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Burden or blessing in disguise: interactions in supply chain complexity

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Abstract

Purpose – While systems theory explicitly considers interactions as part of a system's complexity, supply chain complexity (SCC) is mostly conceptualized and measured as a linear summation of several aspects. The purpose of this paper is to challenge the general understanding by explicitly investigating interactions between and across different types (detail and dynamic) and levels (plant, supply chain, environment) of SCC.

Design/methodology/approach – An exploratory multiple case study methodology is adopted drawing on in-depth semi-structured interviews with respondents from eight manufacturing plants in the food processing industry.

Findings – On the one hand, it is found that different types add and increase overall SCC. On the other hand, the study also shows the opposite: interactions between detail and dynamic complexity can reduce the overall SCC experienced. Additionally, the findings highlight the specific food processing characteristics such as the variability of quality and quantity of raw materials that underlie interactions between types and levels of SCC.

Originality/value – This study adds to theory by empirically showing that interactions across and between types and levels do not automatically increase, but might also reduce SCC. As such, the findings contribute new detail to the concept of SCC: aspects of complexity do not necessarily add up linearly. Additionally, this study is one of the first to demonstrate how specific contextual aspects from the food processing industry relate to SCC.

Keywords Complexity, Food processing industry, Case study research, Supply chain complexity

Paper type Case study

1. Introduction

The negative performance impacts of supply chain complexity (SCC) such as higher costs (Wu *et al.*, 2007), lower delivery performance (Vachon and Klassen, 2002), schedule attainment or customer satisfaction (Bozarth *et al.*, 2009) are well established in theory and practice. At the same time, however, organizations struggle to mitigate the possible negative effects of SCC as it is difficult to trace the performance impact to individual aspects. For example, globalization has led to growth in both organizational product range and number of target markets, which in turn increased the complexity of the supply base in terms of the number of, the degree of differentiation between and level of inter-relationships among suppliers (Choi and Krause, 2006). What becomes apparent is that the level of SCC and its performance outcomes are influenced by interactions. Complex systems theory has long acknowledged this notion of interactions between system elements as a determinant of complexity and consequently performance (Simon, 1962). Given the role and importance of interactions in systems theory, it is surprising that this is hardly covered in SCC research to date (Vachon and Klassen, 2002; Bozarth *et al.*, 2009).

SCC is usually broken down into two types of complexity: detail and dynamic (Bozarth *et al.*, 2009; Aitken *et al.*, 2016). Depending on the focus and scope of studies, other distinctions/classifications have been associated with SCC such as dimensions (Vachon and Klassen, 2002), sources (Perona and Miragliotta, 2004) or drivers (De Leeuw *et al.*, 2013). These aspects are often supposed to lead to a linear increase in complexity (e.g. Isik, 2010; De Leeuw *et al.*, 2013) with negative performance impacts (Wu *et al.*, 2007). There is, however, some recent evidence suggesting that managing complexity involves interactions



as mitigation strategies can decrease some aspects of complexity and increase others (De Leeuw *et al.*, 2013). Accordingly, the notion of SCC having mainly adverse impacts on performance has been challenged (Aitken *et al.*, 2016; Wiengarten *et al.*, 2017). We build on this idea, and zoom in on interactions between aspects of SCC, acknowledging that different types of SCC might reinforce or mitigate the ultimate performance effect. Additionally, none of the studies to date have considered that complexity can originate from different levels that are relevant to SCC. Similarly to supply chain risks (e.g. Jüttner *et al.*, 2003), sources of complexity can stem from an organization, the supply chain and the environment. Such limited understanding also poses potential problems for organizations as they might over- or underestimate the performance effects of SCC and accordingly take misguided decisions in managing SCC. Understanding the interactions influencing the level of SCC might help in better grasping the overall performance effects of decisions such as changing the number of products or expanding to new markets. Accordingly, we argue that the incomplete understanding and the lacking consideration of interactions in SCC are an important gap both theoretically and practically. Considering that SCC is said to be context specific (De Leeuw *et al.*, 2013; Gerschberger *et al.*, 2012) we choose the food processing industry as a specific setting for our study. Drawing on the general idea of systems theory, arguing that interactions are an important driver of a systems behavior (i.e. performance) (Choi and Krause, 2006), we aim to close this gap by exploring the following research question:

RQ. How do types and levels of SCC interact in food processing plants?

We employ a multiple case study drawing on qualitative data from eight food processing plants to develop propositions and make three key contributions. First, our study advances the predominantly conceptual discussion on SCC by empirically investigating interactions of different SCC types over three levels. In doing so, we are able to add important fine grained details on the sources, manifestations and consequences of SCC within and between the organizational, supply chain and environmental level that, to date, have been neglected in research. Second, we contribute to literature by exploring the influence of specific contextualities as present in the food processing industry and their relation to the types of SCC on different levels. This allows us to derive new insights into the importance of context for SCC, which has been highlighted in literature (e.g. De Leeuw *et al.*, 2013), but hardly explored empirically. Third, from a managerial perspective, managers benefit from the enhanced understanding of the interactions when making decisions which influence SCC.

2. Theoretical background

The notion of complexity can be traced back to the seminal paper of Simon (1962), who argued that complexity regards non-simple interactions between elements in a system which explain a systems' behavior. In the 1990s systems thinking was extended to complex adaptive systems theory and acknowledged that systems co-evolve with their environment due to interactions between the system and its environment (e.g. Holland, 1992). Interactions that lead to complexity can be internal and external to a system, based on the principles of self-organization or co-evolution (Choi *et al.*, 2001; Pathak *et al.*, 2007). In a self-organized system no single actor dictates the collective behavior; patterns are created through simultaneous and parallel activities of multiple members (Choi *et al.*, 2001). This prevents chaos and facilitates a state of equilibrium in the system (Anderson, 1999). As such, self-organization enables a system to function without external control due to internal control over interactions between elements within the system (Surana *et al.*, 2005). We label these horizontal interactions. Co-evolution, in contrast, refers to interactions among the system and the environment and therefore entails interactions between multiple levels (McCarthy, 2004). Here, environmental forces require agents within a system to make

changes, which in turn induce changes to the environment (Choi *et al.*, 2001; Pathak *et al.*, 2007). We refer to these as vertical interactions. For further reading, we refer to the complex adaptive systems literature (e.g. Holland, 1992; Anderson, 1999; Choi *et al.*, 2001).

Choi *et al.* (2001) were among the first to argue that supply chains can also be seen as complex adaptive systems in which “collective system performance or behavior emerges as a nonlinear and dynamic function of the large number of activities made in parallel by interacting entities” (Pathak *et al.*, 2007, p. 550). In this study, we draw on the idea of horizontal and vertical interactions as introduced in (complex adaptive) the systems theory to further explore the concept of SCC. We define SCC as “the level of detail complexity and dynamic complexity exhibited by the products, processes and relationships that make up a supply chain” (Bozarth *et al.*, 2009, p. 80). Detail and dynamic complexity relate to the self-organization of the system, i.e. horizontal interactions. At the same time, co-evolution requires consideration of complexity on different levels: the plant, supply chain and environment (Bozarth *et al.*, 2009), i.e. vertical interactions. The possible origins and manifestations of types of complexity and levels of complexity are depicted in Table I and will be further outlined below.

2.1 Types of SCC

The conceptualization of SCC as detail and dynamic complexity is well accepted in theory (Aitken *et al.*, 2016; Serdarasan, 2013; Bode and Wagner, 2015) and overarches other aspects used in studies of SCC such as diversity, variability, complicatedness or standardization (e.g. Vachon and Klassen, 2002; Perona and Miragliotta, 2004; de Leeuw *et al.*, 2013). Detail complexity is also referred to as static complexity (Frizelle and Woodcock, 1995) and defined as “the distinct number of components or parts that make up a system” (Bozarth *et al.*, 2009, p. 79). Depending on the level at which a system is assessed previous work addressed detail complexity by measuring the number and variety of products, processes, customers and suppliers (Vachon and Klassen, 2002; Bozarth *et al.*, 2009; Serdarasan, 2013) (see Table I). It therefore relates to the structure of the supply chain (Serdarasan, 2013; Cheng *et al.*, 2014) as evident in the numerousness and variety of components (Vachon and Klassen, 2002). More specifically, while numerousness is linked to the amount of components where “the higher the number of the systems’ component, the higher

	Dynamic complexity (“the unpredictability of a system’s response to a given set of inputs” (Bozarth <i>et al.</i> , 2009, p. 79))	Detail complexity (“the distinct number of components or parts that make up a system” (Bozarth <i>et al.</i> , 2009, p. 79))
Plant (internal to the organization (Jüttner <i>et al.</i> , 2003))	(Lack of) Control over processes Employee induced variability Ability to forecast/plan Manufacturing schedule instability	Number/variety of products Number/variety of processes One of a kind/low volume batch production
Supply chain (internal to the supply chain, but external to the organization (Jüttner <i>et al.</i> , 2003))	Demand/supply variability Parallel interactions Process synchronization	Type of product Number/variety of suppliers Number/variety of customers Process interactions
Environment (external to the organization and external to the supply chain (Jüttner <i>et al.</i> , 2003))	Changes in the geopolitical environment Product lifecycles Trends in the market Developments in the future	Changing needs of customers Changing resource requirements New technologies

Table I.
Definition and operationalization of detail and dynamic complexity

Sources: Based on Serdarasan (2013), Bozarth *et al.* (2009), Vachon and Klassen (2002)

the complexity” (Isik, 2010, p. 3684), variety concerns the homogeneity or heterogeneity of the components of a systems in terms of, e.g., the supply base (Choi and Krause, 2006), types of products (Vachon and Klassen, 2002) or markets served (Bozarth *et al.*, 2009). The predominating logic in literature is (e.g. Isik, 2010; De Leeuw *et al.*, 2013) that higher levels of numerousness or variety lead to a higher level of SCC implying a negative performance impact (De Leeuw *et al.*, 2013). For example, Choi and Krause (2006) argue that variety in the supply base (differences in organizational cultures, operational practices, technical capabilities and geographical separation) requires more or less coordination and hence impact costs and/or responsiveness.

Dynamic complexity is also referred to as operational complexity (Wu *et al.*, 2007). It is related to uncertainty and has been defined as “the unpredictability of a system’s response to a given set of inputs” (Bozarth *et al.*, 2009, p. 79). Uncertainty can then be associated with time and randomness (Serdarasan, 2013) as well as ambivalence and ambiguity (Isik, 2010) in, e.g., processes, demand and/or the geopolitical environment (see also Table I). This makes the application of rules and procedures difficult and hence increases SCC (Bozarth *et al.*, 2009). There is a rich body of literature on uncertainty in supply chains discussing the concept, frameworks and classifications (see Simangunsong *et al.*, 2012 for a review). However, whereas that work sees uncertainty as an outcome/consequence of SCC (Wilding, 1998; Van der Vorst and Beulens, 2002; Flynn *et al.*, 2016), we consider uncertainty as a constituent element of (dynamic) complexity following Bozarth *et al.* (2009), De Leeuw *et al.* (2013) and Aitken *et al.* (2016).

2.2 Levels of complexity

Detail and dynamic complexity can arise on different levels: from within an organization (internal) or from the supply chain (upstream and downstream) (Bozarth *et al.*, 2009). Similarly to the sources of supply chain risks (e.g. Jüttner *et al.*, 2003) and linked to complex adaptive systems theory (Choi *et al.*, 2001), the environment (e.g. industrial context or socio-political influences) can also be an influential factor in complexity (Aitken *et al.*, 2016) as the supply chain and its environment co-evolve (Surana *et al.*, 2005). Therefore, as depicted in Table I, detail complexity can be internal to an organization, e.g., batch sizes, number and heterogeneity of products or production steps (Bozarth *et al.*, 2009); within the supply chain, e.g., number and heterogeneity of suppliers, customers or competitors (Vachon and Klassen, 2002); or exhibited by the environment, e.g., number of rules and regulations (Manuj and Sahin, 2011). Similarly, dynamic complexity is exhibited at the organizational level, e.g., lack of control over processes (Isik, 2010), the supply chain level, e.g., process synchronization (Sivadasan *et al.*, 2002), and the environmental level, e.g., geopolitical climate (Manuj and Sahin, 2011).

2.3 Conceptual framework

Figure 1 introduces our conceptual framework. It consolidates the three main variables introduced above: detail complexity related to variety and numerousness (Bozarth *et al.*, 2009; Vachon and Klassen, 2002); dynamic complexity which concerns uncertainty (Bozarth *et al.*, 2009; Aitken *et al.*, 2016) and the three levels where complexity can arise and manifest, i.e. organizational, supply chain and/or environmental (Jüttner *et al.*, 2003; Bozarth *et al.*, 2009) (see also Table I). While introduced separately the types (detail and dynamic) and levels of complexity cannot be considered in isolation: Bode and Wagner (2015, p. 223) highlight horizontal interactions as they found that the “three drivers or dimensions of complexity act synergistically [...] supporting the notion that in systems the “whole is more than the sum of its parts” (Simon, 1962). Furthermore, more implicitly, it has been argued that reduction of uncertainty (dynamic complexity) cannot be achieved by organizations alone, but that interactions exist between sources of uncertainty internal to an organization and sources external to an organization within the supply chain (Childerhouse and Towill, 2004),

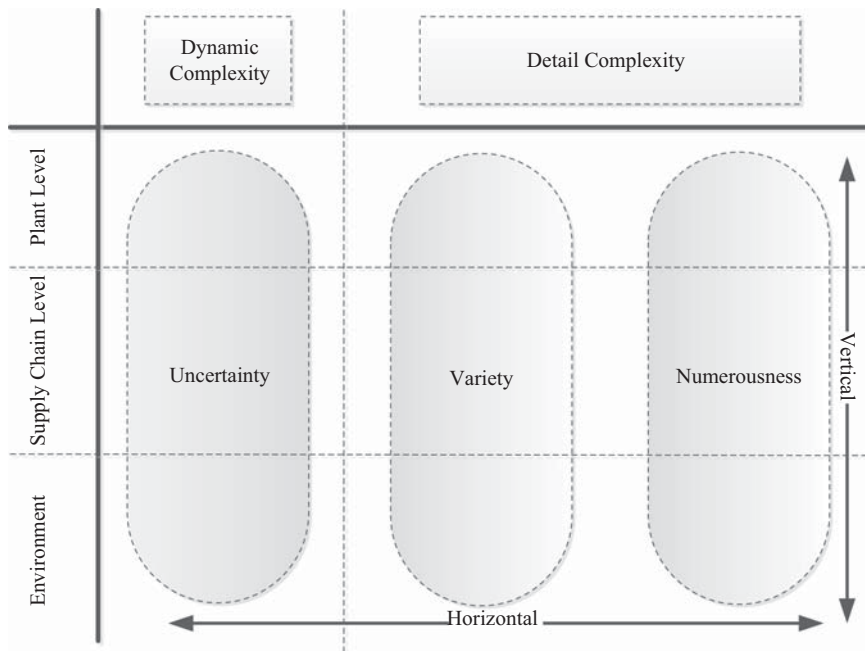


Figure 1.
Conceptual framework

i.e. vertical interactions. For example, uncertainty in relation to raw material arrivals (supply variability) leads to uncertainty at the plant level in terms of increased manufacturing scheduling instability. Such interactions can be observed in several industries, e.g., construction (Gosling *et al.*, 2013), transport (Sanchez Rodrigues *et al.*, 2008), automotive (Martinez Sánchez and Pérez Pérez, 2005) or the food processing industry (Van der Vorst and Beulens, 2002).

At the same time, SCC has been found to be context specific (Gerschberger *et al.*, 2012; De Leeuw *et al.*, 2013). Accordingly, we draw on the systems principles of co-evolution and self-organization to explore horizontal (between dynamic and detail complexity) and vertical (across levels) interactions (see arrows in Figure 1) in a specific setting: the food processing industry. Due to industry-specific characteristics linked to dynamic and detail complexity, the food industry is considered more complex than other industries (Shukla and Jharkharia, 2013). On the one hand, sources of dynamic complexity affect food supply chains due to variability in terms of quality and quantity of the raw materials (Van Donk, 2001) and the perishable nature of raw materials and the end products (Van der Vorst and Beulens, 2002). On the other hand, the divergent product structure (Van Wezel *et al.*, 2006) and the high number of suppliers delivering the same type of raw material (Van Kampen and Van Donk, 2014), both influence the level of detail complexity. While (complex adaptive) systems literature has long acknowledged the role of such interactions in systems (e.g. Holland, 1992; Choi *et al.*, 2001), we have little insights into the causal relationships of SCC interactions in theory to date. Accordingly, we employ a multiple case study aiming to explore how types and levels of SCC interact at manufacturing plants in the food context.

3. Methodology

While the importance of context in SCC has been highlighted in previous research (e.g. Gerschberger *et al.*, 2012; De Leeuw *et al.*, 2013), we do not know the exact influence of it on SCC.

Therefore, our study requires the exploration of the phenomenon (in this case SCC) within its real-life setting. Consequently, we adopt a multiple case study design which is particularly suitable when the boundaries between a concept and the context are not well understood (Yin, 2009).

3.1 Case selection

The unit of analysis in this study is a manufacturing plant, which experiences SCC (in line with Vachon and Klassen, 2002; Bozarth *et al.*, 2009; De Leeuw *et al.*, 2013). Consequently, we purposefully selected eight manufacturing plants from six organizations (A-H) applying theoretical replication in relation to detail complexity. Specifically, we sought out cases that differ in the size of the respective plant (De Leeuw *et al.*, 2013), product variety, i.e. the number of stock keeping units (SKUs) (Vachon and Klassen, 2002), the number of customers and the target market for the processed goods (B2B or B2C) (Bozarth *et al.*, 2009), and the number of suppliers including the origin of the raw materials (local or global) (Bode and Wagner, 2015). To ensure no interferences of national culture (e.g. management style) on the outcome of our study, all (focal) plants are located in the Netherlands. Table II shows an overview of the eight cases.

Case	Volume end product	Number of SKUs	Customers	Number/origin of suppliers	Interviewees
A	350k tons	700	Consumer product, exported worldwide	High, local	A.1 Supply chain manager (36 min), A.2 Logistical manager (41 min), A.3. Planner (50 min), A.4 Manager supply allocation (52 min)
B	130k tons	200	Consumer product, export to Asia and Africa	High, local	B.1 Master planner (52 min), B.2 Business development manager (44 min), B.3 Supply chain manager (62 min)
C	200k tons	150	Industrial processors mainly within the Netherlands	Low, regional	C.1 Supply chain coordinator (58 min), C.2 Purchasing manager (50 min)
D	20k tons	600	Industrial processors, mainly within the Netherlands	Low, local	D.1 Business development manager (62 min), D.2 Planner (62 min)
E	26k tons	1,200	Consumer product, export within Europe	High, global	E.1 Production manager (54 min), E.2 Logistical/SC manager (56 min)
F	100k tons	200	Consumer product, export Middle East, Asia, South America	Low, local	F.1 Logistical manager (82 min), F.2 Production manager (63 min)
G	650k tons	200	Industrial processors, worldwide	High, local	G.1 Planning and distribution manager (66 min), G.2 Manager sourcing and contracting (81 min)
H	150k tons	> 1,000	Consumer product, export to Western Europe	Low, local	H.1 Manager planning and logistics (59 min), H.2 Head of purchasing (76 min)

Table II.
Overview cases

3.2 Data collection

The main sources of data in this study are 18 semi-structured interviews. To be able to triangulate the answers and to ensure familiarity with the interactions entailed in SCC on a global level, we interviewed for each case at least two employees with more than ten years work experience. Furthermore, in selecting interviewees we paid particular attention to their knowledge about either internal processes (e.g. production planner, production manager) or external processes (e.g. supply chain manager, logistical manager). This entailed discussions with key contact persons up front to identify the most suitable respondents. An interview protocol was developed based on literature (e.g. De Leeuw *et al.*, 2013; see the Appendix). In formulating the questions, we paid attention to asking for specific examples that show how key concepts of SCC operate in practice. Besides questions regarding general information with respect to the job and the organization, we asked interviewees how they experience SCC in terms of uncertainty, numerosness and variety, and what they do to deal with those aspects. The main questions from the interview protocol were followed up with more specific questions during the interview to allow us to fully explore the examples that were given. Hence, while all interviewees were asked the same questions, the nature of the semi-structured interviews that we employed, allowed us to further explore the concepts under investigation and specific interactions described by using more detailed questions whenever needed. All interviews took place at the case plants in the period from March 2014 to May 2015 were recorded, transcribed verbatim and send back to the interviewees for verification and validation. Whenever needed, interviews were followed up with e-mails and/or informal discussion to clarify aspects of the interview or to gather additional insights that were required to understand specific situations outlined.

To achieve internal triangulation (Voss *et al.*, 2002), additional to the interviews, information from closed questions was gathered (capturing aspects such as the number of steps in the production process or information regarding the supplier market), along with observations during plant tours and archival data from internal documents and the companies' webpages. This information helped us not only to get a better understanding of the different cases and the inherent types of SCC over the different levels, but was also used during the analysis next to the interviews.

3.3 Data analysis

To analyze the acquired data we followed the three steps of Miles and Huberman (1994): data reduction, data display and conclusion drawing and verification. Hence, we started to reduce data by deductively coding words, sentences or paragraphs from the transcripts related to any of the two types of complexity or levels of SCC. Next, we had to distinguish whether the reduced data related to a source of complexity or the impact of complexity. This allowed us in the following step to not only establish source and impact pairs but also whether the impact could be associated with increased or decreased complexity. We displayed these data in graphics to get an overview of the type of interaction, i.e. vertical or horizontal. What became apparent, however, was that there were also interactions across levels and types of complexity, e.g., when sources of detail complexity at the plant level had an impact on dynamic complexity at the supply chain level. As these were both horizontal and vertical, we labeled them diagonal. To draw conclusions, in a final step, we sought out explanations between the source of complexity and impact of complexity applying interpretative coding. The interpretive coding allowed us to derive several characteristics linked to, e.g., the market, food or production strategies that explain the SCC interaction that we identified. Throughout the data analysis processes we used the conceptualization of the two types of SCC over the three levels from Table I. This also helped in linking food specific terminology (e.g. Van Donk, 2001) we encountered to the main concepts of SCC. After the within case analysis, two researchers independently conducted the cross-case analysis.

Furthermore, throughout the whole analysis process, the researchers had several meetings to reach consensus on the coding schemes, the initial within case analysis and finally the cross-case findings.

4. Findings: interactions in SCC

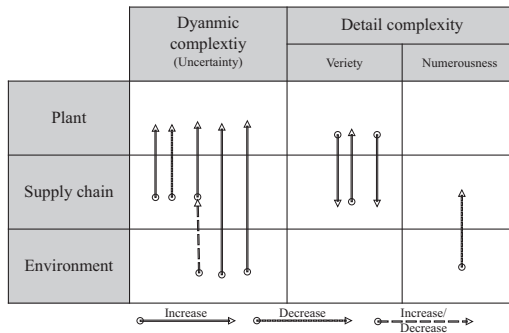
Aiming to explore interactions of SCC from the perspective of a manufacturing plant we find that organizational, food, market and production strategy characteristics influence dynamic and/or detailed complexity across the plant, supply chain and environmental level. In outlining our findings, we first describe vertical interactions (i.e. across levels for each type), followed by horizontal (i.e. across types for each level) and diagonal (i.e. across types and levels) interactions, which emerged during data analysis.

4.1 *Vertical interactions in dynamic and detail complexity*

On the one hand, we find that vertical interactions in relation to dynamic complexity are influenced by organizational, food and market characteristics. The analysis shows that uncertainty is passed from higher to lower levels, i.e. sources of uncertainty stem mainly from outside the plant or even outside the supply chain. On the other hand, we find that vertical interactions in relation to detail complexity are influenced by market, food and production strategy characteristics. Surprisingly, and in contrast to the findings on dynamic complexity, our data show that next to one directional influence from higher to lower levels, detail complexity can originate at lower levels and influence higher levels, i.e. variety and numerousness originating from the plant can increase detail complexity at the supply chain level. Hence, the interactions of detail complexity are bi-directional. An overview of vertical interactions identified and the explanation for the effect on complexity are outlined in Figure 2.

4.1.1 Vertical interactions in dynamic complexity. We find that food characteristics, explained by seasonality as well as variability of quality and quantity of raw materials, influence dynamic complexity at the supply chain and plant level. In particular, the data show that the environmental level factor climate influences the quantity (case G) and quality (cases C, F) of raw materials on the supply chain level with different consequences for dynamic complexity. On the one hand, as in case G, variability in the quantity of raw materials due to weather can increase or decrease supply availability as “if the sun shines and it rains, we will get a lot of [raw materials] and thus [product g]. If it doesn’t rain and there won’t be any sunshine, at the end we have got very little [product g]” (G1). The variability in quality of harvests due to weather in cases C and F, on the other hand, requires adjustments of production technologies, which cannot be planned for until the raw material is available. Hence, dynamic complexity increases as level of control over processes decreases. Unexpectedly, we find that seasonality can be used to decrease rather than increase dynamic complexity at the plant level. By serving different markets that require the end product at different times of the year (the various customers demonstrate different demand peaks due to the harvest cycles of their main ingredient, e.g. potato vs fish processing industry), case D is able to optimize capacity usage without being affected by demand seasonality of individual customers. Accordingly, demand and supply can be matched in the best possible way. Hence, industrial processors can decrease plant level dynamic complexity (manufacturing schedule instability) by exploiting the variation in the demand structure of their customers (supply chain level).

Additionally, our data show that organizational characteristics, contractual purchasing commitments in particular, lead to an increase in dynamic complexity. Supply variability on the supply chain level regarding incoming raw material volumes that have to be processed directly, effect operating plants: whether “there will be demand or not, those [raw materials] will be distributed to our plants and will be available for processing” (G2). The interaction is closely related to the interaction between environment and supply chain due to food



Vertical Interaction in Detail Complexity					
Case	Category	Source	Impact	Explanation	Quote/ Example
G I (A, B) SC → P	Organizational Characteristics	Supply variability	Manufacturing schedule instability (increase)	Difficulties in matching demand and supply due to long term purchasing commitment lead to increased manufacturing schedule instability	"We have to process all the [raw material] we receive. We cannot just order what we expect to need [for scheduling manufacturing]." (A1)
G II (A, B) E → SC		Climate	Supply variability (increase/ decrease)	Effects of weather leads to and increased and/ or decreased variability in quantity of raw materials that can be processed	"If the weather is good for about 3 weeks, then our harvest-forecast [supply] will increase. [...] If the sun is shining and it will rain, we will get a lot of [raw materials] and thus [product g]. If it doesn't rain and there won't be any sunshine, at the end we have got very little [product g]." (G1)
C, F E → P	Food Characteristics	Supply variability	Lack of control in processes (increase)	Variability of the quality of raw materials due to the nature of the products requires short term adjustments to processes and hence, decreases the level of control over internal processes	"The supply is irregular, there is a lot of variation in it, [...]. We have to deal with the surprising issues on the production floor." (F2)
D SC → P		Demand variability	Manufacturing schedule instability (decrease)	Different seasonalities due to the harvest of the main ingredients and different demand patters over the year by the end customer lead to more stable schedules at the plant level	"We try to forecast the seasonality of our customers because they deal with a natural product." [...] "...in our business it is absolutely necessary to forecast the seasonality of our customers to make stable [production] plans." (D1)
E, H SC → P	Market Characteristics	Supply lead time	Difficulty of forecasting/ planning (increase)	Temporal distance between supply and demand lead time (lead time gap) leads to an increased difficulty in terms of matching supply and demand	"But if I decide to sell [product] today, I have to go 40 days backwards since the supplier lead time is very long. And we don't have that horizon of 40 days in advance at the [demand] planning department." (H1)
A, B E → P		Changes in the geopolitical environment	Lack of control processes (increase)	Short notice changes in rules and regulations require adjustments in the production process increasing the lack of control of processes	"And regulation can be seen as variation as well. Requirements, to be allowed to serve a certain market, change as well. The horizon for changes in regulations is mostly a few month. But if you consider that we have to translate this to our production process and recipes this is not long." (A3)
Vertical interaction in Detail Complexity					
Case	Category	Source	Outcome	Explanation	Quote
E I SC → P	Production strategy	Variety of customers	Variety in SKUs (increase)	A higher variety of customers leads to an increase in the variety of SKUs if plants produce customer specific products	"I think the number of recipes is important because if you have one very large recipe it is better to manage than a small one. Large recipes help with efficiency and have performance implications in terms of change over and cleaning times." (E1)
A III, F I, G III P → SC	Food characteristics	Variety of products	Process interactions (increase)	By having a higher variety of products (recipes) at a plant, there is also a higher amount of byproducts-creating an increase in process interactions downstream	"If you want in [location North] more [product a] you need a byproduct of [product b] so these plants are connected as well. To make [product x] you need [product y] so all the derivatives of [raw material] are refined and recombined to different end-products. Each plant contributes to this process we have no stand alone. This is all very complex." (A4)
H II P → SC		Variety of products	Variety of customers (increase)	Byproducts are sold to markets different from the primary market leading to an increase in the customer base	The Netherlands is a [product h1] consuming country, more than [product h2] and so there is a surplus of these products in The Netherlands. For those products, we cannot always find a recipient, and so they are packed in boxes of 10 kg for export all over the world." (H2)
H III E → SC	Market characteristics	Competition in the market	Numerousness of suppliers (decrease)	A demand driven market leads to a decrease of potential customers due to higher competition in the market	"There exist more [raw material processors] than [raw material producers], so it is a crazy market in which we are in competition for suppliers." (H1)

Figure 2.
Vertical interactions
dynamic and detail
complexity

characteristics as overserved in case G which would likely not exist without the organizational characteristic of having long purchasing commitments. Thus, the supply driven nature of cases G, A and B, that is independent of the demand situation, leads to increased dynamic complexity due to the difficulty of matching demand and supply resulting in manufacturing schedule instability.

The third category that we identify is concerned with market characteristics. One of the interactions identified can be explained with the temporal distance between supply and demand lead time (supply lead time) which increases plant complexity in cases E and H due to difficulties to forecast/plan. Demand lead time is very short as “in retail, they decide today what they want next week” (H1). At the same time, the supply lead time is much longer: “If I decide to sell [product h] today, I have to go 40 days backwards” (H1). The key issue is the perishability of the product in relation to the time lag between demand and supply. As supply and demand need to be balanced at the plant level, organizations need to cover for the supply side risks by building inventories. Furthermore, we find that especially plants (cases A, B) that export their products globally face unstable geopolitical environments in which quickly changing legislations increase the lack of control over processes on the plan level. “We have to comply with regulation and list not only the main components of [product b], but all components and everything must be within a certain range. That has impact on our production process as some ingredients are hard to stabilize” (B1).

4.1.2 Vertical interactions in detail complexity. The first characteristic of detail complexity can be explained with the customization of the end product and hence production strategy. We find that that the number of SKUs is determined by the variety in customers if plants produce customer-specific products. At the same time, the level of detail complexity is dependent on the level of customization of the end product: “I think the number of recipes [similar to the bill of material in discrete manufacturing] is important because if you have one very large recipe it is better to manage than a small one. Large recipes help with efficiency and have performance implications in terms of change over and cleaning times” (E1). We find that if solely the packaging line needs to be changed it is perceived as less problematic (case E) than changes that impact the recipes and possibly require new suppliers (case B). Hence, the more generic an end product is, the less problematic are the number and variety of customers (cases A, D). Therefore, the data show that the level of customization, as determined by the customer order decoupling point, is important in determining vertical interactions of detail complexity.

The second category of vertical interactions concerns food characteristics and specifically addresses the role of byproducts that need to be dealt with in producing the primary products, i.e. variety of products (cases A, B, C, F, G, H). Interestingly, while this relationship originates at the plant it increases detail complexity at the supply chain level. We find that cases A and B deliver the former waste products to new target markets, leading to more process interactions at the SC level. “If you want in [location A] more [product a] you need a byproduct of [product b] so these plants are connected. [...] Each plant contributes to this process we have no stand alone. This is all very complex” (A4). Similar interactions are observed in case G, where “in the past, [byproduct] was waste. Nowadays, it is an innovative product and used to produce [product g], to replace [ingredient] in [another product] etc.” (G1).

Similarly to the findings in relation to food characteristics, we also find that byproducts lead to interactions influenced by market characteristics. Here, organizations seek a geographically dispersed customer base for the byproducts to exploit consumer preferences (case H) due to the small size of the local market. The head of purchasing of case H explains: “The Netherlands is a [product h1] consuming country, more than [product h2] and so there is a surplus of these products in The Netherlands. For those products, we cannot always find a recipient, and so they are packed in boxes of 10 kg for export all over the world” (H2). Hence, while the byproducts increase detail complexity in relation to production strategy

characteristics, the added complexity due to an increase in the variety of customers can be beneficial due to price differences in the markets. Moreover, what is interesting here is that in these cases the plants influence complexity on the supply chain level: by satisfying the need of the primary market the plant generates byproducts for which they have to find additional customers. In that process the number and variety of customers increase leading to an increase of complexity at the supply chain level originating from the plant.

4.2 *Horizontal and diagonal interactions*

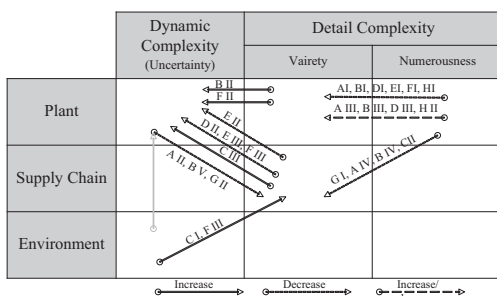
We find horizontal and diagonal interactions between and across the two types and three levels of SCC. The interactions are driven by organizational, food and market characteristics. In particular the analysis of our data reveals that while food characteristics lead to horizontal interactions across different types of complexity, food, market and organizational characteristics lead to diagonal interactions. The particular sources of complexity and the explanation for the horizontal and diagonal effects on complexity are outlined in Figure 3.

4.2.1 Horizontal interactions. All horizontal interactions that we find can be explained by food characteristics. Data in six cases (A, B, D, E, F, H) show horizontal interactions related to detail complexity between the variety and numerousness. In particular our analysis reveals that this can be explained with minimal batch sizes (numerousness), which determine the variety of SKUs a plant can produce effectively: “If you would only have one product it makes it very efficient and we would achieve a huge output. However, we do produce various different types of each product with is related to changeover times, cleaning times, and less efficient use of the resources. So volume does matter” (A1). In fact, four organizations (cases A, B, D, H) stated that their batch sizes are limited by necessary cleaning cycles for the machines. We find that the plants then do not need additional time for switching SKUs, as time for cleaning would be required anyway. Accordingly, organizations can offer a higher variety of SKU without suffering from the negative effects of change overs.

Another horizontal interaction that the analysis shows is between the two types of complexity: detail complexity can lead to an increase in dynamic complexity. The decrease in the level of control over processes in our cases could be linked to the variety in recipes (case B) and variety in process setups (case F). In case F, the variety of process setups can be explained with the need to have standardized outputs while dealing with variable raw materials quality. The production manager argues: “The quality of the end-product has a smaller margin then the quality of the raw material. Therefore, during production we have to – can do – a lot of things to improve the final product” (F1). Similar patterns can be observed in cases A and B, where not only the process setup itself is adapted based on the quality of the raw materials, but also the mixture of the ingredients going into the process to standardize the output. Hence, dynamic complexity increases due to short-term adjustments to recipes to deal with varying raw materials quality which reduces the control over production processes.

4.2.2 Diagonal interactions. Regarding diagonal interactions, we find that food, organizational and market characteristic explain interactions between the two types of complexity over the three levels. Similarly to the interactions identified for detail complexity, our data show that plant level complexity sources can lead to changes in complexity on the supply chain level.

First, within detail complexity and in relation to food characteristics, we observe that the ratio volume per product (one of a kind/low volume batch production) limits the potential customer base at the interface between plant and supply chain. Hence, depending on plant-level batch sizes, the customer variety at the supply chain level decreases or increases. The manager sourcing and contracting in case G elaborates: “If there is a customer who purchases only [xx] tons a year, you need to ask yourself if it is possible. [...] if we are talking about size, the smaller the volumes, the more complex it gets and the bigger



Horizontal Interactions					
Case	Category	Source	Impact	Explanation	Quote
B II P(V) → P(U)	Food characteristics	Variety in products	Lack of control over processes (increase)	The variety of recipes leads to an increase lack of control over processes due to quality variations of the raw material	"A problem is that it takes long to develop a product. If we change a base product it can take longer than a year because we have to audit each supplier. The [raw material] is not the same every day." (B1)
F II P(V) → P(U)		Variety in process setups	Lack of control over processes (increase)	Creating standardized output from variable input requires variety in process setups leading to a decrease of the level of control over processes since short terms changes in setups are harder to plan	"We were talking about the [raw material], the quality of the end-product has a smaller margin than the quality of the raw material. Therefore, during production we have to - can do - a lot of things to improve the final product." (F1)
A I, B I, D I, E I, F I, H I P(N) → P(V)		One of a kind/ low volume batch production	Variety of SKUs (decrease)	Minimum batch sizes decrease the variety of SKUs because of cleaning times and sequence dependencies in scheduling	"It would be fantastic if we can produce a high volume per product, it would result in an easy operation. However, what drives complexity, is the volume per product. It makes all the difference if we produce 3 products, each with high volume or 300 products, all in small batches." (F2)
A III, B III, D III, H II P(N) → P(V)		One of a kind/ low volume batch production	Variety of SKUs (decrease/ increase)	Cleaning cycles after each batch are required even if the same recipe is produced in the following batch. This allows plants to change SKUs without additional time lags hence increases the variety of products which can be produced economically	"If you would only have one product it makes it very efficient and we would achieve a huge output, however we do produce various different types of each product with is related to changeover times, cleaning times, and less efficient use of the resources. So volume does matter." (A1)
Diagonal Interactions					
Case	Category	Source	Impact	Explanation	Quote
E II SC(V) → P(U)	Food characteristics	Variety of suppliers	Lack of control over processes (decrease)	Due to a variety of suppliers delivering different qualities of raw materials, plants can stabilize variability in supply leading to better control over their production processes	"The quality of the raw materials is quite stable. [...] If there are small deviations we always can account for it by adjusting the blends slightly [...] We have 40 different types of [raw materials] from which we produce 200 different [base products]" (E1)
C I, F III E(U) → SC(V)		Variability of quality and quantity of raw materials	Variety of suppliers (increase)	Environmental aspects such as climate create variability in quality and quantity of raw materials. In turn, plants increase the variety in suppliers (i.e. by contracting suppliers from different regions)	"When you are dealing with raw materials, with a natural product, you have to deal with climate: where does it grow, what is the quality and weather like. [...] you look at where you buy from, you buy from various regions. You could also say: "I will buy everything from one region", but if it then turns out that region had a bad summer, resulting in very bad quality, then you will have a problem. Therefore, we don't want to be dependent of one region." (C1)
G I, A IV, B IV, C II P(N) → SC(V)		One of a kind/ low volume batch production	Variety in customers (decrease)	Minimum batch sizes cause a limit in the variety of customers as certain volumes per recipe are needed in order to produce it economically	"If there is a customer who purchases only [xx] tons a year, you need to ask yourself if it is possible. Or if that customer will grow in the future? In that case, if we are talking about size, the smaller the volumes, the more complex it gets and the bigger the chance of obsolescence." (G1)
D II, E III, F IV P(U) → SC(V)	Market characteristics	(Difficulty to) forecasts/ plan	Variety of customers (decrease)	Capacity constraints at the plant level due to high utilization can decrease the variety of customers, since plants start actively managing their customer base	"We used to react on short notice changes and changed our production planning for that. Now we do not engage in such behavior anymore but better plan our capacity [...]. That means that we sometimes must sell a "no"." (D1)
C III SC(V) → P(U)		Variety of customers	Difficulty to forecasts/ plan (increase)	A higher variety of customers leads to an increase in the difficulty to forecasts/plan due to power imbalances in the chain towards the demand side	"We are in a market with overcapacity, a buyers' market, the buyer dictates the market, which means we cannot say, we don't want to do this and that, which makes it more complex." (C2)
A II, B V, G II SC(V) → P(U)	Organizational characteristics	Variety of customers	Demand variability (decrease)	Having many diverse customers aids in decreasing demand variability as plants are less prone to demand variations of single customers and hence decrease the overall demand variability	"On the company level diversity is very helpful because it is a risk mitigation strategy. We spread the risk over several products and markets. [...] Looking at diversity from my perspective it is helpful and needed to have flexibility in processing the continuous inflow of [raw material]. Also a higher number of customers it is nice have to spread the risk." (A3)

Figure 3. Horizontal and diagonal SCC interactions

the chance of obsolescence” (G1). Additionally, data show that on an environmental level the variability of the quantity and quality of raw materials (supply variability) may, besides horizontal interactions, also explain diagonal interactions. Here, we find that organizations seek a higher variety of suppliers across different geographical regions for two reasons. First, additional sources are used to counter the effect of the weather on the harvest (cases C, F). “You have to deal with various quality aspects [...], you buy from various regions. You could also say: ‘I will buy everything from one region’, but if it then turns out that region had a bad summer, resulting in very bad quality, then you will have a problem” (C2). Second, in case F, we see that geographical dispersion is used to exploit the time difference of the harvest across regions as they “[...] get their [raw material] from [suppliers] located below the major rivers in The Netherlands, [...], but in some cases also from the Flemish region and the north of France. In the early season, we get our [raw material] from [suppliers] located in the west of Germany” (F2).

Additionally, market characteristics influence diagonal interactions between the two types of complexity. We find that in situations where demand exceeds plant capacity (cases D, E, F) the number of SKUs decreases: plants then select customers to be served based on profitability. This is, however, not visible in cases A, B, C, G and H. Accordingly, the analysis shows that plants with buffer capacity are more likely to accept small customers that might increase the numerousness of SKUs and the customer base and therefore detail complexity. Hence, we find that the plant level influences the supply chain level: if plans and forecasts show a high capacity utilization it leads to a reduction of the variety of customers to match capacity and demand; deliberate choices are made to limit the number of customers (case D): “We used to react on short notice changes and changed our production planning for that. Now we do not engage in such behavior anymore [...]. That means that we sometimes must sell a ‘no’” (D1). In case C, we see that a misbalance of capacity between the manufacturing plant and the demand side also has implication for the focal plant as they are forced to absorb demand variability with forecasting and planning. “We are in a market with overcapacity, a buyers’ market. The buyer dictates the market, which means we cannot say, we don’t want to do this and that, which makes it more complex” (C2).

Diagonal interactions that span across detail and dynamic complexity relate to organizational characteristics when long-term contractual purchasing commitments (cases A, B, G) are involved. In all three cases, organizations have to deal with supply variability as they have committed to processing all raw materials before receiving it (see vertical interactions in 4.1.1). The gray arrow in Figure 3, accordingly, indicates that vertical and diagonal interactions can also occur simultaneously. As such, we find that our cases counter the increased dynamic complexity at plant level by increasing the variety of customers. In that way a stable demand situation is created, which is required to process the continuous inflow of perishable raw materials. Hence, those cases make a deliberate choice to increase detail complexity to manage the increased dynamic complexity caused by purchasing commitments.

5. Discussion

In line with the aim of this paper to explore the interactions between and across types and levels of SCC at manufacturing plants our study contributes valuable empirical insights to the concept of SCC. In particular drawing on the notion of interactions from systems theory, we provide detail on the horizontal, vertical and diagonal interactions of SCC which show that SCC is not a cumulative concept; our findings highlight the importance of considering SCC over different levels, i.e. plant, supply chain, and environment rather than in isolation as influences go across levels in both direction (from high level to low level and the other way around). Additionally, (we are one of the first to study the influence of context specificity (here food processing) on SCC that has been mentioned in previous research (De Leeuw *et al.*, 2013; Gerschberger *et al.*, 2012).

5.1 Interactions between detail and dynamic complexity

Previous studies consider SCC as a construct that consist of independent and separable aspects (e.g. drivers (De Leeuw *et al.*, 2013) or sources (Vachon and Klassen, 2002)), which negatively impact operational performance. This notion of SCC having only adverse impacts on performance has recently been challenged by, for example, Aitken *et al.* (2016) and Serdarasan (2013). Specifically, Aitken *et al.* (2016) show that performance implications of SCC require a more in-depth picture as SCC can stem from deliberate strategic choices. Our findings correspond to that as we also find potential value in increased SCC. The industrial processor (case C), for example, has a high variety of costumers with differences in demand patterns, which is associated with high detailed complexity. At the same time, however, the company uses these differences in demand patterns to achieve better production planning, increased utilization rates and ultimately less uncertainty at the plant level. Hence, our findings go a step further as we add fine grained details on the specific interactions that can increase and decrease SCC. Horizontal and diagonal interactions between dynamic and detail complexity can either amplify or buffer SCC.

Amplifying correspond to the argument of Simon (1962) that in complex systems the whole is more than the sum of its parts, for which Bode and Wagner (2015) recently presented empirical evidence in relation to upstream SCC and its impact on the frequency of supply chain disruptions. Our findings, however, only partly support this notion. We also find interactions that buffer SCC corresponding to Ashby's (1956) seminal work on requisite variety arguing that you need internal variety in order to respond to external variety. We find, similar to Schneider *et al.* (2017), that an increase of complexity at the plant level might be needed to cope with complexities from the supply chain or environment. Moreover, our data provide evidence that an increase in detail complexity in terms of variety or numerousness can aid in dealing with dynamic complexity. For example, within detail complexity the relation between numerousness and variety shows that a rise in detail complexity can be accommodated if the volume per product is sufficiently large. Hence, the interaction between numerousness and variety (in terms of volume per product) seems to be an enabler for strategic complexity (Aitken *et al.*, 2016). Accordingly, deliberate strategic choices, as for example, diversifying the product portfolio, can only be beneficial when interactions between variety and numerousness are considered.

An important implication of our findings is that the logic of summing up different aspects of complexity and relating them linearly to the overall concept of SCC as done by Isik (2010) or De Leeuw *et al.* (2013) is not always appropriate as horizontal, vertical and diagonal interactions influence SCC in a nonlinear way. Hence, we propose the following:

- P1. SCC is not a cumulative concept. Independently aggregating the effect of separate aspects of SCC might under- or overestimate the overall effect as it ignores potential amplifying or buffering interactions between detail and dynamic complexity.

5.2 Multilevel interactions and SCC

In line with Größler *et al.* (2006) the findings from this paper show that plants (i.e. lower level) tend to adapt to environmental (i.e. higher level) complexity. This is not unexpected as organizations have to respond to an increase in external complexity with a more complex organizational design (cf. contingency theory, e.g. Van de Ven *et al.*, 2013; Sousa and Voss, 2008). At the same time, however, our paper provides evidence that plant-level complexity aspects can also influence the higher levels driven by food and market characteristics. While this is a new insight for the concept of SCC, this was postulated already in the idea of complex adaptive systems theory: actors (e.g. plants) on the one hand shape their environment (e.g. supply chains) while, on the other hand, they adapt to it (Holland, 1992; Choi *et al.*, 2001). The few studies that include different levels of SCC argue that higher levels influence the lower level as complexity at the plant level arises from linkages with the

supply chain (Bozarth *et al.*, 2009; Serdarasan, 2013). We show, however, that this logic can be turned around and that lower level sources can cause an increase or decrease of detail and dynamic complexity at the higher level. Thus, we propose the following:

- P2. SCC across different levels originates not only from the outside in, i.e. higher level to lower level, but also from the inside out, i.e. from the lower level to the higher level.

5.3 *The impact of food characteristics on SCC*

It has been highlighted that SCC is context specific. De Leeuw *et al.* (2013) state, for example, that while drivers of SCC are generic, measurements of drivers have to be adapted to the specific industry (e.g. Perona and Miragliotta, 2004). We show that food processing characteristics increase and/or decrease dynamic complexity, e.g., the interplay between variability in quality and quantity of raw materials, seasonality and perishability of raw materials (Van Donk, 2001). In terms of detail complexity, we see that food process industry characteristics such as a divergent product structure, variety and numerousness of recipes, and byproducts either form a source of complexity or explain why complexity arises. Hence, our findings show that the distinction between generic and domain specific complexity drivers (De Leeuw *et al.*, 2013) also holds for the food processing context. Yet, context-specific characteristics (e.g. variability of quality and quantity of raw materials) are not restricted to the measurement of individual drivers, but need to be extended to explanations of vertical, horizontal and diagonal interactions between different types of complexity and across different levels. For instance, the need to clean after each production run limits the negative impact of higher diversity in the product portfolio as long as batch sizes are sufficiently large. This shows an interaction between variety and numerousness. Thus, we propose the following:

- P3. Industry-specific characteristics explain horizontal, vertical and diagonal interactions of SCC.
- P3a. Creating standardized output from variable input and minimum batch sizes in relation to the variety of recipes explain horizontal interactions of SCC in the food processing industry.
- P3b. Variability of quality and quantity of raw materials and the role of byproducts explain vertical interactions of SCC in the food processing industry.
- P3c. Minimum batch sizes and variability of quality and quantity of raw materials explain diagonal interactions of SCC in the food processing industry.

6. Conclusion

In this paper, we set out to empirically explore interactions between types and levels of SCC. Informed by the systems theory principles of self-organization and co-evolution we found that there are horizontal, vertical and diagonal interactions that buffer or amplify SCC. Hence, individual aspects of SCC are not independent and should not be addressed separately. Moreover, this paper creates awareness that complexity is not necessarily a “bad thing” and that – driven by interactions – the individual aspects of SCC do not contribute linearly to higher levels of SCC.

These findings are also important for managers as they have to maneuver organizations in an increasingly complex world. Many developments in organizations stem from strategic or market oriented changes, which impact SCC in several ways. As mitigating SCC might need considerable managerial attention, it is imperative to holistically understand SCC. Our findings provide such overall insights, calling to consider interactions in SCC. Both, looking at

the single, direct effect of specific changes (e.g. inspired by a search for new markets) or taking mitigating actions targeted at individual complexity sources might turn out to be ineffective or inappropriate and eventually lead to misguided decisions by managers. Moreover, as we find that SCC is driven by context-specific attributes which impact SCC (in our case a natural product as raw materials), it is essential for managers to take such specific characteristics explicitly into account when planning or taking decisions. As such, the framework used in this study might provide management with a useful visualization tool that can help to map out the interactions to see how and where SCC originates and manifests.

Due to previous research highlighting that SCC is context specific, we explored the interactions between types and levels of SCC within the food processing industry. As such part of our findings (i.e. *P3a-Pc*) might only hold within that specific context, while the first two propositions might hold for manufacturing plants in general. Yet, many characteristics that we encountered (e.g. byproducts, expensive production capacity, or minimum batch sizes) are also part of the broader process industries (Lager *et al.*, 2017). Hence, it is likely that our findings also hold in this domain. Further research might focus on looking into another industrial context to explore if similar findings can be generated. This study was limited to exploring individual interactions between types and levels of complexity from a focal plant point of view. At the same time, however, we came across instances where the individual interactions, i.e. diagonal and vertical interactions, occurred simultaneously. Avenues for further research are, accordingly, to further explore what happens if several interactions occur simultaneously and to extend the study toward interactions that happen among supply chains. Additionally, it needs to be noted that it is difficult to empirically assess complexity quantitatively (e.g. Poulis and Poulis, 2016) and we therefore derived increases or decreases in SCC based on interpretive codes without indicating the extent of amplification of SCC. At the same time, however, the qualitative assessment offers a rich perspective on the interactions between different complexity aspects and levels that have previously been disregarded, while at the same time giving a good basis to further explore the exact performance impacts of each interaction in future research. Finally, we would like to highlight, that in line with the qualitative case study nature of our study, we aimed for analytical generalization toward theoretical concepts rather than statistical generalization (Jüttner and Maklan, 2011). Nevertheless, we recommend to use the established relationships as a base for quantitative studies measuring the relationships we propose.

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Appendix

Interview Protocol

(a) General information:

- Please describe you the tasks and responsibilities that come along with you current function?
- What are the main products produced at this plant?
- Could you provide a short description of production process (from the main product)?
- What is the number of employees at the plant and the organization?
- What is your turnover plant in terms of money and volume?
- What are your main customers and how are they geographically dispersed?
- What are your main suppliers and how are they geographically dispersed?
- How is this plant positioned within the supply chain (from far upstream to far downstream)?

(b) Supply Chain Complexity:

Complexity Aspect	Definition (De Leeuw <i>et al.</i> , 2013)
Uncertainty	The lack of predictability and reliability of demand and of supply chain in processes
Diversity	The number of different elements in a system (products, suppliers, customers, activities)
Size	Relative number or volume of elements (products or activities)
Variability	Sudden, large and fluctuating changes in requirements imposed on the system over time
Structure	The interconnections between multiple systems, levels, processes etc. within and across elements
Speed	Required responsiveness across the supply chain (speed at which activities must be performed)

How do you experience the complexity aspects as per the table 1 above? When answering the please include aspects from the internal plant perspective, the supply side and the demand side!

(c) Coping strategies:

- What kind of strategies do you have in place in order to deal with supply chain complexity in terms of the complexity aspects discussed above?
- What strategies do you have in place to manage your suppliers?
- What strategies do you use to manage your demand?
- What strategies are used internally (manufacturing) to cope with complexity?

(d) Food Processing Industry:

- For your organization, what are challenges of doing business within the food processing industry?
- How do industry specific characteristics might influence the level of complexity you experience?

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