The influence of structural and dynamic complexity factors on supply chain resilience: a qualitative study

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Abstract

This study aims to investigate the implications of supply chain (SC) complexity (based on static and dynamic complexity drivers) on constituents of resilience capabilities to deal with disruptions. A systematic qualitative analysis based on critical incident technique has been applied on secondary data collected on disruption incidents. Findings indicate that most of the complexity drivers have positive influence on several resilience constituents; however, negative effects were observed as well. Static SC complexity drivers seem to have both positive and negative effects on resilience, while dynamic complexity drivers seem to reinforce SC resilience.

Keywords: complexity, supply chain resilience, critical incident technique

Introduction

Even though business complexity enables firms to increase in sales (Mocker et al., 2014), it also results in higher management costs, reduced responsiveness and agility, hindering profit growth (Collinson and Jay, 2012; Gottfredson and Aspinall, 2005; Wilson and Perumal, 2009). Despite its potential hindering impact on performance, it is argued that, since companies pursue business growth, complexity increase is inevitable, and nowadays it is becoming more and more important to leverage it as a source of competitive advantage, instead of reducing it. Therefore, the relationship between complexity and performance has a dual nature, as underlined by many authors (Bozarth et al., 2009; Brandon-Jones et al., 2014; Perona and Miragliotta, 2014).

In supply chains (SC), complexity can be seen as the level of complexity exhibited by products, processes and relationships that make up a supply chain (Bozarth et al., 2009). It can be distinguished in static complexity, which states structural characteristics of the network, including the number and variety of elements and the strength of interactions among them, and dynamic complexity, which represents uncertainty and evolutionary events altering the SC, considering both strategic and operational perspectives (Bozarth et al., 2009; Serdarasan, 2013).

The negative impact that SC complexity may have on company performance has been investigated from different perspectives (Bode and Wagner, 2015; Manuj and Sahin, 2011; Brandon-Jones et al., 2014; Craighead et al., 2007; Choi and Krause, 2006; Perona and Miragliotta, 2004). One relevant aspect of this multifaceted relationship is that complexity in the SC could trigger unexpected events and disrupt operations (Bode and Wagner, 2015; Brandon-Jones et al., 2014; Craighead et al., 2007) but could also provide additional resilience capabilities (Birkie et al., 2017), for example through effectively absorbing demand-supply glitches. Consequently, a better understanding is also required on how SC complexity might affect the way businesses cope with SC disruptions (Ambulkar et al., 2015).

SC resilience can be defined as the "adaptive capability of the [SC] to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function" (Ponomarov and Holcomb, 2009). Birkie et al., (2014) operationalised resilience by introducing the core functions characterising the disruption profile: sense, build, reconfigure, sustain and re-enhance. Several researchers focused on resilience constituents, i.e. formative elements such as flexibility, velocity, visibility and collaboration (Johnson et al., 2013; Jüttner and Maklan, 2011; Tukamuhabwa et al., 2015).

Despite an increasing interest among scholars and practitioners and a growing body of conceptual research, empirical evidence on the relationship of SC complexity to resilience in extant literature is nil. This study seeks to contribute to a deeper understanding by investigating the implications of complexity in dealing with real disruptions. Thus, the following research question is set forth:

RQ: How does supply chain structural and dynamic complexity influence supply chain resilience?

The paper is organised as follows. In the next section we review the body of literature addressing some aspects of the relationship between SC complexity and resilience. In the third section, we present the methodology adopted in the present study, followed by the empirical findings reported in the fourth section. We subsequently discuss the main results before concluding with implications and avenues for future research.

Literature review

Relevant academic contributions were searched and selected through Scopus and Web of Science. The following combination of keywords was used for the purpose: "supply chain" AND "complexity" AND "resilience". After the screening of title and abstract, 26 papers were finally selected, temporally distributed between 2007 and 2017. The reviewed papers recognise that resilience can be influenced in different ways by SC complexity. Even though the large majority of papers investigate the linkages between complexity drivers and some resilience constituents (e.g. Brandon-Jones et al., 2014; Cardoso et al., 2015; Falasca and Zobel, 2008; Hearnshaw and Wilson, 2013; Skilton and Robinson, 2009), some authors concentrate on resilience core functions, such as robustness and adaptability (Durach et al., 2015; Hosseini et al., 2016; Mari et al., 2015).

For the purpose of this study, static and dynamic SC complexity has been captured using twelve drivers compiled starting with reviewed literature. These drivers are: *(1) portfolio breadth, (2) product variety and specificities, (3) number and layers of facilities in the supply chain, (4) difference between facilities (in different locations), (5) number and variety of suppliers, (6) variety (and breadth) of customer requirements, (7) product lifecycle events, (8) reconfiguration of SC, (9) improvements to system (i.e. equipment,* *procedures and systems), (10) restructuring and mergers and acquisition, (11) demand-/supply-side operational dynamics,* and *(12) new customers/suppliers*.

Even though Craighead et al. (2007) are the first authors discussing about both SC complexity and resilience capabilities in the same paper, they do not investigate the possible link between the two. The link has been first analysed by Falasca et al. (2008), followed by Skilton and Robinson (2009), Arkhipov and Ivanov (2011), Adenso-Diaz et al. (2012), Brandon-Jones et al. (2014), Cardoso et al. (2015), Gunasekaran et al. (2015), Thome et al. (2016). The most recent study concerning the influence of SC complexity on the effectiveness of resilience capabilities in mitigating SC disruptions is by Birkie et al. (2017), who demonstrate not only the positive direct impact that the former has on performance recovery after a disruption, but also its positive moderating effect on the relationship between resilience and performance. Table 1 maps the contributions in extant literature, highlighting how the two concepts have been operationalised by different authors. It is apparent that resilience has been largely studied from its constituents, and that only few papers addressed the dynamic side of SC complexity (Gunasekaran et al., 2015; Hearnshaw and Wilson, 2013; Thome et al., 2016; Durach et al., 2015; Hosseini et al., 2016).

Table 1. Number of papers on the relationship between SC complexity and SC resilience

Complexity	Resilience constituents	Resilience functions
Static	Adenso-Diaz et al., 2012 (SIM)	Birkie et al., 2017 (REG)
	Arkhipov and Ivanov, 2011 (TH)	Durach et al., 2015 (TH) (LR)
	Brandon-Jones et al., 2014 REG	Hosseini et al., 2016 (TH-CS)
	Cardoso et al., 2014 (CS-SA)	Mari et al., 2015 (SIM)
	Cardoso et al., 2015 (CS-SA)	Sokolov et al., 2016 (TH)
	Elleuch et al., 2016 (CS)	Statsenko et al., 2016 (TH)
	Falasca and Zobel, 2008 TH (pSIM)	
	Gunasekaran et al., 2015 (TH-CS)	
	Hearnshaw and Wilson, 2013 (TH)	
	Mari et al., 2015 (SIM)	
	Sokolov et al., 2016 (TH)	
	Skilton et al., 2009 (TH)	
	Thome et al., 2016 (TH)	
Dynamic	Gunasekaran et al., 2015 (TH-CS)	Durach, 2015 TH (LR)
	Hearnshaw and Wilson, 2013 (TH)	Hosseini, 2016 (TH-CS)
	Thome et al., 2016 (TH)	

Note: main methodology applied in mapped papers:
CS = case study; REG = regression; SIM = simulation; TH = theoretical study or framework;
SA = scenario analysis; LR = literature review; pSIM = proposed simulation, not applied

In an attempt to empirically investigate the relationship between SC complexity and resilience, an additional original contribution of our study is the enhancing of knowledge on the role of dynamic complexity factors; indeed, a limited number of the literature mapped in Table 1 have empirical investigations in the corresponding quadrants.

Study methodology

An overall qualitative approach was adopted in this study, employing critical incident technique (CIT; Flanagan 1954). Critical incidents were established through secondary data collected from corporate websites, annual reports and corporate communications.

The considered unit of analysis was the manufacturing firm's internal supply chain, which is more comprehensive than many previous studies on the topic, though with limitations.

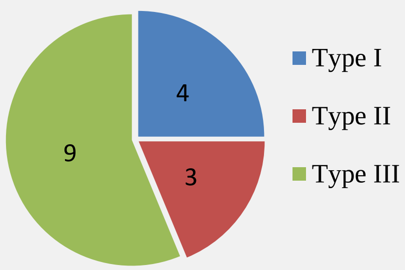
The adopted approach based on CIT and secondary data has been developed and used in earlier research (e.g. Birkie et al., 2017) with quantitative analysis. As the objective of the current study is to build deeper understanding, qualitative analysis has been preferred. In essence, the analysis part follows similar tenets of typical qualitative strategies such as case study, the only difference being the data source (e.g. Eisenhardt, 1989). As such, the identification and mapping of the roles that complexity drivers play on resilience constituents can be seen as within case analysis while the analysis that compares the different incidents can be viewed as cross-case analysis (Eisenhardt, 1989).

The qualitative analysis started from a list of 77 disruption incidents collected based on secondary data sources. These incidents were further short listed based availability of details about resilience actions and complexity factors. These incidents were mapped to get representation of the different industry sectors in the initial list of incidents. We have also given emphasis to severe (type III; Birkie, 2016) incidents as they generally involve more organised resilience effort. The analysed sample consisted of 16 multinational companies in different industry sectors with complex supply chain and had recently been impacted by SC disruptions. The descriptive details of the final sample selected for the study are shown in Figure 1.

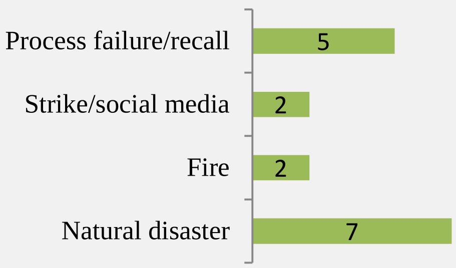
(a) Industry

Auto/aerospace	7
Electronics	2
Chemical/ pharma	2
Food/beverage	3
Personal items	2

(b) Disruption scenario



(c) Cause of disruption



(d) Year

2002	1
2005	1
2007	1
2009	1
2010	2
2011	5
2012	1
2013	2
2015	1

Figure 1. Descriptive details of the 16 cases in the study

Findings

Collectively the selected 16 incident cases show that most of the drivers for static and dynamic complexity played an observable role, either positive, negative or both. Table 2 reports the number of cases (istances) in which different roles of SC complexity drivers on resilience constituents employed were identified (note that more than 16 istances are possible due to ambivalent roles of some drivers). In the table, the number in bold, (**X**), account for the cases where the drivers had a positive influence on resilience complexity; the numbers in italics and square brackets (*[X]*) indicate number of cases with a negative role. The number of cases for identified roles on each constituent from each driver may seem few. However, the table is well populated considering the mix of the selected cases. Each driver is linked to at least two constituents, showing the multifaceted relationship between SC complexity and resilience. From a first glance, it emerges that flexibility and collaboration are the most impacted resilience constituents, while structural complexity drivers influence resilience at a larger extent than the dynamic ones.

Table 2. Number of cases with links between SC complexity drivers and resilience constituents

	Role detected in relation to resilience constituent†			
Complexity drivers	Flexibility	Visibility	Velocity	Collaboration
Portfolio breadth	**3**			**1**
Product variety and specificities	**3,** *[2]*		*[1]*	**1**
Number and layers in SC	**9**	**3**	**2**	**7**
Differences between facilities	*[4]*		*[1]*	*[4]*
Number and variety of suppliers	**4**	*[4]*	*[2]*	**3,** *[4]*
Variety of customer requirements	**3,** *[1]*	*[2]*	*[5]*	**3,** *[3]*
Product life cycle events	**5**		**3**	
Reconfiguration of SC	**4**	**1**	**4**	
Improvements to system	**4**	**1**	**4**	
Mergers and acquisitions	**1**	**2**	**1**	**2**
Demand/supply dynamics	**1**		**2**	**2**
New customers/ suppliers	**1**	**1**		

† italic numbers in square bracket indicate negative roles, positive otherwise

Positive relationships are much more frequent than the negative ones, as each complexity driver positively affects at least two resilience constituents. On the contrary, the table is poorly populated by negative links; in particular, dynamic complexity drivers have never decreased resilience in the investigated cases. The only three drivers that significantly decreased resilience in the sample cases are *differences between facilities*, *number and variety of suppliers,* and *variety of customer requirements*. However, there are also cases in which some drivers played both roles concurrently (ambivalent role). In some cases, it was found that the number and variety of suppliers granted higher flexibility to find a feasible solution, but on the other side made its implementation more difficult because of an induced limited collaboration with qualified suppliers. *Product variety and specificities*, *number and layers in SC* and *variety of customer requirements* significantly influence all the resilience constituents in both positive and negative ways. This analysis is better shown in Table 3 that reports the number of observations of positive and negative links between SC complexity drivers and resilience constituents. On the one hand, all the dynamic complexity drivers positively affect resilience; on the other hand, static drivers can have multiple impacts. A positive influence is dominant, with the exception of *differences between facilities* and *variety and breadth of customer requirements*.

For a better understanding of the composite relationship between SC complexity and resilience, it is necessary to deepen the analysis considering the influence of complexity drivers on specific resilience constituents, i.e. flexibility, visibility, velocity and collaboration. Flexibility is the most affected constituent: *differences between facilities* has a negative impact on it, while all the other complexity drivers mainly positively affect it. In most of cases, the higher the SC complexity, the higher the flexibility due to the redundancies and different alternatives exploitable by the company. Even though a wide portfolio and a high product variety allow to offer substitutes or different configurations to customers, a higher modularity and similarity could help too, and strict specificities determine less freedom in approving new technical solutions. Therefore, *product variety and specificities* may play both positive and negative roles. Structural complexity, either internal or external, increases flexibility too: a complex SC offers geographic diversification, many facilities available to ramp up production, different suppliers to which shift the sourcing and new customer requirements to leverage, as it emerged from most of the analysed incidents. The driver with the highest rate of evidence of its positive role is *number and layers in SC,* while *differences between facilities* shown a negative influence, as support from other facilities is possible only if they share substitutable production capacity. For what concerns dynamic complexity drivers, they all play a positive role, increasing flexibility. Product dynamicity fosters research of substitutes and technical solutions, while internal and external dynamic complexity increases the ability to shift to new structures and procedures or change customers or suppliers with a lower effort. The influences with better evidence are those of *reconfiguration of supply chain (activities and facilities)* and *improvements to system (equipment, procedures and systems).*

Table 3. Number of cases with SC complexity drivers and roles on resilience identified

Complexity drivers	Driver identified in	Info. on role obtained in	Positive role in	Negative role in	Positive/ negative role in	No apparent role in
Portfolio breadth	16	13	3	-	-	10
Product variety and specificities	14	6	4	2	-	-
Number and layers in SC	16	10	10	-	-	-
Differences between facilities	11	6	-	5	-	1
Number and variety of suppliers	16	11	4	2	3	2
Variety of customer requirements	15	10	3	6	1	-
Product lifecycle events	16	10	6	-	-	4
Reconfiguration of SC	14	4	4	-	-	-
Improvements to system	15	4	4	-	-	-
Mergers and acquisitions	16	5	3	-	-	2
Demand/supply dynamics	13	3	3	-	-	-
New customers/ suppliers	7	2	1	-	-	1

Differently, the other constituents are not influenced by all the complexity drivers. However, collaboration is strongly impacted too, mainly by structural drivers. As a matter of fact, dynamic ones did not play a role, apart from *restructuring and M&A* and *demand/supply side/internal operational dynamics*. The former can be leveraged in order to offer alternative suppliers to customers, while the latter allows suppliers development. As for static drivers, the internal structure of the SC ensures higher collaboration among different facilities if they are many, but not much different between different territories. On the contrary, even though a higher number of customers and suppliers allows a wider set of collaborative actors, collaboration with them is better if their number is low, due to the stronger partnerships. Thus, *number and variety of suppliers* and *variety of customer requirements* have both positive and negative influence.

Considering velocity, dynamic complexity drivers play the highest positive role: all of them, except *new customers or suppliers*, positively contribute to it, since they allow the company to be already used to change its operations and adopt new solutions. As a matter of fact, being used to dynamicity, the affected companies can rapidly develop technical solutions, identify substitutes, rebuild facilities, ramp up production, change the manufacturing process and introduce new procedures. On the other hand, static complexity decreases velocity of reaction: for instance, a high number of suppliers hinders their management. Moreover, higher number and variety of customers make more difficult communication and image rebuilding.

Finally, visibility is affected by the SC structure and its evolution in time: the more complex is the set of actors the company relates to, the less is the visibility on them, but the greater is the dynamicity characterizing the supply chain, the higher is the visibility on new and innovative alternatives in case of disruption. Therefore, static complexity drivers substantially limit visibility, while dynamic ones increase visibility. As for the former, the higher is the number of external actors to manage, the lower is visibility on them. Considering the layers of SC, a vertical integrated company directly faces final customers and raw materials suppliers, better communicating with them and having a higher visibility, which allows to better manage actions such as recalls.

Discussion

While the implications of SC complexity on business performance have been largely investigated in literature (Bozarth et al., 2009; Brandon-Jones et al., 2014; Perona and Miragliotta, 2014), managers and scholars still need to fully understand its influence on SC resilience. Indeed, despite the large consensus on the enabling role of SC complexity on resilience (Arkhipov and Ivanov, 2011; Birkie et al., 2014; Brandon-Jones et al., 2014; Cardoso et al., 2015; Durach et al., 2015; Falasca and Zobel, 2008; Gunasekaran et al., 2015; Hearnshaw and Wilson, 2013; Mari et al., 2015; Skilton and Robinson, 2009; Sokolov et al., 2016), a negative relationship has been argued as well (Adenso-Diaz et al., 2012; Cardoso et al., 2015; Durach et al., 2015; Falasca and Zobel, 2008; Hearnshaw and Wilson, 2013; Skilton and Robinson, 2009). However, the extant literature is mainly theoretical and no empirical evidence of the nature of the link between the two dimensions has been provided so far. Therefore, this study is a step forward in addressing this knowledge gap, since it may offer empirically-grounded discussion on the influence of SC complexity drivers on resilience constituents.

Since prior contributions concentrated on specific aspects of the relationship between SC complexity and resilience, our results can be related to several prior works, either providing empirical confirmation or knowledge extension. For example, the positive influence of *the number and layers of facilities in the SC* on visibility, velocity and collaboration has been only theoretically investigated by Durach et al. (2015) and Thome et al. (2016), thus our study provides empirical evidence to their arguments. In addition, by proving the positive influence of all dynamic complexity drivers on the four resilience constituents, this study covers a relevant gap in extant literature, as only few authors addressed this issue and from a theoretical perspective only (Gunasekaran et al., 2015; Hearnshaw and Wilson, 2013; Thome et al., 2016; Durach et al., 2015).

The analysis of the 16 case incidents revealed that the relationship between SC complexity and resilience is multifaceted and ambivalent in nature. Each complexity driver affects at least two constituents. For most drivers the influence is positive, i.e. the higher the complexity the higher the resilience, but there are also aspects of inverse relationship, since some specific complexity drivers impair the level of effectiveness of one or more resilience constituents.

Flexibility is the most affected constituent. SC complexity induced by *differences between facilities* impacts on it negatively, while all the other complexity drivers show positive effects. This is in line with earlier studies arguing that the number of supply chain entities and flows between them are directly proportional to flexibility (e.g. Falasca et al., 2008; Arkhipov et al., 2001). This is explained considering that the higher the SC complexity, the higher the level of physical and functional redundancies exploitable by the company to set up alternative strategies to cope with the disruption. Collaboration is strongly influenced too, but mainly by structural drivers, which play an ambivalent role. On the one hand, the internal structure of the supply chain (e.g. *number and layers of facilities in SC*) ensures higher collaboration among different facilities. On the other hand, even though a higher number of suppliers opens up to a wider set of collaborative actions, tight collaboration can be actually developed when the number of suppliers is low and a single sourcing strategy is applied. Considering velocity, it is highly and positively influenced by dynamic complexity drivers; with the exception of *new customers or suppliers*, all of them increase velocity, since they allow the company to be already used to frequently and rapidly implement changes to its operations and develop new solutions. For instance, being used to new products introduction, Sanofi Genzyme could face drugs shortage due to a virus contamination in 2009 by introducing experimental drugs as substitutes. Another example is Nestlé, which in 2010 rapidly renovated products eliminating palm oil in order to fight social media attacks. Being able to rapidly reconfigure SC activities and facilities positively influences velocity too, as it enables to timely react to incidents, for example easily changing transportation mode. Dell, when faced with the labour lockout involving union dockworkers, chartered 18 planes to cover the lack of cargo ships, ahead of other actors affected in the same way. In this regard, our results enlarge and strengthen the empirical ground for building a consistent conceptualisation and operationalisation of resilience from dynamic capability theory (Birkie et al., 2014). Finally, visibility is influenced by both structural and dynamic complexity drivers: in line with the arguments from e.g. Brandon-Jones et al. (2014) and Skilton and Robinson (2009), the more complex is the set of actors the company relates to, the lower is the visibility on them. Besides, we argue that the greater is the dynamicity characterizing the supply chain, the higher is the visibility.

Conclusions

Structural and dynamic dimensions of SC complexity strongly influence SC resilience. The study proves that their relationship is multifaceted, ambivalent and not easy to be disentangled. Therefore, to achieve a thorough understanding, an in-depth analysis was carried out, investigating the links between complexity drivers and resilience constituents as they emerge from past SC disruption events in different sectors. New elements of the relationship have been revealed, while other received empirical confirmation. Although most of the drivers show a positive influence on several resilience constituents, indicating that the higher the complexity the higher the resilience, negative effects were observed as well, i.e. some complexity drivers may impair resilience constituents. In particular, static complexity drivers have both positive and negative effects on resilience, while dynamic complexity drivers are dominantly positive for the sake of SC resilience.

The extant literature on the influence of supply chain complexity on resilience is still scanty and mainly conceptual, such as contributions on the influence of the number and layers in the supply chain on visibility, velocity and collaboration (Gunasekaran et al. 2015; Hearnshaw & Wilson 2013). In this regard, our study originally contributes to the state-of-the-art and in particular offers empirically-grounded discussion on the influence of dynamic complexity drivers on resilience constituents.

The interactions between SC complexity drivers and resilience constituents, as discussed in the present study, have also practical implications for SC management. Results may support managers in making more informed and better SC management decisions, especially when it comes to complexity management in globally dispersed SCs. Managers could identify for each SC complexity driver the positive or negative consequences on specific resilience constituents and implement strategic or tactical decisions able to compensate weaknesses on one constituent (e.g. visibility) with improvements on another one (e.g. flexibility). In addition, the rich empirical descriptions of critical incidents can be leveraged for designing and implementing successful solutions.

Despite the theoretical and practical contributions, the study presents limitations too. The main one is that not all the SC complexity drivers were addressed, as some - such as "interaction between teams" and "internal operational dynamics" - were difficult to document from secondary data sources only. Furthermore, while attempts were made through predefining structure for encoding, analysis and triangulation, it may not be possible to avoid researchers' possible biases with qualitative analysis.

In conclusion, future research endeavours should concentrate on generalising and strengthening current results through a quantitative research approach for the testing of hypotheses; on the other hand, the scope of the research could be extended to the investigation of the role of different complexity management practices.

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