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Bespoke supply-chain resilience: The gap between theory and practice

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Abstract

Recent research has documented that companies are pursuing a variety of strategies to enhance supply-chain resilience. This paper examines how managers actually think about resilience strategies, and then analyzes the relationship between operations, supply-chain characteristics, and the implemented strategies. We define a "Triple-P" framework that matches resilience strategies to supply-chain archetypes by examining **P**roduct, **P**artnership, and **P**rocess complexity based on interviews of senior supply-chain executives. These interviews revealed two major influencers of resilience strategy, that is, *Homogeneity of internal supply-chain processes* and *Integration with other actors in their end-to-end supply chains*. We found that the supply chains have different resilience requirements, have different ways to achieve resilience (which we conceptualize as "bespoke supply-chain resilience"), and face different obstacles to resilience. This study aims at initiating a dialogue between supply-chain scholars and practitioners to support more research for developing an effective supply-chain resilience strategy.

KEYWORDS

supply-chain archetypes, supply-chain integration, supply-chain resilience, supply-chain segmentation

Highlights

- The two perceived key influencers of a firm's approach to supply-chain resilience are "Homogeneity of internal supply-chain processes (intra-company)" and "Integration with other supply-chain actors (inter-company)."
- These influencers led to the identification of main clusters that we characterize as supply chain archetypes (Process-complexity, Partner-complexity, and Product-complexity) to form the basis of our Triple-P framework.
- While there are differences across these archetypes, there also are some core common challenges which resulted in some core common resilience strategies that were being used.

1 | INTRODUCTION

For the general public, the global COVID-19 pandemic that began in 2020 was a trigger to contemplate the concept of business resilience. However, for globally operating companies, this is just another instance, albeit with unprecedented severity, of an ongoing series of disruptions, leading many companies to prioritize resilience. A recent McKinsey & Company report (Alicke & Strigel, 2020) indicates that the frequency and magnitude of disruptions has increased over the past 20 years, suggesting that companies would be wise to already be planning for the next crisis.

Our discussion in this paper is not centered around the COVID pandemic, but rather around building supply-chain resilience in a broader sense. Our interviewed executives mentioned several earlier disruptions, such as the Japan earthquake and Thailand floods in 2011, as well as ongoing ones such as the US-China tariff escalation and the global climate crisis. These disruptions have led to changes in processes and structure for many globally operating companies.

Recent articles and research have focused on generic resilience strategies. Individual companies, however, operate within idiosyncratic environments and thus need more differentiated guidance. Company managers want to understand the specific obstacles that companies similar to theirs will most likely need to overcome. They will also benefit from an analysis that is granular enough to acknowledge the complex multidimensional issues that reside at the business unit or product group level, and that can lead to differentiated solutions. For example, a capital intensive, long product lifecycle, technology-intensive company may be better off achieving resilience by investing in an appropriate geographical footprint and technologies than by maintaining a large portfolio of suppliers.

The literature, notably Marshall Fisher's advocacy of "the right supply chain for the right product," alongside the contributions of many others, has discouraged one-size-fits-all thinking, and encouraged a supply-chain design that reflects the characteristics and strategic intent of the business. In that sense, the concept of a "bespoke supply chain," meaning a supply chain that is custom tailored for the business setting, is not new. Our research confirms that practitioners operate supply chains that they have tailored to their business setting, and that on occasion might even be bespoke to an individual SKU. We also have observed that even for a given SKU the supply chain is not static, as practitioners may dynamically update supply-chain configurations to match changes in conditions.

Many companies have struggled to achieve resilience during the COVID-19 pandemic, including ones that have historically managed to match the right supply chain to the right product using resilience strategies such as dual sourcing. We conducted surveys to discover what actions managers have taken to improve supply-chain resilience, then organized these findings into a "Triple P" framework (based on **P**roduct, **P**artnership, and **P**rocess complexity) that links operational attributes to resilience strategies.

This paper is organized as follows. The next section summarizes how previous operations management and supply-chain literature on responding to risk and uncertainty developed over time. That is followed by a section explaining our data collection and methodology. Our results are then presented in four parts, which explain the two primary influencers of resilience strategy, the obstacles, and the "Triple-P" framework of "bespoke supply-chain resilience." We conclude by discussing managerial implications, limitations of our study, and future research directions.

2 | SUPPLY-CHAIN TAILORING FOR RESPONDING TO RISK AND UNCERTAINTIES

Before the term supply-chain resilience became popular, supply-chain research had examined how firms should respond to risk and uncertainty of various types, ranging from known unknowns to unknown unknowns. This section gives a short overview of the primarily deductive theorizing literature on how to mitigate supply-chain risks most effectively. We include only representative articles since a comprehensive survey is not our focus.

Fisher's (1997) approach of differentiating between "functional" and "innovative" products is a popular framework that matches a company's supply-chain design to the level of demand uncertainty. The Fisher framework defined the need for custom supply chains to achieve "agility" in a context in which supply is matched with demand day to day via short-term adjustments: Long-term risk management was not addressed in this framework. Lee (2002) expanded on Fisher's framework by including supply uncertainty, and the strategies were expanded to include some long-term practices such as vertical integration, strategic alliances, and dual sourcing. The resulting 2×2 matrix (supply-chain design vs. level of product innovation) distinguishes between efficient, responsive, risk hedging, and agile supply chains for functional and innovative products. All four combinations in the matrix can be observed in the approaches adopted by companies to achieve supply-chain resilience according to Kamalahmadi and Parast (2016). Moreover, other frameworks developed based on practice-oriented

research reflect the premise that cost efficiency and velocity are not the only dimensions that make supply chains successful. The "Triple A" supply-chain framework adds that firms need to be agile, adapt, and align the interests of their company with other supply-chain actors (Lee, 2004). Recently, Cohen and Kouvelis (2021) have re-interpreted this framework on the basis of increasing uncertainties and disruption risks toward unknown unknowns, resulting in the notion of a "Triple A & R" supply chain in which robustness augments agility, adaptability becomes resilience through increased proactivity, and incentives are realigned to deal with the post-COVID "new normal." While these general frameworks can give companies a general direction for how to set up their supply chain, implementation will require more specific adjustments and flexibility to make the supply chain resilient.

As the previously mentioned papers state, one size does not fit all when it comes to finding the right supply chain for a product. Companies face different supply-chain characteristics/features, which lead to a different balance of weights and tradeoffs, resulting in different supply-chain strategies to pursue in practice. The supply-chain literature of the last two decades mapped out what factors should be considered when tailoring supply-chains. For example, Milner and Kouvelis (2005) were the first to study how three different demand distributions, namely standard distribution, Bayesian model, and Martingale model, affect the value of two types of flexibility: quantity flexibility in production or timing flexibility in scheduling. The example of Kanebo Ltd.'s cosmetic division is given, which tried to increase flexibility in order to cope with a large-scale expansion of its product portfolio. A point-of-sale information system for continuous sales updates and flexible filling lines that reduce production lead time by half gave Kanebo the needed flexibility. However, this type of flexibility might be too little or too much for other products or markets. For example, the cosmetics division of a consumer packaged-goods company studied by Saunders et al. (2021) also expected to require a large-scale flexibility initiative, but ultimately just making use of the data that were already available, that is, a micro dose of flexibility, was sufficient. Thus, the findings show that a strict dichotomy between efficient and flexible supply chains can lead to suboptimal matches between products and the appropriate supply-chain type. The Ketokivi et al. (2017) study also draws upon transaction-cost economics to support the idea of supply-chain tailoring based on the product and market characteristics. These authors found that production location decisions can be better explained by analyzing the interdependence between production and suppliers, the market, and development activities, then can conventional economic measures such as industry, size, or degree of value added. High interdependence can come from high coupling, high specificity, or low formalization.

Besides looking at supply-chain tailoring for a single product, there has been some research on configuring the supply chain for a portfolio of products. Federgruen and Katalan (1999) showed that a portfolio approach needs to be implemented, since adding time-sensitive products to a plant which produces time-insensitive products can be extremely costly. Cattani et al. (2010) studied what they termed "spackling strategies" that combine the production of standard and mass-customized products in a flexible plant. The option value from postponing the decision about what exactly to produce can outweigh the cost benefit of producing in a low-cost country. That idea was further developed by de Treville et al. (2017) who considered the cost of a capacity buffer held to meet peak demand for a time-sensitive product as an option cost incurred by that product ("option-based costing"), even if the leftover capacity is then used for time-insensitive products. Thus, there is full flexibility for the profitable time-sensitive product and the leftover capacity can be used for production of time-insensitive products in a high-cost region that is competitive with low-cost regions. Allon and van Mieghem (2010) introduced a similar idea of a tailored portfolio solution in the context of dual sourcing. Their concept of a base-surge sourcing allocation to align the ordering patters with the core competencies of each supplier also requires supply-chain tailoring. In addition, the example of Fendt, an agricultural machinery manufacturer, shows that an assembly line with variable rather than fixed takt times can enable a company to handle a high degree of customization while reducing labor inefficiencies and assembly line balancing complexity (Mönch et al., 2021).

A stream of literature based on real-options theory adds to the discussion of supply-chain resilience, by enlisting flexibility and hedging options to mitigate market uncertainties such as in price or demand (e.g., Huchzermeier & Cohen, 1996). De Treville, Schürhoff, et al. (2014) used real-options theory to quantify the exposure to evolutionary supply-chain risk and analyze how responsiveness through lead-time reduction increases profits. The study shows that the value of a lead-time reductions depends on how the supply risk evolves and whether the lead-time reduction permits a make-to-order strategy. When quantifying the benefits of short lead times for three companies studied, de Treville, Bicer, et al. (2014) found that the executives in all three cases struggled to choose the cost-optimal strategy as they underestimated the underlying costs of long lead times.

Another stream of deductive literature based on mathematical models provides normative recommendations concerning the design and management of supply chains

to mitigate risks and achieve efficiency. Sodhi and Tang (2012), for example, give a comprehensive overview of quantitative models for managing supply-chain risks, defining three approaches to risk mitigation that lead to 11 robust supply-chain strategies. Other papers use simulation-based analysis and modeling to examine the connection between supply-chain structure and resiliency. Kim et al. (2015) modeled and compared the resilience of four different supply-chain network structures and found that conventional metrics such as network density, average walk length, or centralization do not reliably predict network resilience. The results implied that intuitive assumptions such as, redundancy increases network resilience, might not always be true. Tan et al. (2020) also included network structural properties in their simulation-based study and found that cost-effective resilience improvements can come from either reducing accumulated backorders for which redundant structure or backup plant strategies work best, or from accelerating recovery through redundant capacity or backup supply-chain strategies.

Yin et al. (2017) described and analyzed how Sony and Canon moved away from their heavily automated processes as they realized that the efficiency gains provided were less than the cost of the resulting supply-chain inflexibility. Both companies introduced a cellular manufacturing concept called "seru" to increase responsiveness to cope with variable demand.

Another stream of literature—mainly driven by management consultants—identifies policies and strategies that can support resilience. Prominent examples for such reports are John et al. (2020) or Lund et al. (2020). These reports tend to describe companies deploying a specific strategy such as multi-sourcing as opposed to focusing more generally on strengthening partner relationships. Certain resilience strategies tend to recur among the prescriptions of the different reports, including (but not limited to) multi-sourcing, regionalization, increasing operational buffers in terms of inventory or capacity, and stronger partnering with other supply-chain actors. This led Cohen et al. (2021) to conclude that the basic toolkit for achieving supply-chain resilience is generally well understood by both academics and managers. The recommendations in these reports are often generic in nature, however, and do not consider the specific supply-chain characteristics of the company, thus leaving managers with an abstract idea of what an average company could do that lacks the precision that they need to address the resilience needs of their own supply chain. This practitioner-oriented literature invites an investigation of how situational factors should influence the choice of a resilience strategy.

The supply-chain literature describes the need for supply chains to be bespoke reflections of their market and product contexts. This theme has evolved over time and has now come into a new focus due to the rising levels of uncertainty. Our study aims at contributing to this theme by capturing a snapshot of what managers actually do to mitigate supply-chain risks and to increase resilience. Our paper focuses on what we can learn from observing what strategies companies have adopted and initiates a dialogue concerning what how what is done compares to what would be recommended by the supply-chain literature.

3 | RESEARCH DESIGN

We conducted interviews of supply-chain executives and organized the responses into a framework that identifies patterns in resilience strategies across companies and industries based on supply-chain attributes and product and market characteristics. The framework is derived from the reported main influencers of resilience strategies, the supply-chain environment (e.g., product, production, and technology), and the overall business strategy. The information is gathered at a supply-chain level instead of at a company level, as this is the level at which companies implement decisions. Due to the granular unit of analysis used in this study, detailed company information is required. However, this information needs to be understood from the strategic perspective of the company, especially when there are other types of supply chains that operate within the company. This typically requires a senior supply-chain executive to be the survey respondent (see Table 1 for details of the positions of our interviewees). Figure 1 summarizes our research approach and illustrates its exploratory nature.

4 | DATA COLLECTION

We used a mix of primary and secondary sources including interviews, focus groups, and consulting reports. Our emphasis was on semi-structured interviews with senior supply-chain executives. For the first round of interviews, we chose 12 companies in different industries that are regarded as leaders in the management of global supply chains. This included one of the first companies to structurally integrate a supply-chain risk management function into its organization. Each of the interviews in the first round was organized around three topics: (1) Organizational setup and supply-chain structure; (2) Business disruptions and major obstacles to becoming more resilient; and (3) Short-term counter measures and long-term

TABLE 1 Description of interview sample

No.	Industry	Position of the interviewees	Revenue[a] (bn€)	Employees (k)	HQ region	No. of SCs[b]	Divisions	Manufacturing sites	Countries
1	High tech/semiconductor	Senior director global logistic services	15	28	Europe	1	1	8	16
2	Chemistry/agriculture	Global senior director of E2E SC and customer experience Head of global planning excellence	20	34	Europe	2	4	86	150
3	Food/Nutrition	Head of operations	5	2	Asia	1	3	8	3
4	Automotive	VP for material control, transport, delivery assurance	100	134	Europe	1	3	31	140
5	High tech	Head of global risk management	45	76	America	2	4	0	95
6	Consumer goods	VP of global sustainability, safety, and global supply chain strategy	15	34	America	2	2	16	80
7	Industrial goods	VP—Global supply chain operations VP—Global supply chain commercial and residential solutions	15	88	America	2	2	155	150
8	Electronics manufacturing services	Chief procurement and supply chain officer Head of SC solutions Head of mechanical commodity procurement and supplier quality Head of supply chain for health solutions	20	160	America	2	2	100	30
9	Consumer goods	Chief supply chain officer laundry and home care	20	53	Europe	3	3	179	79
10	High tech	VP of procurement and global sourcing	25	60	America	1	7	0	95
11	Semiconductor	VP corporate supply chain	10	41	Europe	2	4	21	37
12	Apparel	Chief operating officer	10	17	Asia	1	3	0	50
13	Apparel	VP global sourcing and manufacturing VP global sourcing	10	77	America	2	3	700	42
14	High tech	Assistant chief of strategic planning	10	35	Asia	1	6	8	79
15	Semiconductor	Head of manufacturing division	10	6	Asia	1	3	8	75
16	Consumer goods	Executive VP of supply chain Europe	50	150	Europe	2	3	290	190
			*						

[a]Rounded.
[b]Considered in this research.

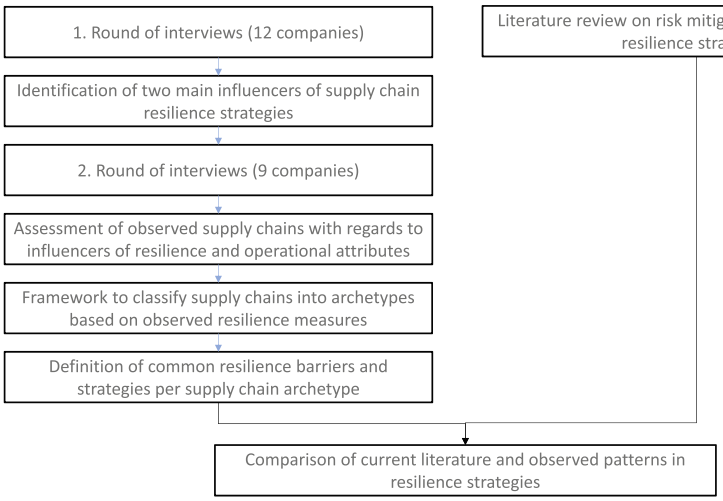

FIGURE 1 Research design

resilience strategies employed by the organization in response to the current pandemic crisis. We also asked for any supply-chain resilience related information that the executives deemed relevant to these topics (see interview questionnaire in Appendix C).

After the first round of interviews, we concluded that focusing on original equipment manufacturers (OEMs) was not sufficient to understand supply-chain resilience patterns. We also observed that companies within the semiconductor industry have remarkable built-in operations resilience due to the volatile nature of their demand, their short technology life cycles, and long lead times for receiving inputs from suppliers and fulfilling demand for customers. Therefore, our next set of interviewees included a contract manufacturer and other first tier suppliers as well as additional semiconductor companies. Moreover, for this second round we updated the interview guidelines to directly ask about the two influencers of resilience decisions that emerged in the first round (see Appendix C).

Table 1 details our data sources. We conducted 21 semi-structured interviews with 22 different top-level supply-chain executives from 16 global manufacturing companies well-regarded for business success in general, and their supply-chain practices in particular (seven of the companies have made Gartner's Supply Chain Top 25 in the last 4 years and four of the companies have been designated as World Economic Forum Lighthouse factories). Two of these interviews were conducted in writing to mitigate the language barrier for nonnative English speakers. All interviews were conducted by a committee of multiple members of our research team. Confidentiality concerns precluded recording the interviews. However, to maximize information capture, a dedicated note taker joined the researchers for each interview. The notes from each interview were immediately circulated among the interviewers for validation. The detailed notes generated in this way served as the basis for all further analysis.

5 | DATA ANALYSIS

As indicated in Figure 1 the research design is centered around two rounds of in-depth interviews with company executives. These interviews were used to observe reactions to the pandemic, measures to increase resilience, and the underlying reasons for choosing a specific strategy directly from the decision makers. The analysis of the interview data used a three-step coding approach (Charmaz, 2006; Patvardhan et al., 2015). First, open coding was used to identify and label statements of the respondents (Charmaz & Belgrave, 2007; Patvardhan et al., 2015). Thereafter, the first order codes were grouped and combined into superordinate concepts (axial coding). The different second-order concepts were integrated into two broader categories which form the basis for one cohesive framework (selective coding).

During the data collection and data analysis phase, we went back and forth between the categories and the resulting framework whenever new insights demanded it. For example, the first round of interviews identified two main drivers for complexity and influencers for supply-chain resilience strategies, which were then further analyzed regarding various characteristics after conducting the second round of interviews that were specifically tailored to these two influencing factors. This iterative process was stopped after 21 interviews, when little new information was being gained with regards to the two influencing factors by conducting additional interviews. The required sample size depends on the research question and the ability and experience of the researcher (Morse, 2000). Our 21 interviews fall in the range that Thomson (2010), based on a review of

100 papers, found to be adequate, which suggests that it is a reasonable benchmark for empirically grounding a research question.

After analyzing the interview results, we conducted internal iterative group panel discussions to individually assess all supply chains in our sample regarding the two influencers and thereafter clarify uncertainties, understand issues, or resolve ambiguities in two rounds of discussions. These discussions continued until consensus was achieved. Usually, at least one researcher in our group had an ongoing relationship with a sample company through case writing, student tours, or professional activities with the executives. This enabled us to develop additional insights about the company. The same method was used to assess all the supply chains reviewed in our sample with regards to eight identified operational attributes on a five-point-Likert scale, which was used to describe the supply chains in more detail.

6 | FINDING COMMONALITIES ACROSS RESILIENCE STRATEGIES

After interviewing 12 supply-chain executives in the first round, it became clear that there are two primary sources of complexity considered by the decision makers that limit a company's options and therefore influence the focus of their resilience strategy. When asked how their supply chains are coping with the current and past disruptions, the interviewees in our sample noted the following principal dimensions of the business that drive their approach to supply-chain resilience:

1. *Diversity of product portfolio*: defined by product variety with different product groups with various product characteristics and supply-chain requirements.
2. *Complexity of supply-chain network*: defined by the complexity, and multilayer structure of the network composed of many different supply-chain actors.

Most explanations for why supply chains have suffered during the current pandemic or one of the many previous disruptions were associated with these two fundamental factors. Using a focus group setting, we then refined these two primary aspects of complexity into definitions of two perceived key influencers of a firm's approach to supply-chain resilience from a practitioner's perspective. We label these influencers as follows:

1. *Homogeneity of internal supply-chain processes (intra-company).*
2. *Integration with other supply-chain actors (inter-company).*

7 | ANALYZING THE TWO INFLUENCERS OF RESILIENCE STRATEGIES

For the second round of semi-structured interviews, we modified the questions to focus more on details of the two previously identified influencers of supply-chain resilience strategies. We conducted nine additional interviews with 11 supply-chain executives to learn more about the different forms of *homogeneity of internal supply-chain processes* and degrees of *supply-chain integration with other supply-chain actors*. The two influencers were subdivided, respectively, into five and four groups.

We define *Homogeneity of supply-chain processes* as the degree to which different supply chains within one company are intertwined and share common resources (e.g., in terms of planning, inventory control, logistics, procurement, manufacturing equipment, etc.). We identify four stages of supply-chain process homogeneity (sorted from low to high homogeneity):

1. "Multiple independent supply chains": Companies with several independently managed supply chains with only very limited sharing of resources across the supply chains. Typically, companies/conglomerates with very broad and diverse product portfolios fall into this category.
2. "Shared services": Companies whose multiple supply chains share some supply-chain processes or resources, typically functions such as procurement, logistics, or distribution.
3. "Central guidance": Companies that manage all products centrally and in the same way, while having fundamentally different supply-chain structures for each. Usually, most internal resources such as personnel, plants, equipment, and IT systems are shared across the company.
4. "One-size-fits-all": Companies that use one supply-chain setup to produce all its stock keeping units (SKUs). There might be slight differences in the way the SKUs are managed (e.g., priority rules, planning cycles) or handled (e.g., packaging). Such companies are usually seen as single-product-companies.

We define *Inter-company supply-chain integration* as the degree to which a supply chain is interlinked and aligned with the supply chains of partner companies, in terms of material flow, information flow and financial flow (Rai et al., 2006). We identify five degrees of supply-chain integration (sorted from low to high integration):

1. "Less dependency/engagement": Companies that have arm's length relationships with their suppliers/supply-

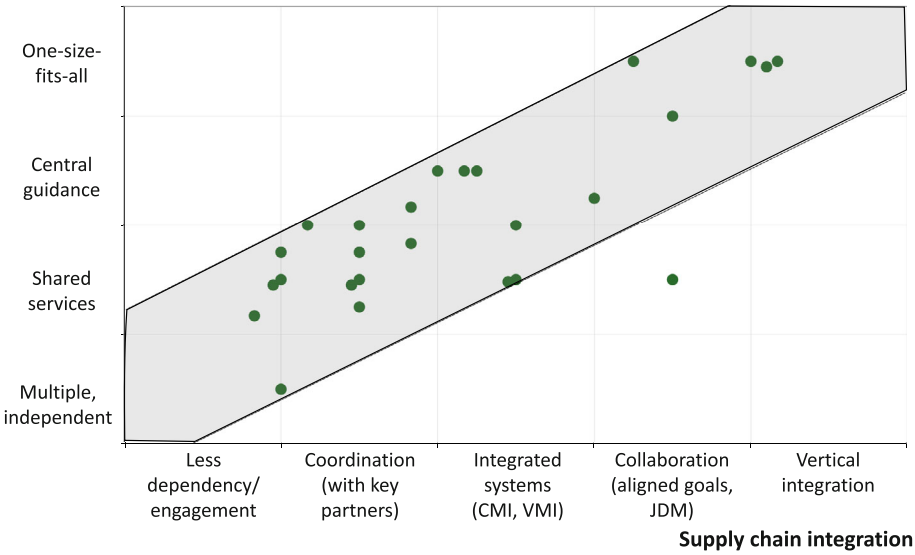

FIGURE 2 Plot of supply chains with respect to two main influencers of resilience strategies

chain partners. These are typically companies that do part of value adding inhouse, and externally sourced materials can be obtained in a transactional fashion. These companies do not have strategic suppliers and for most inputs they can easily switch sources.

2. "Coordination with key partners": Companies that have only a limited number of strategic suppliers with which they coordinate efforts and share some information (e.g., market data). Most of the relationships are still transactional and less engaged.
3. "Integrated systems": Companies that share some parts of the supply chain and have a system interface with their key partners (e.g., for customer or vendor-managed-inventory). These companies frequently share information with some strategic partners. Switching those partners would be very costly and disruptive.
4. "Collaboration": Companies whose supply-chain processes are very interlinked with their partners. Goal alignment is typically strong between these companies and their partners. They may collaborate on the development of new products (e.g., Joint Design Manufacturing). Switching partners would be prohibitively costly in the short to medium term.
5. "Vertical integration": Companies that control two or more, typically investment-intensive, stages of the production that in other contexts might be operated by separate firms. A company with this structure therefore does most of the value adding processes by itself.

An iterative group panel discussion was conducted to assess the supply chains in our data set with regards to the two influencers of resilience strategies. As supply chains are complex and multidimensional, there was not always a perfect match to one of the discrete labels we have used to segment each of the two factors. However, when focusing on the predominant characteristics of a supply chain, all of our expert panel members had no problems positioning the supply chains that emerged in our interviews. The result (average) of the individual assessments after two rounds of clarification and discussion, is shown in Figure 2.

The scatter plot shows a band going from the bottom left to the top right. This positive relationship between *homogeneity of supply-chain processes* and *inter-company supply-chain integration* suggests that the greater a company's interconnectedness with supply-chain partners, the lower is the diversity of its own supply chains (i.e., "You can either go broad or deep, but not both.").

8 | CLUSTERING SUPPLY CHAINS INTO THREE CROSS-INDUSTRY GROUPS

As shown in Figure 2, the 26 supply chains observed in our sample differ greatly in their degree of integration with other supply-chain actors and the overlap with other supply chains within the same company. Clustering is a commonly used method for pattern recognition within data sets. Hence, we conducted a simple k-means clustering to group observations into smaller groups of similar supply chains (Diday & Simon, 1976). To determine the optimal number of clusters we plotted the explained variation as a function of the number of clusters (elbow method) and concluded that three clusters are optimal. Details concerning the clustering can be found in the Appendix A. In our dataset the three clusters contained 5, 9, and 12 supply chains, respectively. Each cluster

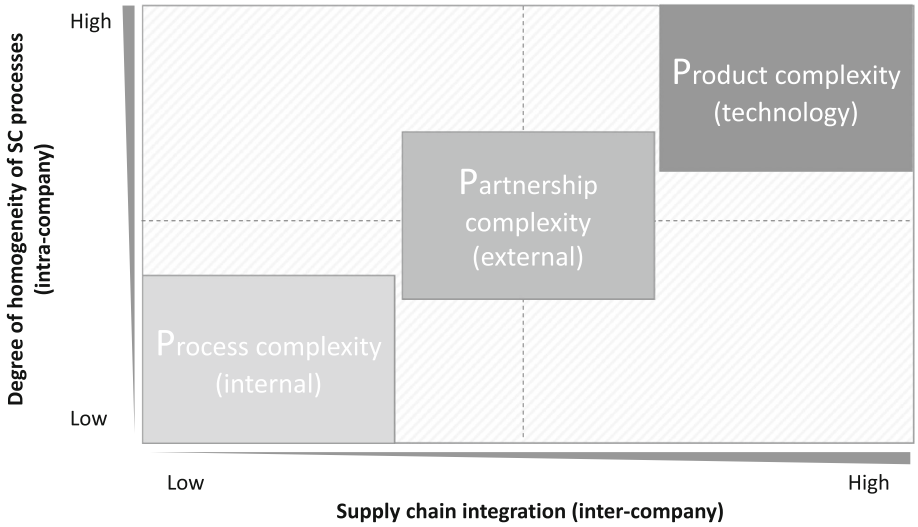

FIGURE 3 The triple-P supply-chain resilience archetypes

comprises supply chains that are similar despite being in different industries. From the attributes of these clusters we postulated that our responding companies belong to one of three supply-chain archetypes, which are defined by a set of common features and strategies.

To understand in more detail the similarities within each cluster and differences between the clusters, we identified eight operational attributes to use in discussing differences between supply chains in addition to the two variables used for the clustering. These attributes emerged from our interviews with the executives as central to their rationales for designing their supply-chain strategies. The first four are aspects of product architecture, the other four relate to supply-chain processes:

- Product complexity
- Homogeneity of product portfolio
- Degree of product modularity
- Level of product customization

Product architecture

- Availability of potential suppliers
- Level of Pull (vs. Push)
- Length of lead time
- Degree of (manufacturing) outsourcing

Process

9 | TRIPLE-P SUPPLY-CHAIN RESILIENCE ARCHETYPES

We assessed all supply chains with regard to these eight attributes. The table in Appendix B summarizes the results. "Availability of potential suppliers" and "Homogeneity of product portfolio" emerge as the two most distinguishing attributes, followed by "Product complexity," "Lead time," and "Level of pull", suggesting that these five operational attributes join with *inter-company supply-chain integration* and *homogeneity of intra-company supply-chain processes* as good predictors for a company's association with a supply-chain archetype. The other three factors varied less consistently among the three clusters.

Following this analysis of attributes, we re-examined the coded interviews to identify patterns with regard to barriers for achieving resilience through supply-chain strategies. The results showed that supply chains belonging to the same archetype share common obstacles to resilience and utilize similar strategies to become more resilient.

A primary area of concern arose for each cluster (see Figure 3). The executives of the supply chains in the top right corner all mentioned their vulnerability to lack of design alternatives due to their technology and the capital-intensive nature of their products. Hence, their perceived main barrier to resilience is product complexity. Resilience in the cluster of supply chains in the middle of the diagram was primarily limited by dependence on resources outside of their own corporate boundary, requiring their executives to orchestrate the extended supply chain. Hence, their main barrier to resilience is partnership complexity. Lastly, executives associated with the bottom left cluster described their primary barrier to resilience as arising from a need to manage a diverse product portfolio with supply chains that are partly independent and partly intertwined. Hence, their perceived main barrier to resilience is process complexity. Figure 3 illustrates the Triple-P framework of challenges to resilience and articulates the three supply-chain archetypes in terms of each one's primary source of complexity.

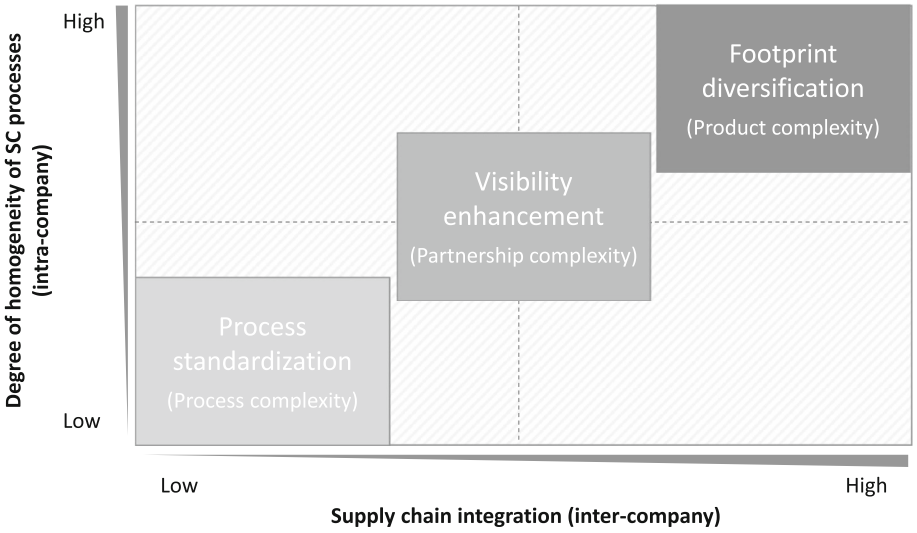

FIGURE 4 Common resilience strategies based on triple-P archetype classification

Figure 4 indicates the common resilience strategies used by each of the supply-chain archetypes in the Triple-P framework.

The next section provides a more detailed description of each archetype and discusses common barriers for resilience and common strategies.

9.1 | Archetype 1: Product complexity

The products in this archetype are produced by homogeneous supply-chain processes even though they serve at least two different markets: larger, long-term contractual relationships with important customers, and a more short-term market with transactional relationships with smaller players. Supply chains in this archetype tend to be vertically integrated to protect intellectual property, with limited outsourcing to a small pool of qualified suppliers. Upstream processes tend to be heavily automated to reduce labor cost, representing high capital investment. The capital investment requires that the upstream processes be run at a high utilization, which then limits flexibility throughout the supply chain.

9.1.1 | Common barriers for the product complexity archetype

Product complexity and the resulting perceived need for heavy upstream automation are the dominant drivers of supply-chain design and resilience decisions for the supply chains in this cluster. First, these factors require the upstream operations to maintain a high-capacity utilization, which creates a push system that makes it difficult to match supply with a volatile demand. The bullwhip effect may also be triggered by such a supply-chain setup when demand exceeds supply (Lee et al., 1997). Second, the need for high utilization, specialized worker skills, and management of IP requires centralization of capacity, making regional production (whether outsourced or in house) difficult—perhaps even infeasible.

One high-tech company's executive gave as their biggest issue to becoming more resilient through geographical diversification (regionalization, which for many firms for now refers to a "China + 1" manufacturing strategy) the sparsity of production-location options offered by its supply base. Executives from the semiconductor industry similarly indicated that their fixed and highly specialized manufacturing infrastructure drastically limits their option space. Another interview partner explained that outsourcing options are limited by the specialized skills needed to make the product, while vertical integration is inhibited by the high capital requirements.

While the centralized planning structure of this archetype provides good visibility of the company's own assets and those of tier-1 strategic partners, visibility beyond tier 1 tends to be limited. Two executives from the semiconductor industry mentioned the need to couple a 6-month rolling demand forecast with daily revision of the order book and the production schedule. Also mentioned is that these supply chains usually depend on significant logistics/transportation operations due to the highly dispersed production process ("global center of excellence" structure). This can reduce resilience when logistics capacity becomes scarce, as occurred during the first months of the global pandemic in 2020 and in late 2021 because of a shortage of containers available to transport goods from China to the United States. Lastly, changes in the mix of customers or market applications—such as producing a chip for the consumer electronics instead of the automotive market—puts stress on the "homogeneity" of the supply-chain processes and the efficiency of automation.

9.1.2 | Common strategies for the product complexity archetype

To overcome the limitations arising from product complexity, all respondents in this cluster mentioned their need to maintain a long-term focus, and their investments to diversify the production footprint and build redundancies into their center of excellence structures. These strategies can be seen as "dialing back" the initial decision to automate upstream operations and run them at a high utilization. One semiconductor company invested in having two internal facilities for each technology with some redundant capacities, another company standardized its equipment and production methods to be able to move production seamlessly in case of emergencies, and one of the high-tech companies invested heavily in second sourcing by offering incentives to its strategic suppliers to diversify into new countries or to "groom" new partners in the target countries. Our observations suggest that supply chains within this cluster tend to buffer uncertainty using capacity (access capacity, multiple-site facilities) instead of inventory, as inventory is oftentimes customer specific and prone to obsolescence.

Several of the executives interviewed also mentioned their use of sophisticated supply-chain risk-management programs for owned assets and tier-1 partnerships. A large supplier of photolithography systems, for example, involves a small number of highly specialized technology-intensive tier-1 suppliers in joint product development, which spreads the risk and capital investment, and permits joint monitoring of the critical path and optimization of production processes. The supply-chain structure that has emerged from this joint product development emphasizes single sourcing for tier-1 suppliers but allows multi sourcing for supplier's suppliers.

These risk-management programs—developed in response to prior disruptions such as the Japanese earthquake or the Thailand floods in 2011—may not address deeper tiers of the supply chains. Executives in these companies have thus sought to push digitalization up the chain to increase visibility and facilitate data analytics. While increased visibility has not increased resilience on its own, it has helped these decision makers to estimate the responsiveness required in a fully automated environment to control mismatch costs.

Thus, supply chains in this archetype all view product complexity as a major constraint and do not see an alternative to upstream automation. The limited flexibility resulting from this setup is then mitigated by either increasing responsibility through footprint diversification and capacity buffers or standardizing processes even further.

9.2 | Archetype 2: Partnership complexity

Supply chains in this cluster handle complex product portfolios of either standardized make-to-stock (MTS) or make/engineer-to-order products (MTO/ETO) for B2B settings. Products are made complex primarily due to the large number of components, which results in supply chains with up to 5–10 tiers, and many suppliers at each tier. The company retains partial ownership of assembly and testing processes for quality purposes and lead-time control, and of a few key components to protect IP. The company uses strategic partnerships with key tier-1 suppliers and decentralized supplier management for others, management of which is partly delegated to the tier-1 firms. Here the product life cycles (5–7 years) are shorter than in the product-complexity archetype, with possible platform redesigns and minor upgrades of some systems within a cycle. Supply chains of this type sometimes sell both to tighter-margin markets in make-to-stock format and to higher-margin B2B markets with a make-to-order process. The supply chains reflect some process differentiation to handle this diversity on the demand side, while leveraging synergies for the procurement of commodities, transportation, and some distribution activities. Firms of this type, for example, an original equipment manufacturer from the automotive industry, typically pursue regionalized strategies, with only few facilities playing global roles. This makes the company-owned part of the supply chain shorter than for supply chains from the product-complexity archetype.

9.2.1 | Common barriers for the partnership complexity archetype

The perceived need to select lowest cost-per-unit suppliers increases the total number of suppliers and the supply-chain length. The obstacles presented by this archetype are experienced by all these supply chains. As the OEM or full-service contract manufacturer, these firms are responsible for orchestrating the entire end-to-end supply chain—or at least big chunks of it. Although well-managed supply chains of this archetype usually have clear visibility, live data, and robust operations within their corporate boundaries, they are vulnerable to disruptions in the multilayered supply network. The number and geographic dispersion of deep-tier suppliers makes it difficult to establish comprehensive visibility or business continuity measures. Examples from our interviews suggest that the barriers to resilience originate outside of the corporate boundaries of the focal firm: (1) a high-tech respondent stated that he is also responsible for

connecting different suppliers (tier 2 and 3) to find options in case of a disruption, (2) an automotive executive explained his company's need to oversee supply-chain design changes at strategic tier 1 or 2 suppliers as well as supporting lower-tier suppliers with employees or financial resources, (3) an industrial-goods manager explained that his company is not able to do business continuity planning for the entire supply base due to the "multi-thousand" of supplier chains, and (4) an executive from the agriculture industry described how the liquidity hardships of the firm's customer base (farmers) threaten demand.

Other issues that were mentioned multiple times were that dual-sourcing strategies often still rely heavily on Chinese supplier bases, and that the financial health of small suppliers is a major concern. Moreover, having more than one market segment with differential requirements requires having different supply-chain strategies with differences in some of the supply-chain processes. Thus, supply-chain differentiation increases the degree of difficulty of streamlining what are traditionally more central and hierarchical corporate-planning activities. Another barrier to resilience mentioned was that transportation capacity constraints accentuate supply shocks. Lessons were learned in prior shocks, but still great pain was felt during the pandemic crisis. Lastly, customers expect and demand—but are not willing to pay for—"resilience insurance." The firms in this cluster struggle to establish mutual understanding of who will bear the cost of enhancing resilience. Although allocating costs is often more about power than system optimality, an upstream supplier that shuts down the total supply chain can cause substantial pain.

9.2.2 | Common strategies for the partnership complexity archetype

As the common strategy to overcome partnership complexity, the respondents managing this archetype all named heavy investment in tools, people, and mechanisms to expand their "reach" into lower tiers and manage the end-to-end supply-chain design. One high-tech respondent mentioned a bi-directional communication system and central resilience team to support suppliers. Other respondents described creation of a "control tower" to guide supply-chain design and execution, and to support lower-tier suppliers (automotive respondent). Some of these control towers were coupled with investment in supply-chain analytics to make it possible to monitor the entire supply chain and proactively share information regarding potential disruptions or forecast errors with partners (electronics manufacturer). An industrial-goods manufacturer uses a central database to monitor and evaluate suppliers across business units. A high-tech company leverages its long-term investment in a supply-chain risk-management function to monitor multiple tiers of suppliers. An agricultural company together with its distributors created a customer financing program to ensure demand and make long-term profit more predictable. Supply chains in this cluster, contrary to "product complexity" supply chains, primarily buffer with inventories instead of capacity. Oftentimes, inventory "within the chain" (at suppliers) is used, as well as inventory across pooled different products or regions, often managed through centralized procurement functions.

Supply shocks of the last decade have shown that a diversified footprint combined with regionalization can effectively increase resilience. This strategy is often implemented by supply chains in this cluster. When regionalization is constrained by supplier availability in the region and therefore depends on longer-lead-time global suppliers, vertical integration or industry coordinated (even implicitly with competitors) supplier development becomes easier to justify. Supplier development in a "China + 1" type strategy had been underway for at least a year for these supply chains due to intensification of bilateral US-China tariffs prior to the pandemic. For firms in this cluster, supplier development can be done typically within a year, which is significantly faster than in the "product complexity" supply chains. Regionalized suppliers can be constrained by material availability, making it worthwhile to invest in raw-material inventories even for lean and pull supply chains. Some executives also mentioned that they have found effective strategies to reduce product complexity such as postponement, and rationalization of supply chains such as having a list of preferred suppliers. One executive from the apparel industry told us that "data analytics is becoming more and more important, but you need a relationship as well" to decide which suppliers are worth investing in before and during a crisis. Lastly, these supply chains are making efforts in automation and digital transformation of their first two tiers, but cheap labor is still prioritized in the deeper tiers. OEMs thus must often rely on "certifications" rather than first-hand monitoring of those deeper tiers.

9.3 | Archetype 3: Process complexity

Supply chains in this cluster sell broad portfolios of consumer products. Their variants are used by industrial supply chains in support of service industries. Multiplicity of products and very different value propositions

require a wide variety of supply-chain strategies, ranging from efficient but longer-lead-time flow chains to highly responsive short lead-time ones. Companies in this archetype heavily outsource to contract manufacturers and supply-chain orchestrators that have access to a global supplier network. The access to a diverse supplier portfolio allows for labor-wage arbitrage, currency exchange-rate hedging, and easy access to capacity for dealing with demand shocks.

9.3.1 | Common barriers for the process complexity archetype

Respondents from this cluster are mainly concerned with internal obstacles and internal process complexity when it comes to increasing supply-chain resilience. The diverse product portfolio with partly independent, partly intertwined supply chains increases complexity, confuses the execution of supply-chain strategies, and inhibits fast decision-making and transparency of product profitability. Even when the locus of decision-making is decentralized, complexity can remain high due to a constantly changing product mix and shared functions or assets to leverage economies of scale. For example, one interviewee named the proliferated product portfolio as a major issue for his consumer-products company. Other respondents from the apparel and chemistry industry reported that their resilience problems are a response to complexity driven by inorganic growth and lack of post-acquisition integration. A consumer-goods executive referred to the firm's large and inflexible production base that complicates flexibility. Other supply chains are experiencing opposing demand developments within one business unit and country due to their diverse product portfolio.

A key barrier to resilience named by multiple interviewees from this cluster was the lack of visibility into the supply chains of their strategic partners such as contract manufacturers, third-party logistics providers, or supply-chain orchestrators. Although supply-chain risk management is practiced to some extent with key suppliers, it was often not expanded deeper into the chain made up of small suppliers in emerging markets. In this archetype, supply-chain strategies tend to be segment specific, which makes it difficult to adjust to demand shifts or other shocks at the company level. Demand for consumer goods and industrial-service products can be price sensitive, encouraging decision makers to maximize capacity utilization and minimize costs. This makes it difficult to justify excess capacity in the chain, thus creating industry-wide bottlenecks not controlled by the firm.

9.3.2 | Common strategies for the process complexity archetype

Interviews associated with the "process complexity" archetype identified two strategic directions that were followed by all these companies. First, all focused on complexity reduction through portfolio and supplier rationalization that required the focal company to take an active role in supply-chain management. Five interviewees from consumer goods, agriculture, and apparel companies described how portfolios were streamlined to focus only on the SKUs with greatest profit and highest customer need. We did not observe capacity buffering for time-sensitive products. This is in line with de Treville et al.'s (2017) finding that managers have difficulty implementing a capacity buffer even when they can see the benefits from simulation models. Two interviewees streamlined their supply base to include only like-minded partners while ensuring that critical components are still multi-sourced. Second, all engaged in some sort of standardization of components, production methods, or assets to increase flexibility of the local/regional production network. For example, two companies increased standardization of mass-category products through late-stage customization (postponement). Another respondent described increasing resilience through increasing process and asset modularity. Another company works on increasing flexible production capacities through collaborative manufacturing partnerships with third party providers. Supply chains in this cluster need to optimize both inventory levels and capacity utilization due to the price pressure in their respective markets. In case of supply shocks these companies are experienced in finding "creative" solutions for handling shortages, such as the use of alternative materials or flexible bills of material.

Other strategies employed by supply chains from this cluster include efforts at regionalization for some products that are either costly to transport or have higher margins. Some automation investments can be made in key parts of the chain to bring the chain closer to the customer. Two executives mentioned that having material inventories closer to markets pays off for longer global chains. Moreover, operational flexibility in the product and channel portfolio, supplier network, and revenue management are part of the most effective path to resilience. These supply chains invest less in redundancy, and only with multiple smaller suppliers in emerging markets. They prefer to increase mix flexibility through flexible automation and process flexibility. Another interesting finding is that digital transformation happens mostly on the retail segment of the chain, where data analytics is heavily used for revenue management, while these practices are much less prevalent on the supply side.

10 | DISCUSSION

This study has provided a snapshot of what we have observed concerning how resilience efforts vary between three common supply-chain archetypes, illustrating how supply-chain management has evolved from the dichotomy between efficient and flexible supply chains proposed by Fisher (1997). We observed that the primary complexity type faced in a given archetype aligns with the initial resilience strategy, as well as with the barriers and resilience challenges that the firm should expect to face. The resulting Triple-P framework that we propose can be compared with a made-to-measure suit with the three archetypes being the base pattern. Supply chains from the "product complexity" cluster are typically constrained by the perceived need to automate upstream operations which limits flexibility and therefore are most vulnerable to issues related to the nature of the product, such as the lack of responsiveness and design alternatives. A common strategy to overcome issues arising from product complexity is a long-term commitment to a production footprint that reflects investments in diversification as well as redundancy within a dedicated plant structure. Supply chains from the "partnership complexity" cluster are most vulnerable to issues related to other supply-chain actors outside their own corporate boundaries. Hence, companies of this archetype invest heavily in the means to expand their "reach" upstream and downstream to manage the entire end-to-end supply chain. Supply chains from the "process complexity" cluster are most vulnerable to internal complexity arising from a diverse product portfolio supported by multiple independent supply chains. These companies, on the one hand, use portfolio and supplier streamlining, and, on the other hand, adopt standardization of components, methods, and assets to increase flexibility of their production network.

However, as in tailoring a suit, bespoke adjustments based on the individual environment and operational characteristics of a supply chain improve its resilience capability. The literature cited in this paper suggests alternatives for improving supply-chain resilience that go far beyond what we observed in our study. While we observed considerable variation in supply-chain management and design between the three archetypes that emerged from our interviews, our review of the literature suggests that current practices fall short of what would be theoretically possible. The seru production approach (Yin et al., 2017) described earlier exemplifies what is possible for a firm that rethinks the constraints typically assumed for its archetype. Although many executives mentioned lessons learned from prior shocks, still great pain was felt during the pandemic crisis. Managers learn from past shocks, but still have difficulty to prepare their supply chains for the next extreme disruption. Seru firms were observed to proactively design their supply chains to provide resilience to a wide variety of states of nature that they could possibly face, in sharp contrast to the strategies implemented by many of the firms that we observed that only begin to increase resilience once a shock has emerged. Based on our snapshot and our review of the literature, we recommend that decision makers not only invest in identifying the archetype that fits them, but also question the assumed constraints and consider opportunities to deploy the levers defined in the literature to tailor their supply chain resilience far beyond what we have observed during this study. The observed gap between what exemplar managers implement and what research findings recommend suggest that the supply chain research community should consider how to market their models and conclusions to be more implementable.

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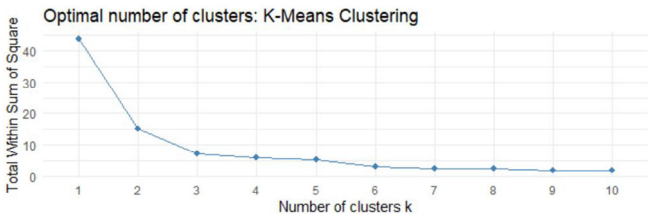
APPENDIX A

All analysis was performed with R software. For analyzing the right number of clusters, the "fviz_nbclust" function from the *factoextra* package was used with *k-means* as clustering method and *total within sum of square*.



For the clustering, the *kmeans* function from the *cluster* package with a clustering algorithm from Hartigan and Wong (1979) was used.

```
K-means clustering with 3 clusters of sizes 12, 9, 5

Cluster means:
  SCIntegration  HomoSCP
1      1.741667 2.012500
2      2.966667 2.544074
3      4.283333 3.900000

Clustering vector:
 [1] 3 1 2 1 2 2 1 1 1 2 2 2 2 1 1 1 3 3 3 1 2 1 2 3 1 1

Within cluster sum of squares by cluster:
[1] 2.7225694 3.7037506 0.8055556
 (between_SS / total_SS =  83.5 %)
```

APPENDIX B

The following table shows the results of the iterative group panel discussion to individually assess all supply chains with regards to the eight operational attributes on a scale from 1 (low) to 5 (high). For each cluster, the average score and standard deviation of the respective operational attribute is shown. The table reads as follows: In terms of product complexity, supply chains from cluster 1 average 4.9 out of 5; in contrast, supply chains from cluster 3 average only 1.7.

	Cluster 1 (top right)		Cluster 2 (mid)		Cluster 3 (bottom left)		Delta Avg. 1 vs. 2	Delta Avg. 1 vs. 3	Sum of deltas
	Avg.	Std. dev.	Avg.	Std. dev.	Avg.	Std. dev.			
Product complexity	4,9	0,2	3,2	0,8	1,7	0,5	1,7	3,2	4,9
Homogeneity of product portfolio	4,9	0,2	2,8	0,8	1,8	0,8	2,1	3,1	5,2
Product modularization	1,8	1,5	3,4	1,1	1,9	1,3	1,7	0,2	1,8
Level of product customization	4,3	0,7	3,5	1,2	2,0	1,3	0,8	2,3	3,1
Availability of supplier	1,1	0,2	3,1	0,6	4,4	0,5	2,0	3,3	5,3
Level of pull	4,8	0,3	3,4	1,2	1,6	1,2	1,4	3,2	4,6
Lead time	4,8	0,4	2,9	0,8	1,8	0,9	1,9	3,0	4,8
Degree of outsourcing	2,4	1,9	3,1	1,2	2,5	1,5	0,7	0,1	0,8

Scale from 1(low) to 5(high)

APPENDIX C

Interview guide for first round interviews.

Topic	Interview questions
Organizational setup and supply chain structure	1. Please tell us about the general supply-chain situation at your company. 2. How many different supply chains do you operate for how many "Product Groups" within the company? Please name two examples for different supply chains and how they are different. 3. What are the key variables or drivers your company uses for defining the number of different supply chains? 4. Do some "product groups" with different supply chains share resources in sourcing, manufacturing, or distribution?
COVID-19 pandemic and other disruptions	1. How and to what extent did the current pandemic disrupt your supply-chain operations? In what ways is the pandemic different from previous disruptions? 2. Were there any differences across product groups/business units with regards to the disruption? If so, please explain. 3. What are your major obstacles for becoming more resilient?
Measures to become more resilient, agile, or responsive	1. Has your company already implemented any changes as a response to the pandemic? Please elaborate on the short-term measures that are already in place 2. What are the key learnings from handling the current pandemic? 3. Which other actions are you planning on implementing going forward?
IT infrastructure	1. Which tools/technology do you use to steer your supply chain (i.e., for gaining end-to-end visibility to perform risk analysis and to conduct scenario planning)?

Interview guide for second round interviews:

Topic	Core question (+ sample interview questions)
Organizational setup and supply chain structure	Please tell us about the general supply-chain situation at your company. • How many different supply chains do you operate for how many "Product Groups" within the company? Are these product groups standardized or vary depending on the "function" (e.g., production, distribution)? • What are the key variables or drivers your company uses for defining these groups?
COVID-19 pandemic and other disruptions	Please tell us about your companies' situation with regards to the COVID pandemic. • How and to what extent did the pandemic disrupt your supply-chain operations? In what ways is the pandemic different from previous disruptions? • Were there any differences between product groups/business units with regards to the disruption? If so, please explain.
Partnership	How do partnerships (with suppliers, contract manufacturer, distributors, or customers) help to achieve more resilience? • To increase geographical resilience, what are the ways in which you induce your current suppliers to diversify their factory locations, or do you try to groom new suppliers in new geographies? In doing so, can you ensure that social and environmental responsibility standards are upheld? • To increase technological resilience, what are the ways that you can help a supplier to invest for such upgrades? What new risks do you see by helping a supplier to have deeper sophistication and capabilities? • For companies that own their manufacturing, you may not have a network of diversified manufacturing sites due to the required heavy investments. How can you provide yourself some form of geographical resilience?
Supply-chain integration	How does the structure of the supply chain portfolio help to become more resilient? • Are your supply chains centrally controlled or managed independently (within regions or business units)? • To what degree are the supply chains within your company intertwined and share common resources (e.g., in terms of planning, inventory control, logistics, procurement, manufacturing equipment, etc.)? • How did the current supply-chain structure influence your level of resilience? Are you planning on changing the structure?
IT infrastructure	• Which tools/technology do you use to steer your supply chain (i.e., for gaining end-to-end visibility to perform risk analysis and to conduct scenario planning)?