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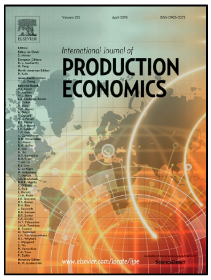
*DOI:*
10.1016/j.ijpe.2019.03.026




Green operations: what's the role of supply chain flexibility?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PII: S0925-5273(19)30122-7

DOI: 10.1016/j.ijpe.2019.03.026

Reference: PROECO 7340

To appear in: *International Journal of Production Economics*

Received Date: 04 July 2018

Accepted Date: 28 March 2019

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# Green operations: what is the role of supply chain flexibility?


## Abstract

This paper aims to understand the specific role that supply chain flexibility (SCF) can play in the successful adoption of green operations (GO) strategies based on evidence from the automotive industry. By conducting an exploratory case study with three automakers, it is found that different GO strategies require the support of different SCF dimensions. More importantly, the magnitude of the role played by each flexibility dimension varies depending on the degree of innovativeness in the *green design* initiatives, the types of *green purchasing* initiatives, and the strategic orientation of *green manufacturing* initiatives being adopted. Our case studies contribute to the theoretical understanding of the complex SCF-GO relationship by identifying the essential theoretical constructs and indicating their lower layer interactions in a systematic way. In practice, our findings may help managers assess which SCF dimensions can contribute more significantly to their specific GO efforts, and then strategically plan, develop, and deploy relevant flexibility to support beneficial outcomes. Our study contributes to the OM literature by clarifying the multidimensional effects of SCF on GO.


**Keywords** Green operations, supply chain flexibility, case study, automotive, sustainability

## 1. Introduction

Dynamic consumer demands and market competition have caused pressure for rapid response for customized products and services. For instance, Volkswagen (VW) could potentially offer over a billion of different variations of VW Golf to its customers (Scavarda et al., 2010). However, a mass customization strategy can place significant burden on the focal firm and its supply chain with respect to managing cost, quality, and responsiveness (Malhotra and Mackelprang, 2012). Developing supply chain flexibility (SCF) is a common approach adopted by organizations to meet these challenges (Christopher and Towill, 2000). SCF represents the ability of a firm's supply chain to make agile, adaptive, and responsive changes to meet market requirements by coping with uncertainty and ensuring the smooth flow of products and services through the supply chain (Blome et al., 2014). Empirical studies confirm that organizations can enjoy superior performance by fostering high-level SCF capability (Thomé et al., 2014; Sánchez and Pérez, 2005).

In addition to responding to product and service customization pressures, organizations are also facing environmental sustainability concerns. There is a growing emphasis for manufacturing firms to adopt green operations (GO) strategies to reduce their negative environmental impacts (Zhu et al., 2007; Liu et al., 2017). Examples include Toyota's eco-design initiatives, and VW's green purchasing programs (Nunes and Bennett, 2010). In recent years, extensive research has been conducted to explore effective ways to tackle environmental problems, many of which have focused on examining the association between lean manufacturing and sustainability (Cherrafi et al., 2016; Das, 2018; Cherrafi et al., 2018; Zhu et al., 2018). However, the contribution of an optional approach focusing on SCF has been overlooked in the context of GO. Whether there is an association (directly or indirectly) between SCF and GO is still under discovered. Can SCF possibly make positive contributions towards GO? Answering this critical question has significant implications for the OM literature due to a widely spread concern that firms operating in rapidly changing contexts prefer a flexible working approach instead of the efficiency-focused lean approach (Fisher, 1997; Christopher and Towill, 2000). For instance, if a firm possesses strong volume flexibility supported by its external suppliers and logistics partners, it may be able to quickly scale up production for its newly developed green products to satisfy customers and gain competitive advantages. The firm may enjoy more revenue by rapidly offering the necessary quantity of green products to the market. Tesla Motors suffers a bottleneck of scaling up its production for new models with green value propositions, providing a testifying example on the negative impact of not having necessary SCF (Vengattil and Chatterjee, 2018).

According to the resource-based view (RBV) (Barney, 1991; Hitt et al. 2016), the adoption of strategies requires the support of firm-specific resources and capabilities. It has been further pointed out that firms need to possess and deploy specific capabilities in the pursuit of green strategies (Christmann, 2000; Gold, 2010; Liu et al., 2016). As Duclos et al. (2003) noted, the benefit of SCF lies in the ability to facilitate the adoption of meaningful organizational strategies that satisfy customer demands and improve overall firm performance. We would like to posit that SCF as a key organizational capability will also support the adoption of GO strategies. However, existing literature offers limited insights into this SCF – GO relationship. For example, an early attempt was made by Klassen and Angell (1998) to examine the relationship between manufacturing flexibility and environmental management, but they treated flexibility as an amalgamated construct. Similarly, Liu et al. (2016) explored the association between SCF and GO in the automotive sector, but also treated SCF as a single integrated construct. Prior research has confirmed that SCF is rather a multidimensional construct (Vickery et al., 1999; Duclos et al., 2003; Stevenson and Spring, 2007; Malhotra and Mackelprang, 2012), with each dimension contributing differently to a firms' performance (Sánchez and Pérez, 2005; Malhotra and Mackelprang's, 2012). That means different dimensions of SCF may play dissimilar roles in the adoption of a specific GO strategy. Hence, there is still a need to understand in what way SCF will contribute to GO, especially considering the multidimensional nature of SCF.

In this study, we will address these knowledge gaps through investigations guided by the primary research question: *what is the role of SCF in the successful adoption of GO strategies?* To answer the question, we conducted an exploratory case study involving three automakers. We focused on the automotive industry because the sector's reputation has often been associated with issues concerning environmental management (Gonzalez et al., 2008; Liu et al., 2016). Flexibility is also one of the key factors underpinning the success in this industry (Sánchez and Pérez, 2005). Studying this sector can therefore produce valuable insights for academics and practitioners. This focus will also allow us to possibly compare and contrast our observations with the well reported lean practices in this industry.

After this introduction, we will review the relevant literature and establish the theoretical background for our case studies in section 2. The research methodology will then be introduced in section 3 followed by section 4 to outline our analysis process and highlight the key research findings. Section 5 will discuss the wider implications of the research findings. Finally, in section 6, we draw our conclusions, and offer directions for future research.

## 2. Literature Review and Theoretical Foundation

### *2.1 Green operations (GO)*

Due to an increasing need to address environmental issues, GO has attracted considerable attention in recent years (Liu et al., 2017; Liu et al., 2016; Beske and Seuring, 2014; Cherrafi et al., 2018).

GO concerns the integration and alignment of environmental management strategies into production and operations to improve environmental performance (Marchi et al., 2013; Beske and Seuring, 2014; Liu et al., 2017). The key elements of GO include green design (GD), green purchasing (GP), and green manufacturing (GM) (Liu et al., 2017; Liu et al., 2016; Wong et al., 2012; Nunes and Bennett, 2010; Cherrafi et al., 2018). GD refers to the systematic consideration of design performance with respect to environmental improvement over the full product life cycle (Liu et al., 2017; Nunes and Bennett, 2010). Examples include design for resource conservation, using recycled materials in product, and design of product for reduced consumption of energy. GP considers environmental performance improvement in the procurement process (Zhu et al., 2007; Seles et al., 2016). Exemplar practices include environmental audit of suppliers and supplier environmental certification. GM is about reducing harmful environmental impacts during the production stage, for example pollution prevention and control in factories, reduction of energy consumption and emissions, and enhancement of operational efficiency at plants (Deif, 2011; Liu et al, 2017).

Adopting GO strategies creates many benefits not only to the focal firm but also to its supply chain partners (Handfield et al., 2005). For example, a green design strategy can be adopted by a firm to differentiate itself from its rivals by offering eco-friendly products and services. Customers may be willing to pay premium prices for these products, thus representing a clear economic advantage both for the focal firm and for its suppliers that manufacture products with less harmful raw materials or in a more environmentally sound manner (Marchi et al., 2013).

Given highly fragmented production networks and increasing globalization, firms are confronted with the complexity of coordination on GO matters because of enlarged distances, and differences in business culture and environmental legislation. The more complex a firm's supply chain, the more the firm is compelled to shape its green strategies to reduce environmental problems (Marchi et al., 2013). Therefore, strategic decision-making in GO becomes critically important and challenging, especially when firms are constrained by their limited resources and capabilities (Wu and Pagell, 2011).

### *2.2 The concept of flexibility*

Flexibility is often recognized as a key capability for achieving a competitive advantage (D'Souza and Williams, 2000). Teece and Pisano (1994) thus characterized firms that have honed such a capability as 'high flex'. Research on flexibility has traditionally focused on internal manufacturing flexibility (Duclos et al., 2003). D'Souza and Williams (2000) noted that manufacturing flexibility represents the capability of the manufacturing function to make necessary adjustments to respond to environmental changes without a significant sacrifice to firm performance. Despite dissimilar definitions existed the literature, it is generally agreed that manufacturing flexibility is a multi-dimensional construct (D'Souza and Williams, 2000; Duclos et al., 2003; Koste et al., 2004; Malhotra and Mackelprang, 2012; Merschmann and Thonemann, 2011). However, some of the proposed dimensions are "primary" (e.g., volume flexibility, modification flexibility, and mix flexibility), whereas others are "secondary" (e.g., machine flexibility, labor flexibility, and material handling flexibility) and the secondary dimensions may be components subsumed under the primary ones (Watts et al., 1993), suggesting a hierarchical nature to manufacturing flexibility (Koste and Malhotra, 1999; Thomé et al., 2014).

The various dimensions of manufacturing flexibility proposed in the literature and the hierarchical nature of flexibility dimensions concentrate on flexibility within a single plant or organization. As noted by Koste and Malhotra (1999), the tiered perspective of flexibility starts at the top with strategic flexibility and moves down through functional, plant, and shop floor flexibility and, finally to individual resource flexibility. However, for a firm to bring a new product or a modified product to market more parts of the "system" must be considered than only the internal plant (Duclos et al., 2003). Studies have thus shifted focus away from manufacturing flexibility to the linkages between manufacturing units and suppliers and customers, i.e., supply chain flexibility.

### *2.3 Supply chain flexibility (SCF)*

An early study on SCF can be found in Vickery et al. (1999), in which they argued that SCF should be examined from an integrative, customer-oriented perspective. Their definition encompasses the flexibility dimensions that directly impact a firm's customers and the responsibility of two or more functions, whether internal or external to the firm. Duclos et al. (2003) contended that a complete definition of SCF would include the flexibility dimensions required by all the participants in the supply chain to successfully meet customer demand. They proposed a conceptual model of SCF consisting of six dimensions, refined to five by Lummus et al. (2003). These include *operations systems flexibility, logistics processes flexibility, supply network flexibility, organizational design flexibility*, and *information systems flexibility*.

Although different conceptualizations exist in the literature, it is commonly accepted that SCF has both *internal* and *external* dimensions (Vickery et al., 1999; Duclos et al., 2003; Stevenson and Spring, 2007; Malhotra and Mackelprang, 2012; Thomé et al., 2014; Seebacher and Winkler, 2015). Internal SCF mainly concerns a focal firm's manufacturing flexibility. Four key dimensions have been discussed in the literature, including (1) *modification* flexibility (MOD), describes how quickly and efficiently a product alternation can be made to meet more specific customer demands; (2) *mix* flexibility (MIX), the ability of the system to produce a range of different products during the same planning period; (3) *new product* flexibility (NEW), the plant's ability to introduce substantially new discrete products into production; (4) *volume* flexibility (VOL), the ability to change the volume of output of a manufacturing process (D'Souza and Williams, 2000; Koste et al., 2004; Malhotra and Mackelprang, 2012; Thomé et al., 2014; Blome et al., 2014;).

By synthesizing the dimensions from previous studies and emphasizing an integrative view, these external SCF include supplier, logistics, and supply (network) flexibilities. Specifically, *supplier* flexibility (SUP) refers to the supplier's ability to consistently accommodate various customer requests (Malhotra and Mackelprang, 2012). *Logistics flexibility* (LOG) is the ability to efficiently and cost effectively receive and deliver products as sources of supply and customers change (Duclos et al., 2003; Thomé et al., 2014), whereas *supply network flexibility* (NET) refers to the ease of changing supply chain partners in response to business environment changes (Lummus et al., 2003; Jin et al., 2014).

Not all firms can achieve the same level of flexibility in their supply chains as SCF is a specific organizational capability (Malhotra and Mackelprang, 2012; Merschmann and Thonemann, 2011; Sánchez and Pérez, 2005; Vickery et al., 1999). Firms that have strong SCF can achieve superior performance (Thomé et al., 2014; Sánchez and Pérez, 2005). Despite much has been done to decipher the SCF – performance linkage in the existing literature, limited research has explored how SCF might influence company's strategic efforts towards environmental management, especially considering the multi-dimensional nature of SCF.

### *2.4 The conceptual framework*

Based on the review and synthesis of literature on SCF and GO, we construct our conceptual model to guide our research (see Figure 1). From a resource-based view (RBV) perspective (Barney, 1991), the successful adoption of green strategies requires the support of specific resources and capabilities (Morash, 2001; Liu et al., 2016). In particular, SCF is a key firm-specific capability

(Seebacher and Winkler, 2015), which may enable the successful adoption of green strategies in the automotive firms. In order to address our research question, we aim to explore the key SCF dimensions and the current GO strategies (exemplified by GO initiatives/practices being adopted) in the automotive industry, and to examine whether there are relationships between each key SCF dimension and the respective GO strategy.

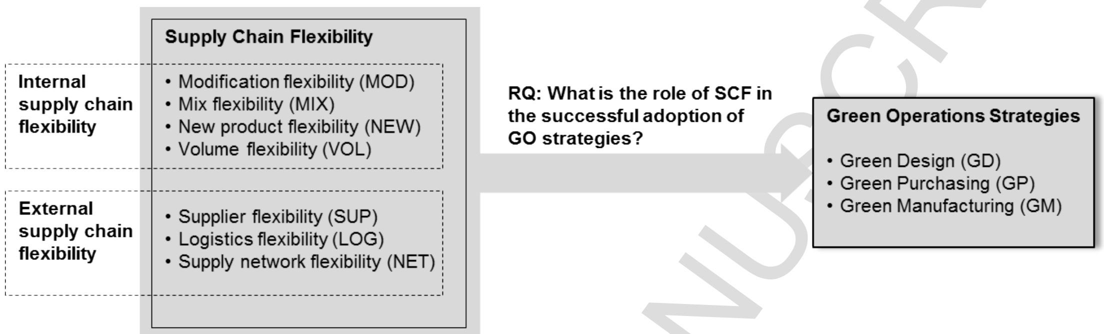



**Figure 1. The conceptual framework**

For example, in the event of designing and launching new greener products, firms would possibly need to possess strong new product flexibility (NPF) as it can help the firms to quickly generate ideas and effectively introduce new products (Zhang et al., 2002). NPF thus can enable firms to respond quickly to changing customer needs with respect to sustainability with new innovative products offerings. Moreover, incorporating new greener products into existing product portfolios may also require a strong mix flexibility (MIX) as it can enable the firms to economically and effectively produce different combinations of products given certain capacity (Zhang et al., 2003). Green strategies also necessitate the use of sustainable materials in production, which can be facilitated by firms having strong modification flexibility (MOD) as it can quickly and efficiently support product modification. Therefore, it is believed the successful adoption of certain GO strategies may require the support of certain SCF, both internally and externally, as depicted in Figure 1. We will explain our research method to investigating this relationship in the next section.

## 3. Methods

A multiple case study methodology (Stake, 2006) was used to explore this SCF – GO relationship in a view to identifying key variables and linkages between the variables that are not clearly envisaged in the existing literature (Voss et al., 2002; Yin, 2018). This research design allows us to gain in-depth understanding of new or complex phenomena by yielding a high level of details around SCF and GO. In addition, because of the explorative nature of this research due to the lack of an established theoretical model in the literature, the primary focus of our case analysis is to gain an overall understanding rather than a complete test of the causal effect between SCF and GO (Yin, 2018).

Although a study on SCF and GO may suggest a firm's supply chain should be the unit of analysis or the "object of study", in this research we consider a focal firm perspective. This is because SCF should be treated as the focal firm's strategic capability and should be viewed from the integrative perspective, which supports the focal firm's performance outcomes (Vickery et al., 1999; Malhotra and Mackelprang, 2012). We also take on board of Yin's (2018) suggestion that one must focus the case on the perspectives of analysis that will most likely illuminate the research question.

We select automakers for our exploration to possibly contrast our observations with the widely reported practices on lean and green operations in the automotive industry. Potential candidates were identified from the Dow Jones Sustainability Index that contains both social and environmental criteria. These industry leaders are considered more active in pursuing environmental management. Annual corporate sustainability reports of identified organizations were evaluated to determine whether any initiatives to improve environmental performance existed. We identified 28 potential car manufacturers and over a half of them expressed little interest in supporting our research at the initial contact. Among the firms that were happy to continue the discussion, 6 of them were prepared to provide necessary access to their entire supply networks as well as offering senior support on strategic matters as well as. We finally picked up 3 firms that would likely lead to distinctive situations to analyze thematic patterns around the SCF and GO relationship (Eisenhardt, 1989).

Selecting an appropriate number of cases is important in ensuring research quality, validity, and generalizability (Voss et al., 2002). The 3 case firms revealed similar multi-tiered supply networks and each adopted some level of GO initiatives. Most importantly, a high level of access was afforded by top executives of the 3 case firms. This access enabled us to gain deeper insights into their respective SCF and GO. We visited their main manufacturing hubs where they produce their most passenger vehicles. Table 1 provides the characteristics of the 3 case firms. For confidentiality reasons, the names of the case firms remain anonymous.

**Table 1 – Case characteristics**

| Case | Ownership | Main market segments | Annual sales | Size (no. of employees) | Suppliers | Informants | No. of interviews |
|---|---|---|---|---|---|---|---|
| A | Joint venture | Passenger vehicle | Approx.1.67m units (of 2016) | Approx.30,000 in total | 555 1st tier suppliers, over 90% of which were located within 300km radius. | Vice-president, Chief logistics manager, supply managers, environment department managers, production managers | 13 |
| B | State owned | Passenger vehicle | Approx. 0.70m units (of 2016) | Approx.24,000 in total | 400 1st tier suppliers, approx. 73% of which were located locally, and requiring its suppliers to be located within 200km radius | SCM managers, CFO, R&D managers, purchasing managers, environment department managers, production managers | 14 |
| C | Private | Passenger vehicle | Approx. 0.32m units (of 2016) | Approx. 6,000 in total. | 600 1st tier suppliers, over 80% of which were located within 400km radius | Chief logistics manager, purchasing managers, R&D managers, environment control managers, plant managers | 12 |

Data collection started in August, 2016 with the support of a semi-structured interview protocol with open-ended questions (see Appendix). The questions worked as an initial guide to conduct the case interviews. Necessary adjustments and alterations were made throughout and after each interview in order to better capture particular aspects of the subject being investigated (Yin, 2018). The protocol called for multiple respondents from multiple functional areas, including members of the top management team, R&D, operations/production, environmental management, purchasing, and logistics/SCM managers (see Table 1). Interviewing multiple respondents allowed us to examine different aspects of internal and external SCF of a case firm and their GO initiatives. In general, each face-to-face interview lasted between 60 and 120 minutes, with 8 interviews lasting more than 120 minutes because the respondents were more knowledgeable in answering our questions due to their roles in relevant departments (e.g., SCM). The interviews were recorded under formal consent of the respondents and later transcribed. We made follow-up telephone/Skype interviews to further investigate and clarify unclear issues. We also collected data from direct observations within the case firms, presentations, company websites, reports, and newsletters. Data collection was stopped in March, 2017 when a saturation point was reached, where additional data would not add new information to support understanding of the research question (Eisenhardt, 1989).

Data analysis comprised both within and across case analysis. The process as outlined in Yin (2018) and Voss et al. (2002) was followed. Accordingly, we have initially written up case overview for each firm (Eisenhardt, 1989) in order to generate internally consistent descriptions of each case's SCF and GO initiatives (a total of 165 pages). The next stage began with the open coding of the interviews by grouping phrases, sentences, or paragraphs into codes and categories in an inductive fashion. Each researcher individually coded the data and then we compared the individually coded data to assure consistency. In particular, the coding categories for GO were relatively straightforward and agreement was reached on GD, GP, and GM respectively. Indicative analysis for these categories is presented in Table 2.

**Table 2 – GO examples in three case firms**

| Case | Green design (GD) | Green purchasing (GP) | Green manufacturing (GM) |
|---|---|---|---|
| A | Energy-efficient vehicles; electric vehicles (EVs); plug-in hybrid vehicles (PHEV); green technologies in design (e.g. energy-efficient powertrain/ engine/transmission); lightweight design (e.g. intelligent multi-material design in body and engine); use of sustainable materials (e.g. natural fibers, high/ultra-high-tensile steels, and recycled parts). | Purchasing more sustainable materials; environmental certification of suppliers; strong environmental criteria on suppliers; environmental training and support for suppliers; environmental assessment and monitoring of suppliers. | Environmental management systems; environmental certifications (ISO14000 series; ISO50001), pollution prevention technologies, emission monitoring and control; green factories; new painting shop (e.g. 75% VOCs reduction); use more sustainable energy source (e.g. solar power); waste management and recycling (e.g. waste water recycling, heavy metal and mechanic oil recycling); 91% waste recycling rate; noise reduction; Productivity and process optimization (e.g. resource efficiency platform); lean production. |
| B | Energy-efficient vehicles, EVs, new green technologies in engine and transmission design (e.g. direct injection); new body shape design; sustainable materials (e.g. avoid the use of hazardous and non-biodegradable materials, use high-strength and lighter material in body structure) | Purchasing more sustainable materials; environmental certification of suppliers; research and design collaboration with suppliers; Environmental criteria on suppliers (e.g. reduce hazardous materials usage, use more bio-degradable materials) | Quality improvement (e.g. ISO/TS16949); ISO14000 series certification; environmental management systems; green factories (e.g. use LED lights, energy-saving air conditioning and water conservation); new painting shop; energy savings in production; Productivity and process improvement; pollution prevention technologies; emission monitoring and control; lean production |
| C | Energy-efficient vehicles; PHEV, EVs, fuel cell vehicles; lightweight design; green technologies in design. | Purchasing more sustainable materials; suppliers environmental performance assessment and monitoring | Production process improvement and optimization; pollution prevention and control (e.g. hazardous waste, waste water and solid waste); noise reduction; new painting shop and process; environmental certifications; green factories; lean production |

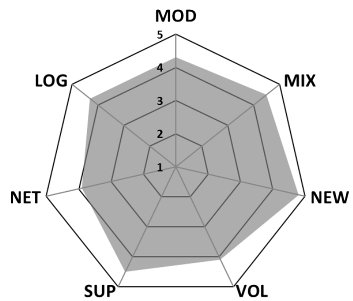
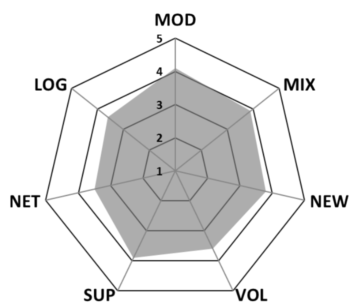
The coding categories for SCF are depicted in Table 3. The level of SCF in each firm was evaluated using the capability maturity model (Srai and Gregory, 2008), ranging from 1: Initial to 5: Optimizing. The results are presented in Table 4 in radar diagram for review and comments within the research team and with senior managers from the case firms. Disagreements were resolved through further analysis and updates till a high degree of consensus was reached on all constructs before combining the data into a consensus document. Triangulation involved combining the findings from multiple interviews, as well as observations and data from multiple sources to mitigate biases and to enhance reliability and validity (Yin, 2018).

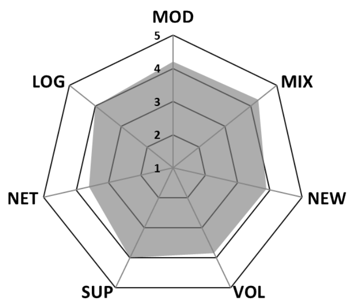
**Table 3 – Description of coding categories for SCF**

| Coding Category | Description | Example codes | Examples |
|---|---|---|---|
| Modification flexibility | Instances in which the interviewees discussed how quickly and efficiently they can alter their car models or their ability to make frequent modification of product features for a large number of existing models to meet more specific market demands. | "Modify", "modification", "quickly alter product features", "frequent modification", | "…we can quickly modify our product features to satisfy different customers' demands." |
| Mix flexibility | Instances in which the interviewees described their ability to produce many different types of vehicles during the same planning period or to make quick and significant alternations to their product portfolios to compete in the market. | "mix", "make different styles", "different models", "large product ranges", "product portfolios", | "…we have a large product range - producing over a hundred different models in our factories, [with] an annual production capacity of 900,000 units…" |
| New product flexibility | Instances in which the interviewees discussed their ability to introduce substantially new discrete vehicles into production or to quickly and effectively design and launch these innovative new models on the market. | "quickly make electric vehicles", "hybrid vehicles", "green models", "sustainable cars", "quickly launch new", | "…the design capability we have enable us to quickly introduce new models to the market"; |
| Volume flexibility | Instances in which the interviewees discussed how quickly and efficiently they can change the volume of output of a manufacturing process to meet specific market conditions. | "output flexibility", "volume flexibility", "volume change", "volume variation" | "…our factories can produce different models, colours, and configurations [cars] at the same time…we can effectively adjust production volume [for each model] according to demands." |
| Supplier flexibility | Instances in which the interviewees assessed their suppliers' ability to consistently and efficiently accommodate their various requests and changes. | "flexible supplier", "quick response", "flexible supply" | "…90% of our tier-1 suppliers are located within 300km range, which enables fast response and JIT supplies…they can quickly change their production according to our requests" |
| Logistics flexibility | Instances in which the interviewees discussed their logistics operation's ability to efficiently and cost-effectively receive and deliver products to meet production/market needs. | "flexible delivery", "logistics flexibility", "efficient logistics", "quick delivery" | "…they[suppliers] locate very closely to our factories...to realize quick delivery to us."; "…the milk-run model we use can effectively facilitate flexible and quick delivery…" |
| Supply network flexibility | Instances in which the interviewees discussed how easy it was for them to change/select supply chain partners in response to changes in sourcing/production requirements. | "quickly change suppliers", "select new suppliers", "new partners", "re-design network" | "…we keep an average 2-3 suppliers per component to main flexible supply" "for majority of the parts we can quickly find and change our suppliers…" |

Cross-case analysis helped to identify common themes and differences on how different dimensions of internal and external SCF could impact GO. The within case analysis helped us to examine SCF and GO within a coherent context, while the cross-case analysis served as a form of replication where the constructs of interest in one setting could be refined and enriched in other settings (Yin, 2018). Table 4 illustrates the overall process of our cross-case analysis.

**Table 4 Cross-case analysis**

| | Flexibility Maturity Level | Green design (GD) | Green purchasing (GP) | Green manufacturing (GM) |
|---|---|---|---|---|
| ***Case A*** | <br>Level defined:<br>1. Initial (ad hoc)<br>2. Repeatable (disciplined, under effective control)<br>3. Defined (standard, consistent process)<br>4. Managed (predictable process, with detailed measures and controls)<br>5. Optimizing (continuous process improvement is enabled, piloting innovative ideas and technologies) | **GD-A1**: Case A was able to quickly launch a series of new hybrid and electric models on the market to compete due to its high NEW in place (++). Internal MOD and MIX, SUP mainly played a supporting role (+). But, it also required strong NET (++) to quickly find/switch to competent suppliers for the new models.<br>**GD-A2:** Minor, frequent, ongoing modification of existing models for energy efficiency & environmental improvement was successful in case A, because it has strong MOD (++). This type of modification also needed the support of internal MIX (+) if shared across different models and external SUP to cope with various changes (+).<br>**GD-A3:** Substantial changes (e.g. lightweighting design) in case A for different models are enabled by its strong MOD and MIX (++), without affecting its normal production and incurring additional cost. Also, these changes were supported by case A's external NET and SUP (+) to maintain smooth and efficient supplies. | **GP-A1:** Case A's sustainable material purchasing was related to its green design. Its strong MOD ensured the use of more sustainable materials/parts in its existing models was performed quickly and effectively (++). Its strong MIX also ensured the efficient substitution with recycled bumpers across several models (++). Case A's strong SUP (++) facilitated the smooth procurement of sustainable materials/parts, without disruptions/major problems, despite having the strongest standards of the three case firms. Its NET (+) also provided necessary support if the existing suppliers failed to comply with/meet its standards, whilst this was not often the case.<br>**GP-A2:** Case A provided strong support and training for all its tier-1 suppliers' environmental certification and legal obligation. The firm had the most stringent standards and monitoring of its suppliers' environmental performance. But, its suppliers had the highest compliance rate due to the firm's strong SUP (++), and some fear of losing businesses with case A, enabled by its NET (+).<br>**GP-A3:** Compared with other two cases, case A could more easily evaluate and select new environmentally qualified suppliers who can meet its standards, which was supported by its relatively stronger NET (++).<br>**GP-A4:** Large purchasing volume supported all case A's green purchasing, as it provided strong bargaining power over suppliers (+). | **GM-A1:** No significant relationship was detected between case A's green factory initiatives and its supply chain flexibility (∅).<br>**GM-A2:** Case A had successfully installed new technologies in its stamp shop and paint shop for production process improvement. Its strong MOD ensured efficient and smooth adoption without major interruption for its normal operations (++). It also had successful ongoing small incremental process improvement at plants, requiring the strong support from its MOD (++), as well as its SUP to cope with any changes (+) (e.g. JIT/JIS supplies).<br>**GM-A3:** Case A had strong MIX, which was further enhanced by its modular transverse matrix system. This had in turn led to improved production efficiency (++).<br>**GM-A4:** Case A had relatively stronger VOL, and a high capacity utilization rate ($C_u$), enabled by its strong MIX. When reaching a high $C_u$, high productivity and economies of scale can be achieved.<br>**GM-A5:** Case A's recycling and reuse efforts (e.g. water pump) were relatively better than the other case firms. Its strong MOD provided strong support for effective modification and production (++), and its MIX ensured different product models can accommodate these changes (+). These initiatives in case A required also strong external support from suppliers, 3PL and recyclers due to the complexity and uncertainty in product returns, necessitating both strong SUP and LOG (++). |
| ***Case B*** |  | **GD-B1:** Case B was also able to launch a series of EV models on the market with the support of its NEW (++). Its existing suppliers SUP provide supporting role in this initiative (+). It however, had some troubles finding competent new suppliers for certain key components, resulting delays.<br>**GD-B2:** Case B also have minor, frequent, ongoing modification of existing models for energy efficiency & environmental improvement supported by its strong MOD (++), and the support of internal MIX (+). Externally, this has been supported by its external SUP to cope with various changes (+).<br>**GD-B3:** Case B's substantial changes in different models for sustainability | **GP-B1:** Likewise, Case B's sustainable material purchasing was also related to its green design initiatives (e.g. using carbon fibre). Though it was not on a large scale, its internal MOD and MIX facilitated the modification and substitution of sustainable materials/parts across different product range without affecting productivity (++). Case B's suppliers most of the time can satisfy its green purchasing requirements, enabled by its SUP (++). In some cases, however, the firm would need to find alternative suppliers, which required its NET support (+).<br>**GP-B2:** By contrast, case B had less stringent standards and monitoring of its suppliers' environmental performance. But its suppliers must comply with the requirements, or they can be penalized or even lose the business with the case firm. This required the firm to have strong SUP (++). When it had to look for | **GM-B1:** Similarly, no significant relationship was detected between case B's green factory initiatives and its supply chain flexibility (∅).<br>**GM-B2:** Case B had also successfully installed several new technologies (incl. paint shop) for process improvement, which was ensured by its strong MOD for efficient and smooth transition without major interruption (++). Besides, it also had small and gradual process improvement. Case B's strong MOD ensured their success. Externally, the suppliers could cope with the changes, supported by the SUP. The case firm also adopted lean, external SUP provided support for efficient supplies, especially for JIT delivery (+).<br>**GM-B3:** Case B's platform technologies and some key components supplier's modular supplies had improved its MIX, which had in turn led to improved production efficiency (++). |

| | GD | GP | GM |
|---|---|---|---|
| | considerations are enabled by strong MOD and MIX (++). But, case B experienced difficulties in finding competent external suppliers who can meet its requirements due to its relatively weaker NET. | alternative sourcing, case B required the support of NET (+) to quickly identify competent suppliers.<br>**GP-B3:** For new green supplier selection, case B was not as efficient as case A as it sometimes experienced difficulties, due to relatively weaker NET (++).<br>**GP-B4:** Similarly, when there was a large purchasing volume, case B could have greater power influence over its suppliers and more easily urge them to meet standards (+) | **GM-B4:** Case B had relatively weaker VOL, and a lower $C_u$ and a larger slack capacity, which led to certain waste and affected productivity.<br>**GM-B5:** Case B's MOD provided strong support for its recycling and reuse efforts (e.g. using recycled aluminum and plastics), ensuring the recycled parts can be efficiently accommodated by current assembly (++). Despite not being rolled out on a large scale, this initiative had been used across different models, supported by its MIX (+). External suppliers and 3PL played important role in such initiatives due to uncertainties in returns, requiring strong SUP (++) and LOG (++). |
| ***Case C***   | **GD-C1:** Case C had also introduced a series of new-energy models on the market; despite not being the quickest of the three, the firm has used all three key technologies (EVs, fuel cell & PHEV), which was enabled by its NEW (++). It also required strong NET (++) to quickly find/switch to competent suppliers for the new models, which created some challenges for the case firm. Existing suppliers provided necessary support, with SUP (+).<br>**GD-C2:** Likewise, those simple, frequent, ongoing modification of existing models for environmental improvement in case C also required strong MOD (++) and the support of internal MIX (+). The external SUP was also needed to cope with various changes (+).<br>**GD-C3:** Any substantial changes for sustainability considerations also required case C to have strong MOD and MIX (++). Case C sometimes also experienced difficulties in finding competent external suppliers who can meet its requirements, but with less extent compared to case B. | **GP-C1:** Case C's sustainable material purchasing is also related to its green design initiatives. Similarly, its internal MOD and MIX facilitated quick modification and efficient substitution with sustainable materials/parts across different product range (++). Case C's suppliers can largely satisfy its green purchasing requirements, enabled by its SUP (++). However, the firm in some cases needed to find alternative suppliers, which requires its NET (+).<br>**GP-C2:** By contrast, case C had also set strong standards and monitoring of its suppliers' environmental performance. Its suppliers also had high compliance rate, which was enabled by case C's strong SUP (++) and certain degree of fear of losing business with case C, supported by NET (+).<br>**GP-C3:** Likewise, case C's new green supplier selection can be successfully done with the strong support of its NET (++), but was not as efficient as Case A.<br>**GP-C4:** It is also discovered that when case C had large purchasing volumes, its green purchasing initiatives can be supported, either for the green materials purchased or the environmental standards imposed onto the suppliers. The case firm could have greater influence onto its suppliers and easily request them to comply with their environmental substandard (+) | **GM-C1:** Likewise, no obvious relationship was detected between case C's green factory initiatives and its supply chain flexibility (∅).<br>**GM-C2:** Case C had also successfully installed new technologies (e.g. new platforms) for process improvement. Its strong MOD facilitated smooth and effective transitions (++). There were also frequent small improvement initiatives, requiring strong MOD for effective modification. Its suppliers could promptly cope with the changes, supported by its SUP (+). Lean practices were evident in the firm, which required the support of flexible suppliers, i.e. SUP, especially for JIT/JIS supplies (+).<br>**GM-C3:** Case C's platform technologies and modular strategy had improved its MIX, which had in turn led to improved production efficiency (++).<br>**GM-C4:** Case C strived to achieve high $C_u$ and could largely achieve economies of scales in production, thereby reducing waste and improving productivity.<br>**GM-C5:** Case C had also started recycling and reuse (e.g. refurbished engines). Despite only being on trial stage, strong MOD were required to ensure smooth adoption of these recycled parts in existing production line (++). Besides, its MIX ensured that the refurbished engines can be installed in different models (+). External suppliers and logistics were also the key plays for the successful recycling and reuse effort, requiring strong SUP (++) and LOG (++). |

Note: ++ Strong Positive relationship: The studied flexibility reveals a very clear and direct positive effect on the success of the GO strategies adopted by the case firm. In other words, this flexibility is a critical enabler, without which the case firm cannot successfully adopt its GO strategies; + Positive relationship: The studied flexibility can positively support the GO strategies adopted by the case firm. However, it is not a critical enabler that the case firm must have in order to achieve the successful adoption of its GO strategies; ∅Unclear relationship: There is no obvious effect on between the studied flexibility and the GO strategies adopted by the case firm.

Example: GD-A2, case A reveals that they can make minor and frequent modifications of existing models for sustainability considerations. They were able to do so because they have a strong modification flexibility in place which enabled them to modify product features effectively without affecting production efficiency and cost. Some of the modifications in GD were shared across different product ranges, requiring the firm to have mix flexibility support in production. Despite suppliers are not directly involved in the modifications in GD, supplier flexibility was also needed to cope with any changes required by the focal firm case A.

## 4. Case analysis towards an integrating framework

### *4.1 GD and SCF*

All three case firms have implemented GD initiatives (see Table 2). These initiatives can be further categorized into three types, based on the degree of innovativeness in GD, i.e., 1) small/minor and frequent modification of existing models for environmental improvement, 2) substantial changes, including for example, lightweighting structural design, and energy-efficient engine/powertrain systems, and 3) radical changes, in this case, electric vehicle (EV), plug-in hybrid vehicle (PHEV), etc. Through our cross-case analysis, we found that all three case firms' GD efforts require the support of certain internal and external SCF. For example, when substituting certain car parts with more sustainable or recycled materials, all the case firms need strong MOD in place to quickly perform the changes without affecting production time and incurring additional cost. The mix flexible manufacturers (case A and case C) can proactively make quick and significant alterations to their product portfolios to launch different types of energy-efficient vehicles on the market without significant plant alternations or expansions. We analyze the case findings (see Table 4) and depict them in Figure 2 below,

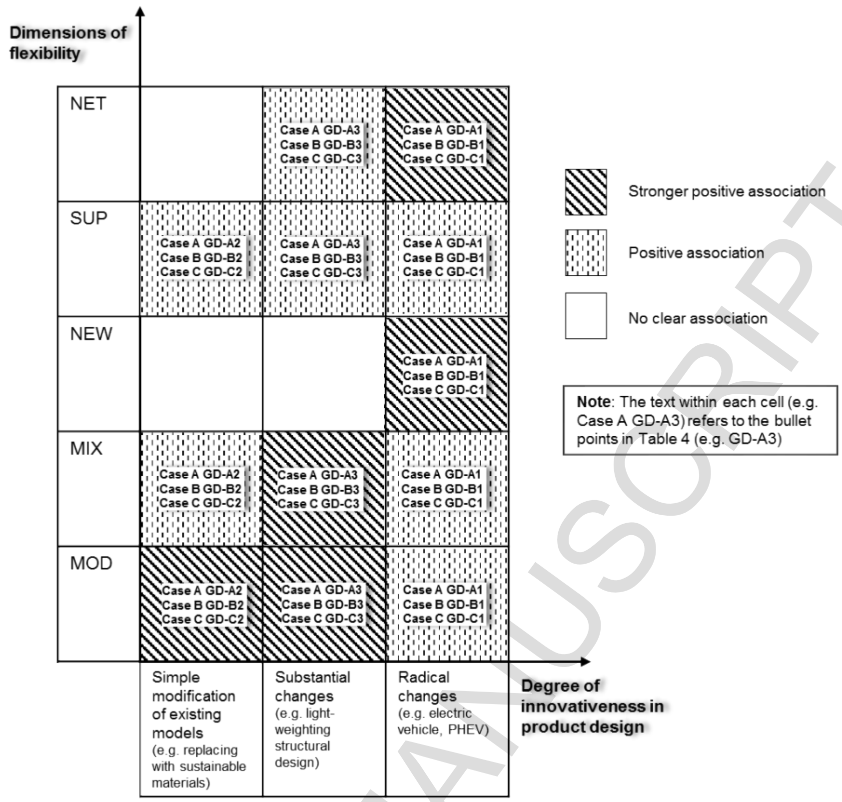



**Figure 2 Effects of flexibility on green design**

As revealed in Figure 2, when the three case firms only modify minor features of their existing models to improve energy efficiency and reduce environmental impact in their GD projects, MOD plays a more important role than other flexibility dimensions. For example, company C made over 20 small modifications (e.g., aerodynamic body shapes, side mirrors, and door handles) on one of its better selling models to lower fuel consumption. Because of case C's strong MOD, it ensured the modifications were quickly and efficiently performed without affecting its normal production. MIX is not strongly needed in this case, but if these modifications are shared across different models, the case firms will need the support of MIX as it can ensure compatibility and production efficiency. Externally, the suppliers are constantly informed and communicated with any small changes. Although all the three case firms have similar level of SUP (see Table 4), case A and C that have relatively stronger SUP have experienced fewer problems when making frequent and small modifications as their suppliers are more responsive and capable to meet their various requirements.

However, when the case firms make substantial changes in their products for environmental improvement, then both strong modification and mix flexibility are required in order to quickly perform the changes and launch these models on the market. According to the plant managers, without strong MOD, they cannot make efficient changes and modifications, and without strong MIX, they cannot produce these mixed models with changes in a timely and efficiently manner. Case company A for example, has created a system that allows any volume-production model to be equipped with any type of powertrains with no additional engineering effort. Its MOD has since been greatly enhanced, as they can easily modify their existing models to equip various types of powertrains. Also, they have improved their MIX, as the new system can enable the firm to efficiently share the same powertrain system in wider ranges. As such, case A has successfully developed a series of green models ranging from conventional to EVs. Externally, although the substantial changes do not occur as often as those minor ones, all the case firms need to maintain an adequate level of external SUP and NET. This is because the suppliers still need to make flexible and fast response to the buying firms' requests, and if the existing suppliers cannot satisfy their requirements, alternative suppliers will be quickly sought after.

Finally, our observation suggests that when the case firms make completely new offerings (e.g., EVs, PHEVs, etc.) on the market to compete, NEW appears to play a more important role than other flexibility dimensions, as is evidenced in all the projects (12 projects focusing on green new designs were observed in our case studies). This is because, for instance, case A has a strong NEW (see Table 4), and when the firm focused on developing EVs to complement its combustion-engine offerings, its strong NEW ensured a quick and effective design and launch. As note by one chief manager, "…we have a stronger design team and the capability we have today has enabled us to come up new better designs at a much faster pace in order to occupy the market." However, in this particular industry, the design and launch of new vehicles also requires the modification of vehicle structure and shapes, as well as creating an EV/PHEV product portfolio. Thus, both MOD and MIX are also required to ensure a smooth introduction of the new series, as explored in all three cases' projects. Externally, existing suppliers must provide necessary support for this initiative by making flexible adjustment according to the new requirements. However, as discovered in the case firms, approximately over 90% of the time, these radical changes in design can lead to the selection of new suppliers for new components. Case A that had a relative stronger NET than case B and C did not reveal any substantial problems in new supplier selection for their new designs; whilst in the latter cases, especially case B did experience some delays and challenges in seeking new competent suppliers.

### *4.2 GP and SCF*

The GP initiatives adopted by the three case firms can be summarized into three types, i.e., 1) purchasing sustainable materials and components, which is associated with the design of green products, 2) supplier certification and monitoring, including setting environmental requirements on existing suppliers (e.g., ISO14000 series certifications and the case firms' own standards), as well as the associated training, auditing, and monitoring, and 3) green suppliers selection, i.e., evaluating and establishing new partnerships with potential suppliers who can meet the case firm's green requirements. According to these three types of GP initiatives, we summarize our cross-case findings in Figure 3 below.

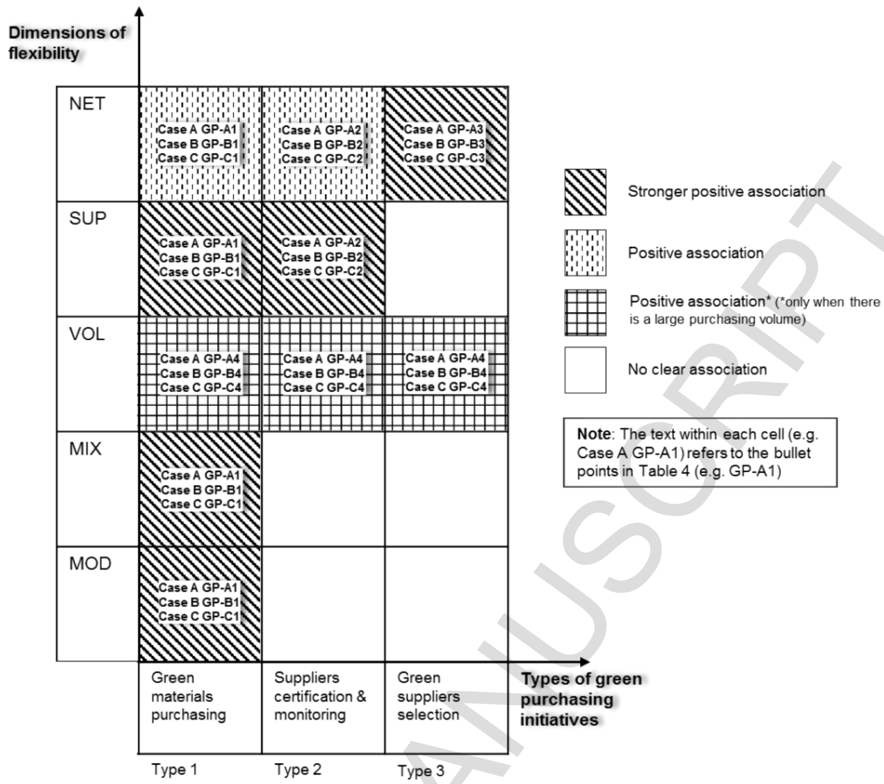



**Figure 3 Effects of flexibility on green purchasing**

Regarding type 1 green purchasing, all the projects (15 observed in our case studies) required strong MOD at their plants to modify their existing products with more sustainable materials and components in an efficient and cost-effective manner. For instance, case A had successfully substituted the bumpers across many existing models with 100% recycled plastics, which was supported by its strong MOD. Similar associations were discovered in case B and case C, for example when they tried to adopt carbon fiber materials, recycled metal and plastics. As a result, type 1 green purchasing initiative in the three case firms was facilitated as they have strong MOD at their plants. Besides, it was found that in all our case firms' green material purchasing initiatives, the stronger MIX the plants have, the wider product mix can be manufactured with more environmentally-friendly parts and materials without affecting productivity and cost. In most cases, as the degree of green product mix increases, the demand for sustainable materials and components also surges. Therefore, MIX can also play a significant role in green materials purchasing. However, MOD and MIX did not present strong impacts on the other two types of GP initiatives, i.e., supplier certification & monitoring, and green supplier selection. Unlike making modifications and altering the mix of existing product sets, the introduction of new green products encompasses intensive changes to product configurations and characteristics. Yet, due to the current mark share and the production volumes of these new types of vehicles, NEW did not reveal a clear association with any types of GP initiatives in our case firms.

Turning to external SCF, as case firm A had a stronger SUP, it could more easily request their suppliers to supply sustainable materials and parts, and/or meet their environmental requirements than case B and C. The suppliers of case A could efficiently accommodate these specific requests and provide timely supplies to case A's plants. By contrast, Case B and C's GP initiatives was not as successful as case A's. They could also request their suppliers to meet their environmental standards (type 2) and supply green materials (type 1), but it was less efficient than case A due to their relatively weaker SUP. Therefore, our observations suggest that a strong SUP can facilitate both type 1 and type 2 GP initiatives.

In addition, as noted by one purchasing manager, "[the existing suppliers] they can satisfy our changing requests, because either they have strong ties with us or they do not want to lose the businesses with us". His point offers useful insights and coincides with our findings that, GP can also be facilitated by NET. When it comes to type 1 and type 2 GP, a lot of the existing tier-1 suppliers could sense the pressure of potentially losing their contracts with the case firms and thus strived to follow the various environmental standards imposed by the buying firms. Although the case firms do not usually use their NET as a weapon to 'threat' their suppliers, a stronger NET signifies a greater choice of available suppliers for the buying firms. Therefore, a strong NET, to certain extent, can also contribute to type 1 and type 2 GP.

Our observations also reveal that, in our case firms however, if the existing suppliers could not supply the requested green parts/components or failed to comply with the environmental requirements, the automakers had to look for alternative new suppliers, i.e., type 3 GP. It subsequently required the case firms to have strong NET in place, with which they can deal with the inflexible suppliers or swiftly change to alternative suppliers without incurring extra cost and delays. Case A and C for example, encountered no major problems for their green supplier selection, as they were located in highly-clustered industrial zones where there were many available environmentally-qualified suppliers. However, case B was located relatively far away from these industrial clusters, bestowing it with less NET. The firm had thus encountered some delays in sourcing some key components for its newly developed hybrid models, as they could not find competent suppliers locally who can make the requested components. "…it is really painful when you don't have many choices [enough NET] …and it costs!", said one purchasing manager.

Worth mentioning, with regard to volume flexibility (VOL), we initially anticipated that frequent volume variations in production may affect supply stability and thus, affecting the efficiency of GP and partnership with external suppliers and logistics providers (Sezen, 2008). Nevertheless, we did not find strong evidence on frequent large volume changes for the models produced in our case firms. Although there were monthly, weekly, and daily volume variations, as one manager put it, "the flexibility we have can enable us to cope with these changes". As revealed in the cases, the only possible association between VOL and GP was when the case firms had significantly increased their production volume with sustainable parts and components, reaching economies of scale in production. As a result, the case firms had to buy more sustainable materials and parts, facilitating type 1 GP. On the other hand, large purchasing volume also means greater bargaining power and influence over suppliers. Therefore, the case firms can impose stronger environmental requirements on their suppliers (regardless of new or existing ones) to meet their sustainable objectives, facilitating both type 2 and 3 GP initiatives.

### *4.3 GM and SCF*

The three case firms have implemented a variety of GM initiatives to target their environmental problems at plants. These initiatives can be broadly classified into three major categories based on their strategic orientations (Hsu et al., 2016), i.e., 1) building green factories, including for example using renewable energies and LED lighting, collecting rain water, and isolating factory noise, 2) production process improvement, including for example process optimization for quality, productivity, and efficiency improvement as well as pollution prevention and control technologies for hazardous waste, water pollution and greenhouse gas emission reduction and elimination, and 3) resource conversation through reuse, recycling, refurbishing and remanufacturing initiatives. The managers often described these initiatives as “reverse logistics” or “closed-loop” supply chains, in which the end-of-life products/parts are taken back to the production system.

When the case firms’ GM orientation is towards building green factories, we found no obvious links between SCF and their green factory initiatives (22 such initiatives have been identified in our case studies). These initiatives are typically one-off projects and focus mainly on factory buildings and facilities, which do not directly relate to production activities. For example, replacing with LED lights and installing solar panels to save energy did not reveal a clear association with either internal flexibility or any external ones. However, if the orientation is towards production process improvement or resource conversation, possible associations are revealed as depicted in Figure 4.

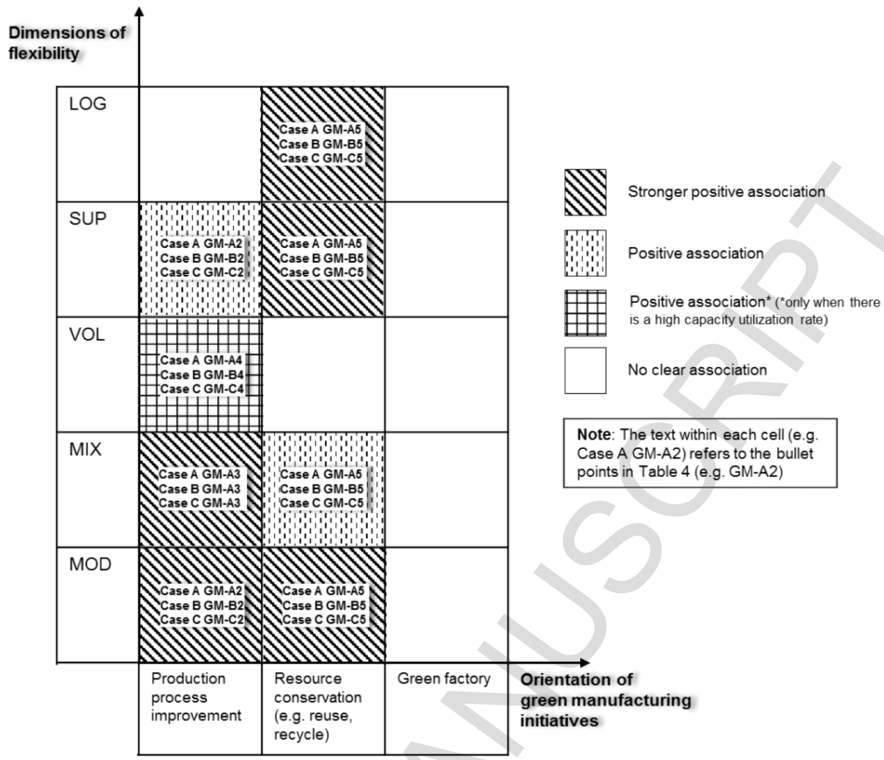



**Figure 4 Effects of flexibility on green manufacturing**

First, with regard to production process improvement, our observations suggest that strong MOD is required to cope with the changes in production process and new technologies. This association was detected in all the process improvement projects discovered in our case firms. For example, case A had successfully installed an automatic serial production line in its stamp shop to improve production efficiency, reduce energy consumption, and insulate noise. The firm's strong MOD ensured that the product models were fully integrated and compatible with the new production line, and the transition did not result in major interruptions to its production. Similarly, in cases B and C, the newly upgraded paint shop had significantly reduced water consumption and VOCs as well as chemical and energy usage. The modification and changes in the whole painting process were also facilitated by internal MOD in these factories to ensure a smooth transition.

In addition to the "big-step" process improvement, the continuous, small, and gradual improvement, and especially the lean paradigm advocated in the automotive industry also require the case firms to have strong MOD to make frequent and swift modifications/changes at plants. As quoted from one production manager, “no matter big or small [process improvement], we got to have the flexibility in place to make quick changes without affecting our daily production”, and “it’s a very important factor for making successful improvement in our factory”, said another.

The advantage of MIX is its capability to create a wide range of product choices to satisfy various customer demands. Intuitively, we anticipated that a wider product mix would tend to lower the efficiency of production, especially when a large number of discrete products are manufactured. Yet, the findings in the three case firms suggest the opposite. The prevalence of platform technology and modularization strategies in this specific sector bestows the automakers strong MIX. All the three case firms were able to flexibly produce a number of different models using the same platforms at their plants. As a result, greater production efficiency can be achieved. It was found in our case observations that the more MIX the case firms had the more production efficiency and lowered unit cost can be achieved when producing a large mix of models within their factories. Case A for instance, has tried to improve its production process by adopting a modular transverse matrix, which has enabled the company to integrate all the relevant drive systems to one model series – from conventional to EVs, thus reducing its cost and energy while maintaining a high level of production efficiency. In this respect, process improvement in GM can be facilitated when there is a strong MIX at plants. As mentioned by one production manager, “our modularization strategy has dramatically improved our ability to offer a greater product mix at much lower cost, and at the same time, enhanced our production efficiency.”, and another “…because of this [MIX], the improvement in our factories can be easily rolled out across many product ranges…”.

As discussed with the plant managers, VOL could affect GM. Building volume flexibility may mean that additional slack capacity is maintained. For example, significant waste and higher cost per unit could occur when case B could not fully utilize its capacity at certain plants. Besides, frequent changes in output volume can affect productivity and efficiency to a certain degree. However, in our case firms, we did not find frequent large volume variations in their production. In fact, each case firm strives to maintain a relatively stable production and output rate. A high capacity utilization rate is often one of their performance targets. When the production volume is large and stable, a high capacity utilization rate can be achieved. As a result, the case firms A and C could normally realize economies of scale and production efficiency, thus lowering their waste and cost. In this regard, VOL can support GM. Worth mentioning, within our case firms, the VOL is closely related to MIX. The factories could maintain a relative stable total output volume by adjusting their model mix for production, which was ensured by strong MIX.

Externally, as the case firms constantly make gradual improvement, their suppliers need to be flexible enough to cope with the small changes and make quick response and deliveries. For example, when the case firms had embraced the lean paradigm and adopted just-in-time (JIT) and just-in-sequence (JIS) deliveries to improve their production efficiency and minimizing waste for example, external suppliers would need to make prompt and flexible production and deliveries to support the buying plants' operations. As one manager said, "…we certainly need their support to achieve our goals [process improvement]", "…if they are not as flexible as we are; it will be very difficult [towards process improvement]". Thus, SUP can also provide support for certain production process improvement at our case firm's plants.

Next, when a firm's GM effort is orientated towards resource conservation, the story is a little different. Similar to process improvement, findings in all our case firms suggest that strong MOD are required at the plants in order to effectively modify the existing product features to equip with the refurbished and remanufactured parts/components (e.g., engines and water pumps). Over 90 percent of these resource conservation efforts in our case firms were not for a single model but were shared across different product ranges, supported by the case firms' MIX. Besides, in the three case firms' recycling and reuse initiatives, the recycled parts/materials would go to their suppliers first, where they got recovered before being reused in car assembly. Our observations reveal that these initiatives in all our case firms would require strong support from the suppliers and the logistics providers as there are high complexity and uncertainty in product returns. The case firms, their suppliers, and logistics providers had to work very closely to deal with the recycling initiatives more effectively. For example, case A's recycled bumper plastics program required not only strong internal MOD, but also the effective coordination from external suppliers, recyclers, and logistics providers. These external partners need to be flexible enough to cope with these uncertainties in recycling and make timely production and delivery to the case firm. "Recycling, remanufacturing, and refurbishing are getting more and more important in this sector, but would require strong collaboration both internally and externally, especially with industrial partners…" said one plant manager. "…you can't do much without the support of our suppliers and logistics partners; it's not just about yourself being flexible, it is about the whole network that functions together…" said another logistics manager. Lastly, we found no strong evidence on how NEW and NET might affect GM in the three case firms.

### *4.4 An integrated framework*

Based on the above analysis, we have developed the following theoretical framework to usefully integrate the key constructs of GO and SCF as well as indicating their relations.

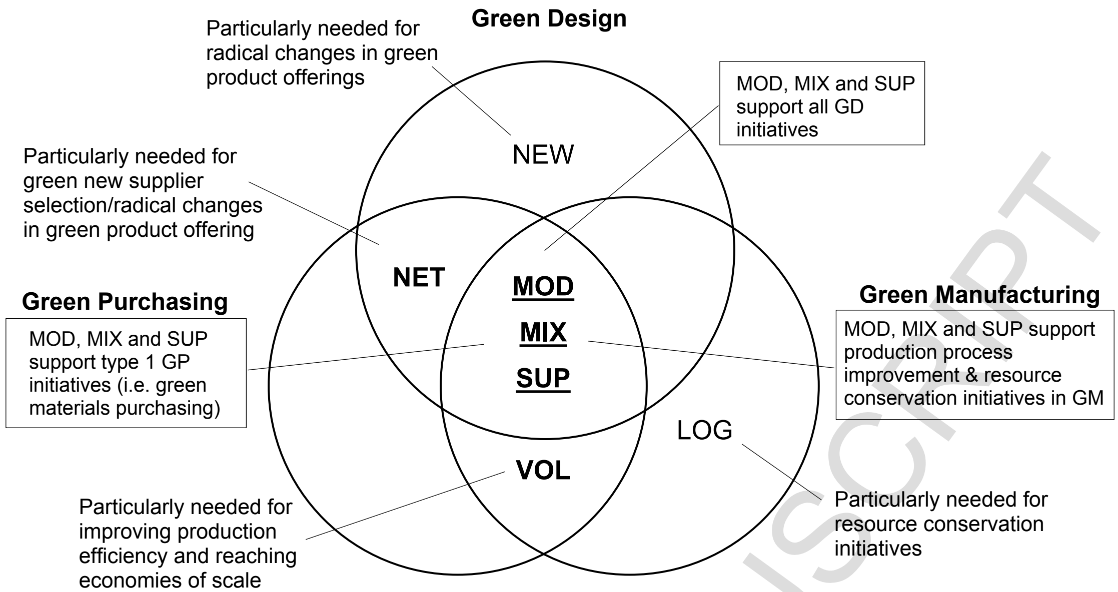



**Figure 5 An Integrating Framework**

As Figure 5 illustrates, MOD, MIX, and SUP are all required for the successful adoption of certain GD, GP and GM initiatives. NET is critical to GD and GP especially when these initiatives lead to the selection of new suppliers. NEW is particularly required for GD when there are radical changes in product offerings. VOL, closely linked to MIX in this particular industry, can facilitate both GP and GM initiatives when it helps the focal firms to achieve production efficiency and economies of scale. LOG is particularly required for GM due to the high complexity and uncertainty in recycling and product returns. In addition, our case analysis indicates that the magnitude of these SCF dimensions for GO adoption varies depending upon the *degree* of innovativeness in the GD initiatives, the *types* of GP initiatives, and the *strategic orientation* of GM initiatives being adopted.

## 5. Discussion

Prior research has largely examined the link between lean and green, however limited attention has been paid to the potential effects of SCF on GO. Our case analysis indicates very clearly that

SCF can be a vital organizational capability contributing to the successful adoption of GO strategies, as previously speculated on the possible capability-strategy linkage (Morash, 2001; Liu et al., 2016). Consistent with previous research (e.g., Fantazy et al., 2009; Malhotra and Mackelprang, 2012; Sánchez and Pérez, 2005), our findings also support the claim that not all flexibility dimensions contribute equally to a firm's performance, and a strategic 'fit' should be explored between SCF and the expected outcomes (Gligor, 2018). We extend that account of studies to the context of environmental management. Our in-depth case studies can contribute to the theoretical understanding of the complex SCF-GO relationship by identifying the essential theoretical constructs and indicating their lower layer interactions in a systematic way. This provides a robust foundation for the continuing growth of this knowledge area of increasing importance.

Specifically, for GD, internal modification, mix, new product flexibility, and external supplier and supply network flexibility play a more important role in its successful adoption. However, their importance varies depending upon the degree of innovativeness in different GD initiatives. This finding is consistent with Norman and Verganti's (2014) study, in which they argued that, as the degree of innovation changes, firms may require different types of flexibility to cope with the associated challenges in order to effectively and efficiently produce and manufacture the products to satisfy varying customer demands.

For GP, internal and external SCF play divergent roles with regard to different types of GP initiatives. In particular, for type 1 green material purchasing, internal modification, mix, and external supplier flexibility play a more significant role than other SCF dimensions, whereas for type 2 and type 3 GP, supplier and supply network flexibility are mostly needed. This finding is consistent with prior research (Malhotra and Mackelprang, 2012; Dubey et al., 2018), as strong supplier flexibility can ensure that the suppliers can flexibly cope with any changes and satisfy the stringent environmental requirements set by the buying firms. Moreover, this finding may also coincide with prior research on power in buyer-supplier relationships (e.g., Benton and Maloni, 2005; Reimann and Ketchen, 2017). When the buying firms have a stronger NET, which resembles a greater power influence over their suppliers, the supply chain members synthesize processes and strategies to achieve better performance. This is also the case when the buying firms have a large purchasing volume, which can bestow them greater bargaining power and influence over the supplier's environmental performance.

GM initiatives in the automotive firms are very complex but can be generally categorized into three major categories based on their strategic orientations (Hsu et al., 2016). Internally, if the orientation is towards production process improvement, modification and mix flexibility is regularly needed, especially for lean manufacturing. The external suppliers often play a more supporting than critical role in this matter. VOL may also play a positive role in GM especially when it helps the focal firm to improve capacity utilization, productivity, and economies of scale. This finding may provide further support of Moattar Husseini et al.'s (2006) work, in which they explored the potential link between volume flexibility and JIT production. Consistent with prior research (e.g., Fredriksson, 2006; Liao et al., 2013), platform and modularization strategies in the automotive sector can offer the case firms greater MIX to manufacture a wider range of products to satisfy their customers, while at the same time improving productivity and maintaining high VOL. In particular, the link between volume and mix flexibility as well as their impact on productivity and efficiency for GM corroborate the findings of Barbosa et al. (2017), who explored the effects of production modularization on production volume and efficiency. Another strategic orientation in GM is focused on resource conservation through recycling, reuse, refurbishing, and remanufacturing. This orientation requires firms to possess strong modification flexibility internally and strong collaboration and flexibility from external suppliers and logistics partners due to the complexity and uncertainty in product returns (Guide, 2000).

By synthesizing our findings, our integrated framework indicates a theoretical model to developing lasting SCF capabilities for GO strategy adoption (see Figure 5). This model suggests managers may have to begin with developing three fundamental dimensions, i.e. MOD, MIX, and SUP for GO strategy adoption. Then, they may gradually improve their NEW for GD, especially when radical changes will be involved in their green product offering. Managers should develop their NET for GP when seeking new green suppliers, and LOG for taking resource conservation efforts in GM. The improvement and accumulation in other flexibility dimensions, especially MIX, may eventually increase VOL, which are beneficial to certain GO initiatives, such as type 1 GP and process improvement programs in GM. As proved by Ferdows and De Meyer's (1990) sand cone model, such an approach will be extremely useful for improving our theoretical understanding of the role of SCF in GO adoption and at the same time can provide a clear path for managers in pursuing their sustainability objectives. However, our study was only conducted in the automotive sector. The developed framework may not hold true in other contexts. For instance, the GM initiatives are very complex in this particular industry. The finding regarding MOD, MIX and SUP and GM may only be valid in this automotive firms where JIT and lean operation is a common practice. Likewise, platform and modularization strategies are widely adopted in this sector, which can offer the automakers greater MIX to be able to manufacture a wider range of products while at the same time improving productivity and a high level of VOL. This particular association between MIX and VOL as well as their impact on GM may not be the same in other contexts.

In practice, as Fantazy et al. (2009) put forward, managers should think carefully about which type of flexibility they develop and possess, and they should not increase all dimensions of flexibility in their power. We echo this assertion that managers should consider carefully which type of SCF they need when pursuing their sustainability objectives, and then strategically plan, develop, and deploy the appropriate level of SCF. This argument is pragmatic, as for example, Gosling et al. (2010) studied how buying firms can configure their supply networks to achieve SCF, and argued that it is possible to gain an appropriate level of SCF by maintaining a pool of suppliers in different categories, including framework agreement suppliers, preferred suppliers, and approved suppliers. Further, managers may also need to balance the internal and external flexibility, and seek a perfect 'fit' between them. As Gligor (2018) suggested, firms with perfect buyer-supplier flexibility fit perform best. Managers should carefully assess their level of flexibility and make the necessary adjustments to achieve fit."

**6. Conclusion**

The role of SCF in the sustainability agenda has for the most part been overlooked in the literature. This paper takes a focal-firm perspective and makes an important contribution to address this missing link. Theoretically, it furthers our understanding the role of SCF as an important organizational capability in the successful adoption of GO strategies. In practice, these results can help managers understand what dimensions of SCF are more important for specific green operations and accordingly, they can proactively develop and deploy appropriate flexibility for their sustainability objectives by for example configuring effective supply networks. As an anonymous reviewer recognized, the results and implications of our study seem quite vivid as it is fully rooted in reality (i.e. actual cases) - quite a number of studies on GO and green supply chain management seem to try catching clouds mainly because they are not rooted in reality but strongly reply on theory-likes. From this point of view, readers from academia and practitioners would benefit a lot from our case studies, and this paper will make a meaningful contribution to the literature.

Despite making an important contribution to knowledge, the study is exploratory and has several limitations. First, our study is only conducted with three focal automotive firms. It helps us to maintain a focused research setting, but may lead to a narrowed SCF perspective. The case study was conducted in the automotive sector, which may also create biases when we are trying to directly translate the findings beyond this sector. The case companies that were selected were also more advanced as evidenced by their inclusion in the Dow Jones Sustainability Index. Non-exemplary or less sustainable organizations may challenge the validity of the findings. Further study, particularly through large-scale empirical study in a wider contextual setting, is strongly recommended to continue growing this important knowledge area and to generate recommendations that can be directly applied in a wider contextual setting.



**References:**

Barbosa, L.M., Lacerda, D.P., Piran, F.A.S. and Dresch, A. (2017), "Exploratory analysis of the variables prevailing on the effects of product modularization on production volume and efficiency", *International Journal of Production Economics*, Vol. 193, pp. 677–690.

Barney, J. (1991), "Firm resources and sustained competitive advantage", *Journal of Management*, Vol. 17, pp.99–120.

Benton, W.C. and Maloni, M. (2005), "The influence of power driven buyer/seller relationships on supply chain satisfaction", *Journal of Operations Management*, Vol. 23 No. 1, pp. 1–22.

Beske, P. and Seuring, S. (2014), "Putting sustainability into supply chain management", *Supply Chain Management: An International Journal*, Vol. 19 No. 3, pp. 322–331.

Blome, C., Schoenherr, T. and Eckstein, D. (2014), "The impact of knowledge transfer and complexity on supply chain flexibility: A knowledge-based view", *International Journal of Production Economics*, Vol. 147, pp. 307–316.

Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A. and Benhida, K. (2016), "The integration of lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model", *Journal of Cleaner Production*, Vol. 139, pp. 828–846.

Cherrafi, A., Garza-Reyes, J.A., Kumar, V., Mishra, N., Ghobadian, A. and Elfezazi, S. (2018), "Lean, green practices and process innovation: A model for green supply chain performance", *International Journal of Production Economics*, Vol. 206, pp. 79–92.

Christmann, P. (2000), "Effects of 'best practices' of environmental management on cost advantage: the role of complementary assets", *The Academy of Management Journal*, Vol. 43 No. 4, pp. 663–680.

Christopher, M. and Towill, D.R. (2000), "Supply chain migration from lean and functional to agile and customised", Supply Chain Management: An International Journal, Vol. 5 No. 4, pp. 206–213.

Das, K. (2018), "Integrating lean systems in the design of a sustainable supply chain model", *International Journal of Production Economics*, Vol. 198, pp. 177–190.

Deif, A.M. (2011), "A system model for green manufacturing", *Journal of Cleaner Production*, Vol. 19 No. 14, pp. 1553–1559.

Devaraj, S., Vaidyanathan, G. and Misra, A.N. (2012), "Effect of purchase volume flexibility and purchase mix flexibility on e-procurement performance: An analysis of two perspectives", *Journal of Operations Management*, Vol. 30 No. 7-8, pp.509–520.

D'Souza, D.E. and Williams, F.P. (2000), "Toward a taxonomy of manufacturing flexibility dimensions", *Journal of Operations Management*, Vol. 18 No. 5, pp. 577–593.

Duclos, L.K., Vokurka, R.J. and Lummus, R.R. (2003), "A conceptual model of supply chain flexibility", *Industrial Management & Data Systems*, Vol. 103 No. 6, pp. 446–456.

Fantazy, K.A., Kumar, V. and Kumar, U. (2009), "An empirical study of the relationships among strategy, flexibility, and performance in the supply chain context", *Supply Chain Management: An International Journal*, Vol. 14 No. 3, pp. 177–188.

Ferdows, K. (1990), "Lasting improvements in manufacturing performance: In search of a new theory", Journal of Operations Management, Vol. 9 No. 2, pp. 168–184.

Fisher, M.L. (1997), "What is the right supply chain for your product? A simple framework can help you figure out the answer", *Harvard Business Review*, pp. 105–116.

Fredriksson, P. (2006), "Mechanisms and rationales for the coordination of a modular assembly system: The case of Volvo Cars", *International Journal of Operations & Production Management*, Vol. 26 No. 4, pp. 350–370.

Gligor, D. (2018), "Performance implications of the fit between suppliers' flexibility and their customers' expected flexibility: A dyadic examination", *Journal of Operations Management*, Vol. 58–59, pp. 73–85.

Gold, S., Seuring, S. and Beske, P. (2010), "Sustainable supply chain management and inter organizational resources: a literature review", Corporate Social Responsibility and

Environmental Management, Vol. 17 No. 4, pp. 230–245.
Gonzalez, P., Sarkis, J. and Adenso-Diaz, B. (2008), "Environmental management system certification and its influence on corporate practices: Evidence from the automotive industry", *International Journal of Operations & Production Management*, Vol. 28 No. 11, pp. 1021–1041.
Gosling, J., Purvis, L. and Naim, M.M. (2010), "Supply chain flexibility as a determinant of supplier selection", *International Journal of Production Economics*, Vol. 128 No. 1, pp. 11–21.
Guide, V.D.R. (2000), "Production planning and control for remanufacturing: industry practice and research needs", *Journal of Operations Management*, Vol. 18 No. 4, pp. 467–483.
Handfield, R., Sroufe, R. and Walton, S. (2005), "Integrating environmental management and supply chain strategies", *Business Strategy and the Environment*, Vol. 14 No. 1, pp. 1–19.
Hitt, M.A., Carnes, C.M. and Xu, K. (2016), "A current view of resource based theory in operations management: A response to Bromiley and Rau", *Journal of Operations Management*, Vol. 41 No. 10, pp. 107–109.
Hsu, C.-C., Tan, K.-C. and Mohamad Zailani, S.H. (2016), "Strategic orientations, sustainable supply chain initiatives, and reverse logistics: Empirical evidence from an emerging market", *International Journal of Operations & Production Management*, Vol. 36 No. 1, pp. 86–110.
Jin, Y., Vonderembse, M., Ragu-Nathan, T.S. and Smith, J.T. (2014), "Exploring relationships among IT-enabled sharing capability, supply chain flexibility, and competitive performance", *International Journal of Production Economics*, Vol. 153, pp. 24–34.
Klassen, R.D. and Angell, L.C. (1998), "An international comparison of environmental management in operations: the impact of manufacturing flexibility in the US and Germany", *Journal of Operations Management*, Vol. 16 No. 2, pp. 177–194.
Koste, L.L. and Malhotra, M.K. (1999), "A theoretical framework for analyzing the dimensions of manufacturing flexibility", *Journal of Operations Management*, Vol. 18 No. 1, pp. 75–93.
Koste, L.L., Malhotra, M.K. and Sharma, S. (2004), "Measuring dimensions of manufacturing flexibility", *Journal of Operations Management*, Vol. 22 No. 2, pp. 171–196.
Liao, K., Deng, X. and Marsillac, E. (2013), "Factors that influence Chinese automotive suppliers' mass customization capabilities", *International Journal of Production Economics*, Vol. 146 No. 1, pp. 25–36.
Liu, Y., Srai, J.S. and Evans, S. (2016), "Environmental management: The role of supply chain capabilities in the auto sector", *Supply Chain Management: An International Journal*, Vol. 21 No. 1.
Liu, Y., Zhu, Q. and Seuring, S. (2017), "Linking capabilities to green operations strategies: The moderating role of corporate environmental proactivity", *International Journal of Production Economics*, Vol. 187, pp. 182–195.
Lummus, R.R., Duclos, L.K. and Vokurka, R.J. (2003), "Supply chain flexibility: building a new model", *Global Journal of Flexible Systems Management*, Vol. 4 No. 4, pp. 1–13.
Malhotra, M.K. and Mackelprang, A.W. (2012), "Are internal manufacturing and external supply chain flexibilities complementary capabilities?", *Journal of Operations Management*, Vol. 30 No. 3, pp. 180–200.
Marchi, V.D., Maria, E.D. and Micelli, S. (2013), "Environmental Strategies, Upgrading and Competitive Advantage in Global Value Chains", *Business Strategy and the Environment*, Vol. 22 No. 1, pp. 62–72.

Merschmann, U. and Thonemann, U.W. (2011), "Supply chain flexibility, uncertainty and firm performance: An empirical analysis of German manufacturing firms", *International Journal of Production Economics*, Vol. 130 No. 1, pp. 43–53.

Miller, G., Pawloski, J. and Standridge, C.R. (2010), "A case study of lean, sustainable manufacturing", *Journal of Industrial Engineering and Management*, Vol. 3, No. 1, pp.11–32.

Moattar Husseini, S.M., O'Brien, C. and Hosseini, S.T. (2006), "A method to enhance volume flexibility in JIT production control", *International Journal of Production Economics*, Vol. 104 No. 2, pp. 653–665.

Morash, E.A. (2001), "Supply chain strategies, capabilities, and performance", Transportation Journal, Vol. 41 No. 1, pp. 37–54.

Norman, D. and Verganti, R. (2014), "Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change", *Design Issues*, Vol. 30, pp. 78–96.

Nunes, B. and Bennett, D. (2010), "Green operations initiatives in the automotive industry: an environmental reports analysis and benchmarking study", *Benchmarking: An International Journal*, Vol. 17 No. 3, pp. 396–420.

Reimann, F. and Ketchen, D.J. (2017), "Power in Supply Chain Management", *Journal of Supply Chain Management*, Vol. 53 No. 2, pp. 3–9.

Sánchez, A.M. and Pérez, M.P. (2005), "Supply chain flexibility and firm performance: a conceptual model and empirical study in the automotive industry", *International Journal of Operations & Production Management*, Vol. 25 No. 7, pp. 681–700.

Scavarda, L., F., Reichhart, A., Hamacher, S. and Holweg, M. (2010), "Managing product variety in emerging markets", *International Journal of Operations & Production Management*, Vol. 30 No. 2, pp. 205–224.

Seebacher, G. and Winkler, H. (2015), "A capability approach to evaluate supply chain flexibility", *International Journal of Production Economics*, Vol. 167, pp. 177–186.

Seles, B.M.R.P., de Sousa Jabbour, A.B.L., Jabbour, C.J.C. and Dangelico, R.M. (2016), "The green bullwhip effect, the diffusion of green supply chain practices, and institutional pressures: Evidence from the automotive sector", *International Journal of Production Economics*, Vol. 182, pp. 342–355.

Sezen, B. (2008), "Relative effects of design, integration and information sharing on supply chain performance", *Supply Chain Management: An International Journal*, Vol. 13 No. 3, pp. 233–240.

Shah, R. (2003), "Lean manufacturing: context, practice bundles, and performance", *Journal of Operations Management*, Vol. 21 No. 2, pp. 129–149.

Srai, J.S. and Gregory, M. (2008), "A supply network configuration perspective on international supply chain development", *International Journal of Operations & Production Management*, Vol. 28 No. 5, pp. 386–411.

Stake, R. (2006). *Multiple Case Study Analysis*. London: The Guilford Press.

Stevenson, M. and Spring, M. (2007), "Flexibility from a supply chain perspective: definition and review", *International Journal of Operations & Production Management*, Vol. 27 No. 7, pp. 685–713.

Teece, D. and Pisano, G. (1994), "The dynamic capabilities of firms: an introduction", *Industrial and Corporate Change*, Vol. 3 No. 3, pp. 537–556.

Thomé, A.M.T., Scavarda, L.F., Pires, S.R.I., Ceryno, P. and Klingebiel, K. (2014), "A multi-tier study on supply chain flexibility in the automotive industry", *International Journal of Production Economics*, Vol. 158, pp. 91–105.

Vengattil, M. and Chatterjee, L. (2018), "Tesla falls on Model 3 production delay, but analysts upbeat", 4 January, available at: https://uk.reuters.com/article/uk-tesla-production-stocks/tesla-falls-on-model-3-production-delay-but-analysts-upbeat-idUKKBN1ET1G2 (accessed 16 March 2018).

Vickery, S., Calantone, R. and Dröge, C. (1999), "Supply chain flexibility: an empirical study", *Journal of Supply Chain Management*, Vol. 35 No. 3, pp. 16–24.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002), "Case research in operations management", *International Journal of Operations & Production Management*, Vol. 22 No. 2, pp. 195–219.

Watts, C., Hahn, C.K. and Sohn, B.K. (1993), "Manufacturing flexibility: concept and measurement", *Operations Management Review*, Vol. 9 No. 4, pp. 33–44.

Williams, B.D., Roh, J., Tokar, T. and Swink, M. (2013), "Leveraging supply chain visibility for responsiveness: the moderating role of internal integration", *Journal of Operations Management*, Vol. 31, No. 7, pp.543–554.

Wong, C.W.Y., Lai, K., Shang, K.-C., Lu, C.-S. and Leung, T.K.P. (2012), "Green operations and the moderating role of environmental management capability of suppliers on manufacturing firm performance", *International Journal of Production Economics*, Vol. 140 No. 1, pp. 283–294.

Yin, R.K. (2018), *Case Study Research: Design and methods*, 6th ed, Sage Publications, London.

Zhang, Q., Vonderembse, M.A. and Lim, J.-S. (2002) "Value chain flexibility: A dichotomy of competence and capability", *International Journal of Production Research*, Vol. 40, No. 3, pp.561-583.

Zhang, Q., Vonderembse, M.A. and Lim, J.-S. (2003), "Manufacturing flexibility: defining and analyzing relationships among competence, capability, and customer satisfaction", *Journal of Operations Management*, Vol. 21 No. 2, pp. 173–191.

Zhu, Q., Shah, P. and Sarkis, J. (2018), "Addition by subtraction: Integrating product deletion with lean and sustainable supply chain management", *International Journal of Production Economics*, Vol. 205, pp. 201–214.

Zhu, Q., Sarkis, J. and Lai, K. (2007), "Green supply chain management: pressures, practices and performance within the Chinese automobile industry", *Journal of Cleaner Production*, Vol. 15 No. 11–12, pp. 1041–1052.

## Appendix: Interview Protocol and Instrument

**Project introduction**. Explain the aims of the study. Explain the key terms and clarify that we focus on the environmental aspect of the sustainability along the supply chain. Statement of confidentiality.

1. Background of interviewees and the case company

2. Overall sustainability strategy
   2.1. What are the main reasons of the case firm moving towards sustainable development

2.2. Rate the organization's sustainable performance

3. Green Operations
   3.1. Understand the case firm's green operations practices/strategies (e.g. product design, green technologies, environment protection programs, etc.)
   3.2. Successful stories of green operations, (e.g. environmental performance improvement, cost reduction, waste minimization, etc.)
   3.3. What are the major weaknesses/barriers for your company's green operations adoption?

4. Supply chain flexibility
   4.1. The case firm's overall supply chain flexibility and what it means for the company's success
   4.2. Explain the internal and external flexibility dimensions, and ask the candidates to describe and evaluate them (using the capability maturity model below with explanation).
      6. Initial (ad hoc)
      7. Repeatable (disciplined, under effective control)
      8. Defined (standard, consistent process)
      9. Managed (predictable process, with detailed measures and controls)
      10. Optimizing (continuous process improvement is enabled, piloting innovative ideas and technologies)
   4.3. Ask the candidates what the relationship/influence is between internal and external flexibility; can internal flexibility be achieved without the support of external flexibility. Any examples?

5. The relationships between supply chain flexibility and green operations
   5.1. Ask the candidates whether internal/external flexibility has any impacts on their green operations adoption, any examples?
   5.2. Alternatively, ask if there are any challenges for their green operations because of the lack of supply chain flexibility? How do they overcome these challenges?
   5.3. Ask the candidates to provide any examples if their green operations adoption is successful because they have an adequate level of supply chain flexibility in place.
   5.4. Taking the internal perspective, ask further questions on each modification, mix, new product and volume flexibility, and their impacts on any green operations adoption. Ask for examples.