storing raw materials, optimizing production activity timelines, and enhancing inventory management through effective production planning. As a result, the environmental impact is positively impacted for the better.

Furthermore, the adoption of lean Supply Chain Strategy can present significant opportunities for both enhanced productivity and environmental improvements. However, companies in Malaysia may tend to concentrate primarily on cost reduction aspects of supplier involvement, overlooking the potential benefits of collaborating closely with suppliers to address environmental concerns. As Henao et al.^[38] pointed out, the primary focus of supply management in lean supply chain strategy revolves around eliminating waste related to excess inventory or capacity by reducing supply variability.

In line with this perspective, A previous investigation conducted by Iranmanesh et al.^[51] and Huo et al.^[66] produced outcomes that align with the findings of this study, indicating that Just-in-Time (JIT) manufacturing methods used for inventory management in supply chains lead to smaller but more frequent deliveries, resulting in increased transportation frequency and longer truck journeys, which, in turn, have adverse environmental impacts. Likewise, Yang et al.^[27] and Piercy and Rich^[34] also reported associated problems with such delivery patterns, including the use of less efficient and smaller transportation vehicles, contributing to overcrowding and pollution generation. Moreover, other issues arise, including increased possibilities of waste generation due to supply chain inventory requirements and the need for additional packaging, which subsequently requires proper disposal.

The second finding shows that agile Supply Chain Strategy (ASC) also significantly influences the environmental performance of manufacturing firms in Malaysia, corroborating the findings of Ciccullo et al.^[7], Venugopal and Saleeshya^[6], and Mathiyazhagan et al.^[10]. The implementation of agile supply chain leads to positive outcomes due to the maintenance of high buffer stocks in auxiliary production materials. This enables manufacturers to effectively respond to significant increases in demand from a dynamic market while meeting consumers' needs.

Additionally, an agile supply chain strategy supports the production of customized products based on personalized customer preferences, facilitating the growth of new market shares through private label products tailored to specific customer segments. This results in increased sales turnover and expands beyond regular

products. Furthermore, adopting agile supply chain strategy allows companies to respond proactively to fluctuating weather conditions, as it enables the maintenance of abundant volume inventory for buffering, thereby mitigating environmental impacts.

Moreover, firms can identify opportunities to reduce waste and minimize resource inputs, such as water and power consumption, during production. Collaborative efforts with suppliers for sustainable purchasing and process improvement can also contribute to reducing harmful substances throughout the fabrication process and enhancing worker safety.

The third key finding reveals that lean Supply Chain Strategy (LSC) impacts Supply Chain Responsiveness (SCR), which in turn influences environmental performance. The implementation of lean supply chain strategy prioritizes regular production demands and cost efficiency by utilizing low-cost raw materials and employing a highly efficient operation system to produce finished products at the pace demanded by customers, minimizing waste. The focus on standard quality standards ensures sturdy packaging that maintains its integrity despite its standard weight.

Establishing a harmonious relationship between significant customers and manufacturers enhances demand information and production planning timelines. A reduction in finished stock inventory optimizes customer service^[9]. Through strong collaboration with key customers, manufacturers can entrust products to customers' warehouses. This logistic process of consigning products to customers' warehouses leads to ongoing sales growth, minimizing manufacturers' rental costs for warehouse space, ensuring accessibility of finished goods at safe inventory levels, and retaining existing market segments against competitors.

The solid alliance between customers and industries also provides benefits such as improved product necessity information and production preparation time, prevention of damages arising from inventory storage in consumer warehouses, and increased responsiveness in meeting consumer demands^[45,67]. Consequently, manufacturers can accurately and promptly respond to customer demand requirements, enhance delivery service levels of finished products, reduce stock storage costs, reduce environmental effects, increase sustainable product sales, and increase company profitability^[21,45,46,68–70]. Thus, it can be concluded that SCR partially mediates the relationship between lean SCS and environmental performance.

The fourth significant finding highlights the impact of agile Supply Chain Strategy (ASC) on Supply Chain Responsiveness (SCR), resulting in improved environmental performance. Manufacturers integrate closely with their primary supplier network, enabling swift responses to design changes in packaging products requested by customers. This integration also allows them to identify new market opportunities and gain a deeper understanding of raw materials from suppliers^[17,53,70,71]. As a result, they become more flexible and innovative in responding to changing competitive pressures and opportunities.

The orientation of major suppliers is involved in every aspect of production, including design, engineering, procurement, delivery, and recycling, assisting industries in obtaining valuable input for product design and access to raw materials^[53]. Sharing information about the availability of supporting raw materials from manufacturers with their major supplier network provides certainty regarding the waiting time for raw material delivery^[46], leading to cost-efficient purchasing and storage of raw materials. This, in turn, results in reduced waste as there is prudent consumption of raw inputs, leading to cost savings on raw resources and waste disposal.

Furthermore, a shift towards a circular flow of goods enables manufacturing industries to potentially reduce emissions to levels below the threshold. Firms that prioritize high responsiveness with their supplier network actively share information related to production schedule planning, enabling leading suppliers to timely distribute auxiliary materials as needed^[26]. As a consequence, establishing a strong relationship with

the major supplier network reduces the cost of storing raw materials in warehouses, ensuring the availability of production raw materials based on manufacturers' demand^[54,68,72]. In conclusion, supply chain responsiveness partially mediates the relationship between agile SCS and environmental performance.

6. Theoretical and managerial implication

This research provides a theoretical collaboration between the resource-based view and relational view theories to explore the relationship between lean Supply Chain Strategy (LSC) and agile supply chain strategy (ASC) in enhancing environmental performance through Supply Chain Responsiveness (SCR) in the manufacturing industry of Malaysia. The supply chain responsiveness is considered a mediator in this model, bridging the research gap between lean supply chain strategy and agile supply chain strategy concerning environmental performance.

From the resource-based view perspective, manufacturers achieve relational performance through strong partnerships with their supplier network, leading to improved certainty in production schedules and timely delivery of raw materials. Additionally, collaborations with involved customers, such as sharing sales projections and ensuring timely delivery of finished products, contribute to greater sustainability. The efficient management of logistics waiting periods also influences waste reduction and emission control, ultimately impacting environmental performance positively.

From a practical standpoint, the research findings hold significant implications for managers. Firstly, it is evident that an agile Supply Chain Strategy (ASC) proves to be more effective in enhancing environmental performance when compared to a lean supply chain strategy. Given the intense competition in the manufacturing industries and the market's tendency towards seasonal variations, manufacturers strive to swiftly respond to customer demands, including changes in packaging design and personalized product customization. Consequently, support for buffer inventory remains relatively high to ensure responsiveness.

Secondly, the implementation of lean supply chain strategy has a more considerable impact on Supply Chain Responsiveness (SCR) than an agile supply chain strategy. The lean supply chain strategy optimizes the collection of auxiliary raw materials from the primary supplier network through large-scale minimum volume purchase orders (POs) and delivers finished products to the primary distributor based on monthly cooperation agreement contracts. This streamlined approach enhances the efficiency of the supply chain and contributes to the overall responsiveness of the system. Lastly, these findings offer valuable insights for managers, indicating that adopting an agile supply chain strategy can significantly boost environmental performance, while implementing a lean supply chain strategy can have a substantial effect on enhancing Supply Chain Responsiveness.

On the other hand, the agile supply chain strategy prioritizes flexibility in supporting raw materials, utilizing adaptable purchase orders, and delivering finished products tailored to the specific needs of customized customers, including private label products for sale to end-users. In contrast, the lean SCS can enhance environmental performance more effectively by adopting an integrated approach with customers. Manufacturers can regularly place product stocks into customers' warehouses on a weekly or daily basis to optimize the absorption of production results. These pathways provide valuable guidance for managers to enhance environmental performance.

7. Conclusion and limitation

The findings of this study provide valuable evidence regarding the role of lean Supply Chain Strategy (LSC) and agile supply chain strategy (ASC) in enhancing environmental performance in Malaysian

manufacturing firms. It is observed that agile supply chain strategy proves to be more effective in dynamic conditions, particularly in the context of seasonal variations, compared to a lean supply chain strategy that performs better in stable conditions. Moreover, the research suggests that Supply Chain Responsiveness (SCR) mediates the relationship between lean supply chain strategy, agile supply chain strategy, and environmental performance.

Nonetheless, the effective mediation of supply chain responsiveness has a greater impact on the relationship between lean supply chain strategy and environmental performance compared to its influence on agile supply chain strategy and environmental performance. The firm's strategic orientation leans supply chain strategy more towards supply chain responsiveness, as the developed model of supplier network, logistics process, and operations system embraces an open innovation strategy to achieve sustainable performance, enhancing production capabilities while also improving environmental performance within the manufacturing industry. Particularly in the manufacturing sector, this approach allows for an increase in energy and production needs without adversely compromising the environment. Furthermore, these research findings are expected to contribute to the enhancement of the manufacturing sector and, in turn, promote the overall Malaysian economy.

This analysis has certain limitations, highlighting the need for future research. The current study adopts a cross-sectional design, making it essential to conduct longitudinal research in subsequent studies. This will enable a more in-depth examination of the effects of lean supply chain strategy and agile supply chain strategy on supply chain responsiveness, ultimately enhancing environmental performance.

Moreover, it is worth noting that this research solely focuses on the manufacturing industry within a single country. To strengthen and validate the findings, it would be beneficial to gather data from industries in other countries. Such cross-country data collection would provide more robust evidence and confirmation of the study's outcomes.

Author contributions

Conceptualization, II; methodology, II and IC; validation, NAAS; formal analysis, IC; data curation, II; writing—original draft preparation, II and IC; writing—review and editing, IC, BS and NAAS; supervision, NAAS. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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